Water Management

Sam Dennis
Section Editor
Water Quality Variability in Two Creeks of the Collins River Sub-Watershed

Anonya Akuley-Amenyenu, Sarah Hovis, Ravneet Kaur and Sam O. Dennis

Department of Agricultural and Environmental Sciences
Tennessee State University, Nashville, Tennessee 37209

sdennis@tnstate.edu

Index Words: Water quality, Collins River, Middle Tennessee, pollutants, surface water

Significance to Industry: Collins River watershed is located in Middle Tennessee and drains parts of Cannon, Coffee, De Kalb, Grundy, Marion, Sequatchie, Van Buren and Warren Counties. Among these counties Warren County represents about fifty percent share of the Collins River Watershed (6). Also Warren County, sales from nursery, greenhouse, floriculture and sod commodities contributed $58,321,000.00 to the States’ economy in 2012 and was ranked 1st among the 95 counties in the State (1). In 2014, Warren County had a 0.3% increase in population, resulting to an increase from 39,840 in 2010 to 39,969 in 2014 (9). Likewise, the city of McMinnville also had a 0.5% increase in population about the same period (2010 to 2013) (8). Increasing population growth and the impact of global climate change continue to place heavy demands on water quality and quantity. These conditions are driving consumers’ attention to drinking water source availability and its vulnerability to contamination. The source of our drinking water includes surface water (e.g. streams, rivers, lakes) and groundwater sources (e.g. springs and wells). As water travels over the landscape, it dissolves natural minerals and sometimes picks up contaminants from agricultural production such as nursery and greenhouse operations. These contaminants may include sediments that may have resulted from runoff due to plowing and diskig of fields, fertilizer and pesticides residue. The long-term suitability of both surface and groundwater resources for drinking water are been threatened by non-point source pollution from agricultural production systems (7). Other threats include microbial contaminants that may come from sewage treatment plants, agricultural livestock operations, septic systems, industrial or domestic wastewater discharges, (5). In retrospect, polluted water can reduce the amount of water needed for drinking purposes as well as for agriculture and industrial uses (6).

Nature of Work: Hills Creek and Mountain Creek in Warren County, Tennessee are tributaries of the Collins River. Nursery and greenhouse crops are the primary agricultural operation in the area. These two creeks were sampled because of their location in the Collins River sub-watershed. Rainfall supplied almost all of the crop production water demand.

Grab water samples were collected weekly for eight weeks during 2013 fall season with weighted bailers from corresponding bridges. The water samples were collected during base flow (normal stream flow) and in very few instances after rainstorm events.
Rainfall events occurred in week 2 and 6 during the sampling period. Samples were collected at two different locations (upstream and downstream) of each creek. During each creek visits, water samples were collected in 500 ml LDPE (low density polyethylene) sample containers, placed in a cooler with ice and then transported to the lab for analysis. The water samples were analyzed for nitrate-N, ammonium-N and Ortho-P. The following cations: sodium, potassium, magnesium and calcium were also analyzed (2). Standard methods for water sample analyses were used to analyze all the nutrients of interest (6). In order to determine the water quality parameters of interest (dissolved oxygen, total dissolved solids, specific conductance, turbidity, temperature and pH); a DataSonde or data logger unit called Eureka Manta™ (Eureka Corp Austin TX), interfaced with the applicable sensors was used. The data logger was deployed in the creeks to at least a 45-cm depth and real-time water quality data of the parameters mentioned above was recorded in situ. The Manta data logger was calibrated according to instrument specifications and programmed to record measurements every 10 minutes. The Manta was used at each creek and was cleaned before taken to subsequent site(s) for data logging. While sampling, visual observation of aquatic habitats and wildlife present in the creeks were also noted.

Results and Discussion:  The average concentrations of nutrients in parts per million (ppm) are presented in (Table 1). The nitrogen data represents the summation of the water nitrate –nitrogen and ammonia- nitrogen; nitrite was highly negligible and was not included in the summation. The phosphorus (P) reported constitutes the dissolved (P) in the water. It ranged from 0.02 ppm in Mountain creek to 0.08 ppm in Hills creek. It is worth mentioning that the dissolve form of phosphorous usually serves as potential nutrient for algal bloom in water and as such may support eutrophication in surface water. On the other hand, there was no visual incidence of eutrophication in both creeks.

Some of the cations determined are important because they are present in agricultural liming materials (i.e. calcium and magnesium) that are widely used by farmers. Both creeks have relatively low concentrations of cations, except for calcium and magnesium. Due to the hydro-geologic conditions of Middle Tennessee, limestone rocks is of abundance and that tend to weather into terrains referred to as karst, it is expected that calcium and magnesium will be relatively high in the creeks. Calcium concentration ranged from 46 ppm to 94 ppm in Hills creek. Figure 2a and 2b represents selected water quality parameters of Hill Creek and Mountain Creek. Hills Creek had the lowest average turbidity value (~2.5 NTU). Turbidity values tend to increase when suspended particles (silt, clay, bacteria etc.) in the water increases. Turbidity relates to suspended sediments in creeks and streams. Specific conductance is important in water quality because it is a measure of dissolved salts in the water. Hills Creek had the highest specific conductance (Figure 2a). The total dissolved solids (TDS) of Hills Creek were also higher than that of Mountain Creek. Certain biotic organisms are useful in determining surface water quality as they are indicator of polluted or non-polluted water. Crayfish were observed in Mountain Creek during our sampling period. Crayfish presence indicates moderately clean water. Thus, they are
seldom found in polluted waters (3). Several fishes were also observed in all the streams sampled. Fish presence can also be used to indicate water quality because of their sensitivity to water pollution. Most of the fish found were in the family of Sunfish (Centrarchidae). Fish in this family are moderately tolerant to pollution and habitat alterations (4). Based on the number of fish observed in both Creeks, Mountain Creek tends to have a better water quality characteristic than the Hills Creek. In general, the creeks monitored didn’t seem to be much polluted during base flow conditions. However during storm events, large volume of sediments was added to the streams from surface runoff, especially in areas where the landscape has been disturbed. While growers are being viewed as contributors to surface water quality degradation, a good BMP of individual nursery fields could enhance water quality and total maximum daily loads (TMDL) of essential nutrients at the watershed scale.

Literature Cited

Table 1. Selected nutrient parameters - Hills Creek and Mountain Creek.

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<th>Calcium</th>
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<td>MC*</td>
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<td>0.03</td>
<td>6.71</td>
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</table>

*HC= Hills Creek, MC= Mountain Creek

Figure 1a. Warren County, Tennessee Map http://www.un.org/waterforlifedecade/quality.shtml

Figure 1b. Map of Collins River Watershed
**Figure 2a.** Selected Water Quality Parameters - Hills Creek and Mountain Creek.

**Figure 2b.** Selected Water Quality Parameters - Hills Creek and Mountain Creek.
Assessing Use and Management of Alternative Irrigation Water Sources for Green Industry Activities

Raul I. Cabrera¹, Susan Cooper², Genhua Niu³, James Altland⁴ and Youping Sun³

¹Rutgers University, 121 Northville Road, Bridgeton, NJ 08302
²Texas A&M AgriLife Research, 1619 Garner Field Rd., Uvalde, TX 78801
³Texas A&M AgriLife Research, 1380 A&M Circle, El Paso, TX 79927
⁴USDA-ARS, Agricultural Engineering Building, 1680 Madison Ave., Wooster, OH 44691
cabrera@aesop.rutgers.edu

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Significance to Industry: The use of alternative irrigation water sources is now an imperative foundation to the sustainability of green industry activities. Severe and lengthy droughts and stiff competition from other extensive food production and human uses/allocations, and scrutiny on the environmental impact of green industry activities is leaving them with restricted access to good quality irrigation water sources. Most non-traditional water sources have relatively high salinity and concentration of undesirable ions, which are very challenging for the production and maintenance of ornamental plants. We have initiated short- and long-term studies on use and management of alternative irrigation waters, targeting use of reclaimed water for nursery-greenhouse production and graywater for landscape irrigation. Our preliminary results indicate that laundry graywater could be used satisfactorily, over the short term, to irrigate landscape plants, except when containing bleach, which reduces plant growth and aesthetic quality compared to irrigation with good quality potable or well water. In addition to plant growth and quality responses, our studies will provide much needed insights into the long-term effects of irrigation with graywater on the chemical and biological properties of landscape soils.

Nature of Work: Nursery/greenhouse crop production and urban landscape management are very intensive activities, associated with large applications of water, fertilizers and agrichemicals (3, 4, 8). Water availability and quality, and their management, are therefore essential issues to the sustainability of the green industry as a whole. Climate change (i.e. severe and prolonged droughts) and fierce competition for water have placed these industries under a scenario of diminished availability of good quality irrigation water. The aesthetic (non-edible) nature of ornamental crops and landscape plants will likely limit or restrict their access to high-quality water sources (5). Therefore there is a need to earnestly consider major usage of alternative, poor-quality irrigation water sources, and the best management practices that can lead to their successful use.

Among these alternative water sources, some viable candidates include brackish water, reclaimed water and graywater (Table 1). Brackish groundwater, from naturally saline
aquifers or those affected by coastal saltwater intrusion-aquifers are abundant in some areas of the country (1, 5, 11). Their salinity, however, exceed the maximum levels recommended for most nursery and landscape plants, in addition to surpassing the thresholds for toxic concentrations of Na and Cl (7, 9). Municipal reclaimed water is another viable alternative for irrigation, already being used in golf courses and municipal landscapes and parks in western parts of the US. Depending on the degree of treatment, however, reclaimed waters could have similar drawbacks as brackish water, with moderate to relatively high levels of total salinity and undesirable specific ions like Na, Cl, B (6). Availability and supply of reclaimed water is unfortunately limited, as its collection, treatment and distribution are strictly regulated, employing a separate pipeline system accessible to only few large end-users. Usage of reclaimed water for irrigation requires the use of modified sprinklers or drippers to minimize contact with plant foliage and people, the latter due to concerns about pathogenic microorganisms that could still be present in undesirable concentrations (5, 6). As with brackish water, successful use of reclaimed water call for the use of salt-tolerant plants (7, 9), suitable irrigation equipment and management, leaching requirements, and short- and long-term management of urban soils and their associated watersheds to minimize salt accumulation and undesirable effects on the urban ecosystem (6).

Graywater, defined as residential wastewater from laundry, showers and bathtubs, is an additional alternative water source with potential for residential landscape irrigation. Graywater can constitute as much as 50-60% of the total wastewater from a household, and might yield up to 65,000 gallons per year from an average US family (10). Laundry effluents are the largest graywater fraction from a household, and could provide ≥5 inches per year of supplemental irrigation to an average-sized (5,000 ft²) landscape (5, 10). The routing of the drain hose from washing machines to a simple drip irrigation set-up is a relatively inexpensive option to reuse laundry graywater compared to plumbing retrofits to use graywater effluent from bathtubs and showers. Among the issues that discourage an extensive and permitted use of graywater for landscape irrigation is a lack of documented (research-based) knowledge on the short and long-term effects of graywater and its constituents (significant levels of detergent surfactants, plus nitrogen, phosphorous, boron and other elements) on plants and soils. Furthermore, as with reclaimed water, there is the need to identify their associated microorganisms and chemicals that are of concern for public health, plus the irrigation equipment considerations and practices needed to successfully manage and apply graywater (5, 10).

**Results and Discussion.** We have initiated a series of studies addressing the use and management of alternative irrigation water sources. Next we present preliminary results from our studies with graywater irrigation.

A greenhouse study was conducted, evaluating the effects of short-term irrigation with graywater of varying composition on the growth and quality of several ornamental plant species growing in #3 containers with a peat moss: bark: sand (2:1:1 by volume) substrate. The substrate had been amended with dolomitic limestone (5 lb/yd³) and Osmocote™ 14-14-14 (6 lb/yd³). The four treatments used were tap water (control; pH
7.0, 0.4 dS/m), water with detergent (Tide™), water with detergent plus fabric softener (Downy™), and water with detergent, softener and bleach (Chlorox™). The graywater treatments were made with a conventional washing machine (generating 40-gallons per combined wash/rinse cycle) using the detergent, softener and bleach at the manufacturers’ suggested rate for a large laundry load. Results after 18-weeks of irrigation with these graywaters indicate that overall plant growth and aesthetic quality in yaupon holly (Ilex vomitoria), agave (Agave angustifolia), yucca (Yucca filamentosa) and juniper (Juniperus horizontalis) was comparable with plants irrigated with the control tap water. Similar results were observed in other species, but their growth and quality were negatively affected in plants irrigated with graywater containing bleach. Mexican heather (Cuphea hyssopifolia), lantana (Lantana camara), mondo grass (Ophiogon japonicus) and garden carnations (Dianthus chinensis) had the worst effects with the graywater containing bleach, exhibiting significant browning and necrotic leaf tissues (carnations, mondo grass) and/or chlorosis (lantana and Mexican heather). These undesirable growth responses and symptoms are attributed to the high total chlorine levels (>60 ppm) found in this graywater containing bleach, compared to the other graywaters and the tap water control (all averaging 0.4 ppm total chlorine). While total and free chlorine levels in water containing bleach (i.e. sodium hypochlorite) will be reduced significantly over short periods of time (i.e. 24 hours) due to chemical reactions, breakdown and volatilization (1), most, if not all, existing ordinances permitting use of graywater for landscape irrigation require an immediate use these effluents (as they are produced). In addition to chlorine, there are other byproducts of the breakdown of sodium hypochlorite, such as sodium (Na+) and chloride (Cl-) ions (1), that will be deleterious for plant growth and aesthetic quality (6, 7, 9).

A long-term study has been initiated to evaluate the long-term effects of graywater irrigation on landscape plants and soils. A replicated landscape study on a silty-clay loam soil has been established, irrigating a dozen species of herbaceous perennials, shrubs and trees with two graywater treatments and one control (well water: EC ~0.45 dS/m; pH~7). The graywater treatments are water with detergent (Tide™) plus fabric softener (Downy™), and water with detergent and softener plus bleach (Chlorox™). These treatments are being produced by injecting the ingredients with inline pressure-driven proportioners into the irrigation system, delivering final concentrations, at the drippers, similar to those generated by a conventional laundry machine. Preliminary results after 3 months of irrigation (treatments applied 2X/week, 1gallon/plant/irrigation) have, in general, not produced differential growth responses in graywater-irrigated plants compared to plants irrigated with the high-quality well water (control). Plants of lantana (Lantana ×hybrida), rosemary (Rosmarinus officinalis), cedar elm (Ulmus crassifolia) and live oak (Quercus fusiformis) irrigated with graywater containing bleach, however, are showing a consistent trend towards lower foliage chlorophyll index (SPAD) readings and quality scores compared to those irrigated with detergent+softener graywater and the well water controls. We have collected leaf tissue and soil samples and they are being processed for nutrient and chemical analyses. Composite soil samples (1” diameter x 6” deep cores) are also being collected 12 inches from the trunks of rose (Rosa × Knockout™) plants and submitted for microbiological analyses, to characterize soil biological diversity and activity in the rootzone of these treatments.
Based on the results from the previous greenhouse study, we are hypothesizing that irrigation with graywater, particularly that containing bleach, bleach will reduce soil biological diversity and activity values compared to irrigation with well water.

We are projecting that our studies will yield results that will help growers and landscape managers appraise the quality – and assess the benefits-risks associated with intensive and extensive use – of alternative irrigation waters. It is further envisioned that these results will assist in the development of management practices and solutions that permit safe, cost-effective and sustainable large-scale use of these non-traditional water sources.

Literature Cited
Table 1. Main chemical quality parameters in suitable irrigation water for ornamental crop and landscape plants, contrasted with slightly brackish and reclaimed water (Data from 1, 5, 6, 7).

<table>
<thead>
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<th>PARAMETER</th>
<th>Suitable Water</th>
<th>Slightly Brackish</th>
<th>Reclaimed</th>
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<td>7.3 – 8.3</td>
<td>7.0 – 8.0</td>
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<tr>
<td>EC (ds/m)</td>
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<td>1.6 – 4.7</td>
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<td>B (mg/L)</td>
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</tr>
<tr>
<td>HCO₃ (mg/L)</td>
<td>120 - 180</td>
<td>80 – 250</td>
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A Cost Effective Tipping Bucket Assembly for Real Time Container Leachate Measurements and Irrigation Management

Quinn Cypher¹, Wesley Wright² and Amy Fulcher¹

¹Department of Plant Sciences, University of Tennessee
2431 Joe Johnson Drive, Knoxville, TN 37996
²Department of Biosystems Engineering and Soil Science, University of Tennessee
2506 E. J. Chapman Drive, Knoxville, TN 37996

afulcher@utk.edu

Index Words: container nursery production, irrigation, leachate, leaching fraction, natural resource conservation, sensor, water, water scarcity

Significance to the Industry: As concerns about water scarcity increase, minimizing water consumption is becoming a priority in many parts of the US and abroad. Agriculture is a large consumer of freshwater in the US. Efforts to refine and reduce water use during the production of nursery crops allow growers to expand without requiring additional water resources and positions them to compete in a national market. This research developed a sensor that measures irrigation application and container leachate in real time. The data collected using this sensor can help inform irrigation scheduling decisions, potentially reducing water use and input costs, and improving yields.

Nature of Work: Irrigation management is an essential aspect of container nursery crop production. Measuring leachate and determining leaching fraction (leachate volume/total irrigation volume) are effective ways to determine the appropriate volume of irrigation water to apply and can be used to improve irrigation scheduling and to conserve water (4, 8). Determining the leaching fraction of one plant during one irrigation cycle is typically done by manually capturing and measuring the volume of irrigation water and the leachate (effluent) coming out of the bottom of the container. Other methods include weighing the leachate and irrigation water (7), and aggregating leachate on a collection pad from multiple plants before measuring (6). However, manual methods of leachate measurement are time and labor intensive and therefore difficult to perform at a nursery on a scale suitable to capture day-to-day and plant-to-plant variation. Furthermore, these methods are only functional at a small scale; they would be difficult to adapt to a large-scale outdoor nursery environment under overhead irrigation.

Overhead irrigation is the most commonly used delivery type for containers smaller than 5-7 gallons (3). Under typical nursery conditions, the volume of water to reach the surface of the substrate varies due to the lack of 100% distribution uniformity (3) and the varying capture factor of the different species and individual plants (5). The fact that varying amounts of water reach the top of a container paired with likely variation in
rehydration capacity of the substrates and water use by individual plants will likely lead to container-to-container variation in leachate and leaching fraction. An improved understanding of leachate and leaching fraction can be used to make irrigation application decisions and improve irrigation efficiency (7). Therefore, an automated system to capture leachate and irrigation in real time that would function in an outdoor nursery under overhead irrigation was developed. The leachate gauge described here is based on a tipping bucket mechanism, which is an effective way to measure a relatively small amount of flowing water in real time. Our objective was to design and develop leachate gauges that would function in an outdoor nursery setting with overhead irrigation and deliver accurate, real time data using a tipping bucket mechanism and readily available materials.

To be fully functional and useful in an outdoor nursery setting, the ideal leachate gauge would satisfy these criteria: 1) be designed to support the weight of a container with substrate and a plant, unlike using an off-the-shelf rain gauge, 2) have a base that allows for leveling on uneven surfaces, 3) have a customizable funnel-shaped fitting to fit a range of nursery container sizes, and 4) prevent rain and overhead irrigation from entering the gauge except through the top of the container. The leachate gauges should also be capable of serving as irrigation/rainfall gauges. By using at least two: an irrigation gauge with a second serving as a leachate gauge, leaching fraction can be calculated without the need for unit conversion.

Leachate gauges were constructed from five major components: base, housing, funnel, irrigation shield, and tipping bucket mechanism as shown in figure 1.

**Base.** The base was constructed from an 8 inch (203 mm) x 7 inch (178 mm) x 0.5 inch (13 mm) aluminum plate. Ten holes were drilled into the base: two for attaching the tipping bucket frame; two to allow access to the tipping bucket adjustment screws; three for the housing attachment; and three for leveling bolts (Figure 2). The holes for the tipping bucket adjustment and for attaching the housing were drilled using a #18 (0.169 inch; 4.3 mm) bit, and the holes for the leveling bolts were drilled using an F (0.257 inch; 6.5 mm) size bit. The holes for the leveling bolts were drilled at two corners and in the center of the opposite side for a three point leveling design. They were then tapped using a 5/16-18 HSS tap to allow the leveling bolts to thread into the holes. The holes to attach the tipping bucket and to allow access to the tipping bucket calibration screws were positioned to center the tipping bucket frame on the base. The three holes that were drilled to attach the housing were also located to center the housing on the base. The tipping bucket frame was attached to the base using two stainless steel #6-32 1.24-inch (32 mm) machine screws. The base was attached to the housing using three 1.25-inch (32 mm) self-tapping fine threaded wood screws (Kreg®, Kreg Tool Co., Huxley, IA), which allowed attachment to the PVC pipe housing without pre-drilling.

**Housing.** A 6-inch (152 mm) tall length of 6-inch (152 mm) schedule 40 polyvinylchloride (PVC) pipe [inner diameter 6 inches (152 mm), outer diameter 6.625 inches (168 mm)] was used for the housing of the assembly. A 2.5 inch (64 mm) round hole was cut in the side of PVC pipe to allow viewing of the tipping bucket mechanism.
and visual alignment of the funnel. The hole was covered in fiberglass window screening attached with Velcro to keep small animals from entering the housing yet allow easy removal for inspection. A 3/16-inch (4.8 mm) hole was drilled two thirds of the way up the housing to allow the lead wire to pass into the housing. A second 3/16-inch (4.8 mm) hole was drilled in the bottom of the housing to allow water (and leachate) to escape after measurement.

**Funnel.** Funnels were made from a 0.055-inch (1.4 mm) thick sheet of a copolymer consisting of 15% polyethylene and 85% polypropylene. Acrylonitrile butadiene styrene (ABS) plastic and polycarbonate were also considered; however, the above-mentioned copolymer was available locally, cost effective and functioned well during prototyping. Funnels were made by cutting a circle from the plastic material, drilling a 3/16 inch (4.8 mm) hole in the center and making a cut from the edge to the center. The material was then overlapped and fastened using pop rivets and backing washers (3/16 inch; 4.8 mm) thus creating a low profile funnel. A wood burner was used to weld the overlapping plastic material together near the funnel tip and the hole was drilled to 3/16 inch (4.8 mm) creating a uniform hole in each funnel. Brackets to attach the funnel were made from 0.5 inch (12.7 mm) x 2 inch (50.8) x 0.05 inch (1.3 mm) aluminum that was bent at an angle to match that between the housing and the funnel. Pop rivets (3/16 inch; 4.8 mm) were used to secure the funnels to the brackets. Silicone was used to seal the holes left by the pop rivets and the joint where the plastic sheeting was overlapped to create funnels. Self-tapping screws (#8 x 0.75 inch; 19 mm) were used to attach the aluminum brackets to the housing (PVC pipe).

The funnel size must be specific to the container size used if using the irrigation shield method described below and therefore should have an outer diameter slightly smaller than the inner diameter of the container being used. As the outer diameter of the funnel is a function of the funnel angle and the diameter of the pre-formed funnel material it may be necessary to create a slightly oversized funnel prototype and remove material until the desired size is achieved. Once the funnel’s radius is determined a compass is used to mark the material for additional funnels.

A standard fiberglass window screen material was placed over the funnel to keep loose substrate and debris that come out of the container drain holes from clogging the funnel. Holes 0.25 inch (6.4 mm) in diameter were drilled around the extreme edges of the funnel. This allowed airflow around the irrigation shield and to the container drain holes. Since the funnels were sized to match the inner diameter of the top of the container and thus are larger than the base of the container, the air holes do not influence the capture of leachate or irrigation.

**Irrigation Shield.** For the leachate gauges to function properly, they must measure only the water that drains from the container while excluding irrigation water that falls outside the container. An empty container of the same size as the target container was used to create an irrigation shield (Figure 3). The container was cut approximately in half and the bottom portion removed. The top half was inverted and placed over the funnel. The
planted container was placed inside the empty container. As containers typically have a larger top diameter and a smaller bottom diameter, a seal is created where the two containers come together preventing overhead irrigation from entering the funnel from the side of the container.

**Tipping Bucket Assembly.** A tipping bucket assembly (Texas Electronics, Dallas, Texas) formed the basis of the sensor. For use with containers up to #3, tipping bucket assemblies that were designed for 0.16 fl oz (4.73 ml) per tip were used. For containers above #3, tipping bucket assemblies designed for 0.28 fl oz (8.25 ml) per tip were used. The volume per tip represents the minimum resolution of the leachate gauges. Based on use in rain gauges, a tipping bucket calibrated to 0.16 fl oz (4.73 ml) per tip has a +/-1% accuracy at flow rates below 15.9 fl oz/hr (473 ml/hr) and a +0, -3% accuracy at flow rates between 15.9 fl oz/hr (473 ml/hr) and 32.0 fl oz/hr (945 ml/hr). A tipping bucket calibrated to 0.28 fl oz (8.25 ml) per tip has a +/-1% accuracy at flow rates below 27.8 fl oz/hr (823 ml/hr) and a +0, -3% accuracy at flow rates between 27.8 fl oz/hr (823 ml/hr) and 55.7 fl oz/hr (1647 ml/hr). At greater flow rates, accuracy drops to +0 to -5% up to 47.8 fl oz/hr (1418 ml/hr) and 83.6 fl oz/hr (2471 ml/hr) for the tipping buckets calibrated to 0.16 fl oz (4.73 ml) per tip and 0.28 fl oz (8.25 ml) per tip, respectively (1, 2). An 18 gauge stranded, shielded, two conductor lead wire was stripped, tinned and attached to the tipping bucket assembly to connect the leachate gauges to a data logger.

**Tools Used.** Constructing the tipping buckets required the use of specialized tools. Although many of the tools listed here are not strictly necessary, the time necessary to perform a given operation will likely increase by using less specialized tools or home owner quality tools. All the tools used were available at the University of Tennessee Department of Biosystems Engineering and Soil Science Machine Shop (Knoxville, TN). Table 1 lists the specialized tools used during the production process and their purpose.

**Results and Discussion:**
**Cost of Materials and Production.** The following is based on producing 20 or more leachate gauges, building fewer will require more time per unit and possibly result in higher per unit supply costs (Table 2). The time to produce is in person-hours and does not include time to build a prototype or experiment with different production techniques (Table 3).

Leachate and irrigation gauges were successfully built from readily available supplies and a rain gauge tipping assembly. The total supply cost and the time to build each gauge was estimated at $107.80 and 1.5 hours, respectively. Compared to a high quality commercially available rain gauge ($300-$400 each), this was an economical way to equip a research project and provided added benefits over adapting a rain gauge as described in the Nature of Work section. The cost estimates provided here do not include the purchase cost of the relatively specialized tools used during construction. The leachate gauges, when paired with a standard rain gauge for measuring natural precipitation, have the ability to measure leachate resulting from irrigation and rainfall. Furthermore, when an empty container the same size as the containers used in
production is placed on the leachate gauge, irrigation can be effectively measured at a given location/container. When using the leachate gauge as an irrigation or rainfall gauge remove the bottom of the empty container to allow water to flow unimpeded into the funnel. The leachate gauges are strong enough to support large containers; they were used with #4 containers for tree production without failures. Two rebar stakes placed on either side of the plant and fastened to the container sidewall with cable ties can be used to secure the potted plant.

In conclusion, a custom designed and built leachate gauge was constructed economically with the ability to measure irrigation, rainfall and leachate in an outdoor nursery setting with overhead irrigation. The leachate gauges can be easily adapted to fit the wide range of container sizes used in nursery production. Data collected using these gauges will lead to a greater understanding of irrigation requirements in an outdoor nursery setting where data collection is challenging but of great value to nursery crop production research and extension professionals. This information can be used to refine irrigation practices and thus improve the environmental and economic sustainability of the green industry.

Acknowledgments
The authors express their appreciation to Phil Flanagan and Joey Fulcher for technical assistance and acknowledge funding from USDA NIFA National Integrated Water Quality Program award 2014-51130-22493.

Literature Cited
**Table 1.** Specialized tools and equipment used to develop the leachate and irrigation gauges.

<table>
<thead>
<tr>
<th>Tool</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill Press</td>
<td>Drill holes at a 90° angle to the material. Used to drill the holes in the aluminum plate.</td>
</tr>
<tr>
<td>Drill Press Vice</td>
<td>Hold material while drilling. Used to hold material at a specific and repeatable location. Allowed accurate and repeatable drilling of holes in the aluminum plate by using a template, eliminating repeated measuring.</td>
</tr>
<tr>
<td>Drill Bits: 3/16 inch, 5/16 inch, #12 (0.159 inch) and 2.5 inch Hole Saw</td>
<td>Drill holes in funnel, aluminum plate, aluminum brackets and PVC pipe.</td>
</tr>
<tr>
<td>Metal Cutting Band Saw DoALL Model C-916</td>
<td>Used to square cut the 6-inch PVC pipe into 6 inch lengths.</td>
</tr>
<tr>
<td>Tap and Die Set</td>
<td>Tap (cut threads) the holes in the aluminum plate, allowing bolts to be threaded through the plate for leveling.</td>
</tr>
<tr>
<td>Sheet Metal Shear</td>
<td>Cut 0.050 inch aluminum sheeting into 0.5 inch x 2 inch rectangles for use as brackets.</td>
</tr>
<tr>
<td>Battery Operated Drill</td>
<td>Drill holes in the plastic sheeting to make the funnel and for attaching the brackets. Also used for screw attachment.</td>
</tr>
<tr>
<td>Pop Rivet Tool</td>
<td>Used for pop riveting the funnels and attaching the funnels to the brackets.</td>
</tr>
<tr>
<td>Adjustable Square</td>
<td>Measure and mark aluminum plate and pipe.</td>
</tr>
<tr>
<td>Various hand tools including wrenches, screwdrivers, hammers, saws, tin snips, and clamps</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Cost of materials per leachate or irrigation gauge (based on a bulk purchase of materials for 20 gauges).

<table>
<thead>
<tr>
<th>Item</th>
<th>Material Cost (US $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Plate</td>
<td>11.25</td>
</tr>
<tr>
<td>Leveling Bolts</td>
<td>4.98</td>
</tr>
<tr>
<td>Tipping Bucket Attachment Bolts</td>
<td>0.51</td>
</tr>
<tr>
<td>6 inch PVC Pipe</td>
<td>1.53</td>
</tr>
<tr>
<td>PVC Attachment Screws</td>
<td>0.08</td>
</tr>
<tr>
<td>Aluminum Funnel Brackets</td>
<td>0.25</td>
</tr>
<tr>
<td>Funnel Material</td>
<td>0.72</td>
</tr>
<tr>
<td>Pop Rivets</td>
<td>0.55</td>
</tr>
<tr>
<td>Pop Rivet Backing Plates (Washers)</td>
<td>0.12</td>
</tr>
<tr>
<td>Self-Tapping Screws</td>
<td>0.17</td>
</tr>
<tr>
<td>Silicone Sealant</td>
<td>0.20</td>
</tr>
<tr>
<td>Screen</td>
<td>0.69</td>
</tr>
<tr>
<td>Tipping Bucket Assembly</td>
<td>85.00</td>
</tr>
<tr>
<td>Wire Lead [15 feet (4.6 m) based on cost of a 1000 ft (305 m) roll]</td>
<td>1.50</td>
</tr>
<tr>
<td>Nursery Container</td>
<td>0.25</td>
</tr>
<tr>
<td><strong>Total Materials Cost (one leachate gauge)</strong></td>
<td><strong>107.80</strong></td>
</tr>
</tbody>
</table>
**Table 3.** Person-hours used to build one leachate or irrigation gauge, based on the economies of scale of building 20.

<table>
<thead>
<tr>
<th>Leachate Gauge Production Task</th>
<th>Person-Hours per Gauge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling Aluminum Plate</td>
<td>0.2000</td>
</tr>
<tr>
<td>Tapping Aluminum Plate for Leveling Bolts</td>
<td>0.0625</td>
</tr>
<tr>
<td>Cutting PVC and Drilling Viewing Hole</td>
<td>0.1500</td>
</tr>
<tr>
<td>Cutting Funnel</td>
<td>0.0500</td>
</tr>
<tr>
<td>Shaping Funnel Including Pop Riving and Sealing Overlap</td>
<td>0.1000</td>
</tr>
<tr>
<td>Making Funnel Mounting Brackets</td>
<td>0.0250</td>
</tr>
<tr>
<td>Attaching Aluminum Base Plant to PVC</td>
<td>0.1250</td>
</tr>
<tr>
<td>Attaching Aluminum Brackets</td>
<td>0.1000</td>
</tr>
<tr>
<td>Attaching Tipping Bucket</td>
<td>0.0875</td>
</tr>
<tr>
<td>Stripping and Tinning Wires</td>
<td>0.0500</td>
</tr>
<tr>
<td>Attaching Wires</td>
<td>0.0750</td>
</tr>
<tr>
<td>Aligning and Mounting Funnel</td>
<td>0.1250</td>
</tr>
<tr>
<td>Cutting and Attaching Screen</td>
<td>0.0500</td>
</tr>
<tr>
<td>Screen to Cover Viewing Hole</td>
<td>0.0500</td>
</tr>
<tr>
<td>Cutting Irrigation Shields from Containers</td>
<td>0.0500</td>
</tr>
<tr>
<td>Misc. Troubleshooting, Tool Calibration and Clean Up</td>
<td>0.2000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.5000</strong></td>
</tr>
</tbody>
</table>
Figure 1. Exploded view of the leachate gauge. A. Debris screen (fiberglass window screen), B. Pop rivet (3/16 inch), C. Funnel, D. Funnel attachment bracket (aluminum; 2 x 0.5 x 0.05 inch), E. Self-tapping screws for attaching bracket to housing (#8 x 0.75 inch), F. Housing (6 x 6 inch schedule 40 PVC), G. Screen covering viewing hole (fiberglass window screen), H. Lead wire (18 gauge stranded shielded 2 conductor), I. Tipping bucket assembly, J. Self-tapping screws for attaching base plate to housing (1.25 inch), K. Screws to attach base to tipping bucket frame (#6 x 1.25 inch; stainless), L. Leveling bolts (5/16-18 x 2.5 inch; stainless), M. Aluminum base plate (7 x 8 x 0.5 inch).
Figure 2. Leachate gauge base: 7 x 8 x 0.5 inch aluminum plate.
**Figure 3.** Leachate gauge with #3 (11.4 L) container and irrigation shield. A. #3 (11.4 L) container (white used for illustration purposes), B. Cut away for illustration purposes. C. Union of container and irrigation shield made from the inverted top half of a #3 container, D. Irrigation shield fits over the funnel, E. Leachate gauge.
Biochar Affects Water Management in Soilless Container Grown ‘Green Velvet’ Boxwood and Pinky Winky® Hardy Hydrangea

Nastaran Basiri Jahromi¹, Amy Fulcher² and Forbes Walker¹

¹Department of Biosystems Engineering and Soil Science, University of Tennessee
2506 E.J. Chapman Drive, Knoxville, TN 37996-4531

²Department of Plant Sciences, University of Tennessee
2431 Joe Johnson Drive, Knoxville, TN 37996

nbasirij@vols.utk.edu

Index Words: Biochar, Boxwood, Composted Biochar, Container Crops, Hydrangea, Water Conservation

Significance to Industry: Container grown nursery crops generally require daily irrigation applications, and potentially more frequent applications during the hottest part of the growing season. With recent advances in switchgrass production and its use for natural gas and electricity production, a carbon rich byproduct of pyrolysis, known as biochar, is becoming increasingly available for use in agriculture. Incorporating biochar into nursery substrate could increase the water holding capacity and reduce water and nutrient leaching. Additionally, the progression of substrate moisture sensor-based irrigation has made this technology a practical tool for monitoring substrate moisture. By irrigating only the amount of water required to support plant growth, sensor-based irrigation can reduce water needed for irrigation. A precision irrigation system in combination with a readily available, low cost substrate amendment that increases water holding capacity may reduce the water requirement for high-value crops and mitigate leaching, benefitting nursery growers who are trying to conserve water or expand production on existing and/or limited water supplies.

Nature of Work: Pine bark is the most common container substrate component in the Eastern US. It has high porosity and relatively low water holding capacity, therefore, plants must be irrigated frequently compared to field grown crops in order to supply adequate water. Frequent irrigation can contribute to leaching dissolved nutrients (1). However, the amount and frequency of water applied by irrigation can be adjusted to offset leaching nutrients (2). Refining irrigation to prevent leaching is particularly important because pine bark has low cation and anion exchange capacities (1).

Developing management practices that use irrigation water more efficiently is important for improving sustainability of nursery crop production. Substrate moisture sensors can be an important component of sustainable irrigation practices. Moisture sensors have been effectively used in both manual (2) and automated irrigation systems (3, 4, 5, 6) to use water more carefully by conservatively estimating the amount of water needed to support growth and reducing water wastage due to excess application (6).
In field cropping systems, plant water uptake is a function of soil as well as plant hydraulic properties and this likely extends to soilless substrates too (7). O’Meara et al. (2014) showed that container substrate hydraulic conductivity as well plant species maybe an important mechanism to control water uptake by plants. Moreover, they showed that the commonly accepted threshold for plant available water, 0.20 m$^3$·m$^{-3}$, may not define all soilless substrates as G. jasminoides ‘Radicans’ and H. macrophylla ‘Fasan’ extracted water until 0.12 m$^3$·m$^{-3}$ and 0.16 m$^3$·m$^{-3}$, respectively. While recent research is encouraging for developing conservative irrigation scheduling with a low volumetric water content set point to trigger irrigation (5), water retention characteristics of soilless substrates are inherently prone to and greatly influenced by hydrophobicity (8) and thus, warrant more investigation. Appropriate use of sensors can provide quantitative indicators of crop water needs that improve irrigation decision-making and also enhance water use efficiency in soilless substrates (9) while taking into consideration hydrophobic tendencies of substrate components.

Biochar is a carbon rich byproduct of pyrolysis, which is thermochemical decomposition of organic materials in the absence of oxygen and at low temperatures. During pyrolysis, carbon, hydrogen, and oxygen are burned off and the nutrient concentration is increased in comparison to the original feedstock (10). Biochar can be used as soil conditioner in agriculture (10). For example, biochar has been described as a means to enhance soil nutrient retention (11). In addition, there is great potential to enhance 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 (12, 13). Biochar has also been reported to increase soil pH in acid soils (14) and plant nutrient availability (15). These factors, either individually or in combination, may increase yields of agricultural crops as well as benefit horticultural crops (15, 16, 17).

The effect of biochar depends on type of feedstock, the pyrolysis conditions, and the ecosystem or cropping systems to which it is applied (18). Biochar has a large impact on release and retention of all macronutrients but each macronutrient responds in a different way (19). Because ion species’ movement through a pine bark substrate is heterogeneous, biochar as a component to pine bark-based substrate may differentially influence nutrient retention. Solute movement also depends on distribution of ions through macro-pores and micro-pores, their diffusion across concentration gradient, and interaction with bark particle exchange sites (1). Therefore, biochar may influence nutrients leaching from a soilless substrate and characterizing these distinctions would benefit nursery growers.

Benefits of biochar have been also reported in container and greenroof systems. Addition of 7% biochar to greenroof substrate reduced total nitrogen and phosphorus, nitrate, phosphate and organic carbon in leachate (20). Biochar retained nitrate and phosphate and release those gradually over time in plantless columns. The nutrient release curve peaks occurred later with higher residual nutrient release over time by increasing the biochar rate. (21). Altland and Locke (19) reported that amending a standard commercial soilless substrate with 10% gasified rice hull biochar increased container capacity and reduced unavailable water. Given the potential to improve
irrigation scheduling and conserve water and nutrients by using substrate moisture sensors and addition of biochar to soilless container substrates, our objective was to determine the effect of amending a pine bark substrate with switchgrass biochar or composted switchgrass biochar on crop growth, irrigation requirements, and nutrient leaching for two plant species with disparate water requirements, Buxus sempervirens × B. microphylla ‘Green Velvet’ boxwood and Hydrangea paniculata Pinky Winky® hardy hydrangea.

Buxus sempervirens × B. microphylla (‘Green Velvet’ boxwood) and Hydrangea paniculata (Pinky Winky® hardy hydrangea) grown in 2.25 inch containers (Spring Meadow Nursery (Grand Rapids, MI) were potted into 3.8 L containers on 8 May 2015. Containers were filled with pine bark and amended with 10% and 25% by volume biochar or composted biochar. Containers were irrigated by hand for 4 weeks before initiating the automatic sensor-based irrigation program. One week after transplanting, plants were top-dressed with 18N-6P-12K controlled release fertilizer with micronutrients (Osmocote, Everris, Marysville, OH) at 24 grams per container.

Substrate moisture levels are controlled by EC-5 capacitance sensors (ECHO-5, Decagon Devices Inc., Pullman, WA) connected to a multiplexer (AM16/32, 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. For this experiment, the volumetric water content set point that triggers irrigation is 0.25 m$^3$·m$^{-3}$, slightly greater than 0.20 m$^3$·m$^{-3}$, a commonly accepted value for plant available water, in order to prevent the bark from becoming hydrophobic. The upper set points (optimum volumetric water contents) are the in situ container capacity values, which were based on EC-5 probe measurements following irrigation and drainage of free water. Substrates were treated twice with a surfactant before determining in situ container capacity values. The container capacity values were 0.54 m$^3$·m$^{-3}$ for 100% pine bark treatment with hydrangea, 0.52 m$^3$·m$^{-3}$ for 100% pine bark treatment with boxwood, 0.49 m$^3$·m$^{-3}$ for 10% biochar treatment with hydrangea, 0.44 m$^3$·m$^{-3}$ for 10% biochar treatment with boxwood, 0.55 m$^3$·m$^{-3}$ for 25% biochar treatment with hydrangea, 0.45 m$^3$·m$^{-3}$ for 25% biochar treatment with boxwood, 0.29 m$^3$·m$^{-3}$ for 10% composted biochar with hydrangea, 0.31 m$^3$·m$^{-3}$ for 10% composted biochar treatment with boxwood, 0.37 m$^3$·m$^{-3}$ for 25% composted biochar with hydrangea and 0.35 m$^3$·m$^{-3}$ for 25% composted biochar with boxwood.

Ten independent irrigation zones, one per treatment combination, were constructed with one irrigation line per treatment combination. There are 5 probes per treatment, 50 probes in total. Probes were installed so that the bottom of each probe is 3.5 inches below the substrate surface. Each container is irrigated with a 4 inch dribble ring (Dramm Corp., Manictowoc, WI) to achieve uniform irrigation on surface of the substrate by 4 gallon per hour emitters. Leaching traps were built from 12 inch wide clear vinyl saucers and 0.25 inch clear PVC tubing (Thermo Fisher Scientific, Pittsburgh, PA) and were placed beneath each container. Leachate drains into 500 ml graduated
rectangular bottles (Thermo Fisher Scientific, Pittsburgh, PA) under the greenhouse benches. PVC cut into 1.5 inch long sections were placed in clear saucers under each container to prevent containers from sitting in leachate.

Growth index will be determined at initiation and termination of the experiment using the formula (plant width 1 + plant width perpendicular to width 1 + plant height /3). For dry weight measurements, the above ground portion of plants will be harvested and roots will be hand-washed of substrate. Root and shoot growth will be dried at 55 °C until there is no change in mass. Leaching fraction, water use efficiency, and change in growth index will be calculated. Water application efficiency will be calculated as

\[
\frac{\text{volume of applied water} - \text{volume of water leached}}{\text{volume applied}} \times 100.
\]

Leachate will be collected from 50 containers, half of the containers, each week for eight weeks. Leachate volume, pH, electrical conductivity, N-NO₃, N-NH₄, P-PO₄, and K concentrations will be measured.

Experiments are being conducted at the University of Tennessee North Greenhouse Complex, Knoxville, TN. The experimental design is a randomized complete block in a 2 x 5 factorial arrangement with 10 replications. Factors are are two plant species (Buxus and Hydrangea) and 5 substrates [100% pine bark, pine bark with biochar (10% and 25% v/v) and pine bark with composted biochar (10% and 25% v/v)].

A precision irrigation system in combination with a readily available, low cost substrate amendment that increases water holding capacity may reduce the water requirement for high-value crops and mitigate leaching. The research described here is investigating the role of switchgrass biochar and conservative sensor-based irrigation scheduling with set points predicated on plant available water on reducing both water consumption and nutrients in leachate. Results of this research will help nursery growers conserve water and use nutrient resources more cost effectively.

**Literature Cited**


