Water Management

Anthony LeBude

Section Editor

Routine Leaching Fraction Testing Reduces Micro-irrigation Water Use

Jeff Million and Tom Yeager

Department of Environmental Horticulture
University of Florida, IFAS, Gainesville, FL

jmillion@ufl.edu

Index words Best Management Practice, holly, spray-stake, water conservation

Significance to the Industry There is much pressure for container nurseries to conserve irrigation water. This study provides evidence that periodic adjustments to irrigation rates based on routine monitoring of the leaching fraction (LF=container drainage volume ÷ volume of water applied to the container) can conserve irrigation water while producing high-quality plants. During a 6-month period of production of 'Nellie R. Stevens' holly in 15-gallon containers with spray-stake, micro-irrigation, LF-adjusted irrigation reduced water use 59% and resulted in similar size plants compared to the nursery's traditional irrigation practice with spray-stake emitter. The observed water savings have both economical and consumptive use permitting ramifications.

Nature of Work Leaching fraction testing has been shown to be effective in guiding irrigation and conserving water for outdoor production of landscape plants in a container nursery that predominantly uses sprinkler irrigation (2). Using routine LF testing and adjusting irrigation run times to target a leaching fraction of 10-15%, the nursery was able to reduce irrigation water use 43%. The purpose of the current trial was to test whether LF-adjusted irrigation could also be used successfully for producing landscape plants in larger containers with micro-irrigation.

A demonstration trial was conducted at a container nursery (Holly Factory, Alachua, FL; 29.8^{o}N, 82.5^{o}W) to compare an irrigation schedule based on LF testing with the nursery's traditional irrigation practice, in terms of effects on the growth and water use of holly (*Ilex* x 'Nellie R. Stevens') grown in 15-gallon (17-inch diameter) containers. The container substrate was 60% pine bark and 40% unspecified compost (Sun Gro Horticulture, Orlando, FL). The experimental area included six irrigation test zones each independently controlled by a solenoid valve. Each test zone contained ≈ 800 containers (one plant per container) arranged in two blocks of four rows 300 ft long. There was an ≈ 8-ft alley between blocks. The containers were arranged in an offset pattern with a within-row spacing of 3 ft and a between-row spacing of 3.3 ft. Water was supplied to each of the 8 rows of plants via 1-inch polyethylene pipe. Plastic tubing (0.125-inch i.d.) supplied water from the 1-inch pipe to a single spray-stake (Groove Pot Stake®; Maxijet, Dundee, FL) located at the perimeter of each container. While the Holly Factory traditionally uses green emitters [11.4 gallons per hour (GPH) @ 20 psi] for this crop, the staff wanted to test lower flow rate spray-stakes. Therefore, we divided the six test zones into three pairs of test zones. One pair of zones was fitted with green spray-stakes; a second pair with lime spray-stakes (6.6 GPH @ 20 psi, and a third pair with rust spray-stakes (4.2 GPH @ 20 psi). The 160^o spray pattern exhibited by all three spray-stakes was directed towards the center of the container.

Irrigation treatments were initiated on July 1, 2015. Initially, irrigation was scheduled once daily for 0655 HR. From August 11, 2015 until September 25, 2015, plants were irrigated twice daily with a second cycle added to start at 1815 HR. From September to December 5 (trial termination), plants were irrigated only once daily at 0655 HR. The nursery's traditional practice used for one half of each pair was to irrigate 10 minutes/cycle and manually turn off irrigation if significant rainfall occurred. For LF-adjusted irrigation used for the other half of each pair, four plants from each of the LF irrigation test zones were selected for routine LF testing. LF test plants were placed on 17-inch diameter aluminum pizza pans supported off the ground using 1-ft pieces of 4-inch x 4-inch lumber. A one half inch drainage hole punched at the edge of the pizza pan allowed drainage water to be collected (1). Approximately once every three weeks, a LF test was conducted in both the nursery-controlled irrigation zones and in the LF-adjusted irrigation zones. For a LF test, leachate was collected by placing a pan under the drainage hole of the pizza pan. The volume of water applied to the container was estimated by collecting water from an adjacent emitter into a bucket. Both leachate volume and volume of water delivered by the emitter to the container were determined by weighing to the nearest 0.01kg. When there were two cycles of irrigation per day, we collected leachate and emitter output over both cycles. LF was calculated as below.

$$LF = \textit{volume of leachate} \div \textit{volume of water from emitter} \times 100\%$$

The average LF of the four test plants (LF_{test}) was then used to calculate a new run time to achieve a desired target LF (LF_{target}).

$$\textit{New run time (minutes)} = (100\%-LF_{test}) \div (100\%-LF_{target}) \times \textit{Previous run time (minutes)}$$

We used a target LF of 25% for this trial based on our experience and unpublished data. The new daily irrigation run time was implemented by nursery staff and remained in effect until the next LF test date. LF tests were conducted on days where irrigation water demand was expected to be high (e.g. sunny and warm). This insured that adequate water would be supplied on most other days where irrigation water demand would be approximately equal or less (e.g. cloudy and/or cool).

Plant growth and water use were monitored throughout the trial. For plant growth monitoring, we selected eight plants in each test zone and measured the height and width of each once every three to four weeks. For water use, we kept a running log of daily irrigation run times. To estimate the total water applied to each container in a given test zone, we multiplied the daily irrigation run time (minutes) by the average flow rate (gallons per minute) for that zone. The flow rate for a given test zone was the average (n=20) flow rate measured for four LF test plants during five LF test dates (8/12, 9/23, 10/8, 11/5, and 12/5). All LF testing was conducted by the researchers. All other production practices were carried out similarly for all zones by nursery staff.

Results and Discussion Leaching fraction values for the nursery's traditional irrigation practice ranged from 55% to 82% with 11.4 GHP emitters, 37% to 65% with 6.6 GPH emitters, and 36% to 70% with 4.2 GPH emitters. For LF-adjusted irrigation, LF values ranged from 51% to 73% with 11.4 GPH emitter, 21% to 57% with the 6.6 GPH emitters, and 29% to 56% with 4.2 GPH emitters. We found that even when adjusting the irrigation run times to target a LF of 25%, it was difficult to achieve LF values of 25% or less, even when irrigation amounts were reduced considerably. This indicated that the container substrate was not retaining irrigation water very efficiently even with the low-flow emitters.

While plant size was not greatly affected by irrigation treatments (Table 1), irrigation water use was reduced 59% (173 vs. 426 gallons/container) when using a LF-adjusted irrigation schedule, compared to the nursery's traditional irrigation practice of using a high-flow rate emitter and a fixed irrigation schedule (Table 2 and Fig. 1). When the nursery kept the same irrigation schedule but exchanged the spray-stake emitters with spray-stakes with lower flow rates, the water use dropped proportionately to the observed flow rates in Table 2. The only problem experienced with the lower flow rate emitters was some emitter clogging, particularly at the ends of the 1-inch polyethylene pipes. This was remedied for the most part by installing auto flush valves (5 psi) at the ends of the 1-inch poly-pipe lines. Using LF-adjusted irrigation had less effect on decreasing water usage when using the lower flow-rate emitters. Results showed that routine LF testing to adjust irrigation amounts to minimize leaching can save water in the nursery without reducing plant growth.

Literature Cited

1. Million, J. and T. Yeager. 2016. A simple collection system for routine leaching fraction testing of micro-irrigated container crops. Proc. Southern Nursery Assoc. Res. Conf. 61:171-173.

2. Stanley, J. 2012. Using leaching fractions to maximize irrigation efficiency. Proc. International Plant Propagators' Society. 62:331-334.

Acknowledgement

The authors gratefully acknowledge the Horticultural Research Institute and the Holly Factory for making this research possible.

Disclaimer

Trade names and products are mentioned for informational purposes only.

Table 1. Effect of spray-stake flow rate and irrigation schedule on final plant size of 'Nellie R. Stevens' holly in 15-gallon containers. Irrigation was either based on the nursery's traditional irrigation practice or an irrigation practice based on routine leaching fraction (LF).

Spray-stake flow rate[z] GPH	Plant height (inches)			Plant width (inches)	
	Traditional irrigation	LF irrigation		Traditional irrigation	LF irrigation
11.4	44 (2)[y]	45 (1)		29 (2)	29 (1)
6.6	45 (4)	41 (2)		30 (2)	28 (2)
4.2	42 (3)	46 (4)		28 (2)	29 (3)

[z]Maxijet Pot Groove Stake® specifications @ 20 psi GPH = gallons per hour
[y]Mean (standard deviation); n=8

Table 2. Total irrigation run time and estimated water usage for the nursery's traditional irrigation practice, compared to an irrigation practice based on routine leaching fraction (LF) testing and adjustment to a target LF of 25%.

Spray-stake flow rate[z] (GPH)	Irrigation practice	Observed spray-stake flow rate (GPH)	Total irrigation run time (hours)	Total irrigation water applied (gallons/container)
Green 11.4	Nursery	9.8	44.7	426
	LF	9.4	19.8	173
Lime 6.6	Nursery	7.3	44.7	316
	LF	7.7	38.3	287
Rust 4.2	Nursery	4.4	44.7	193
	LF	4.8	32.3	148

[z]Maxijet Pot Groove Stake® specifications @ 20 psi GPH=gallons per hour

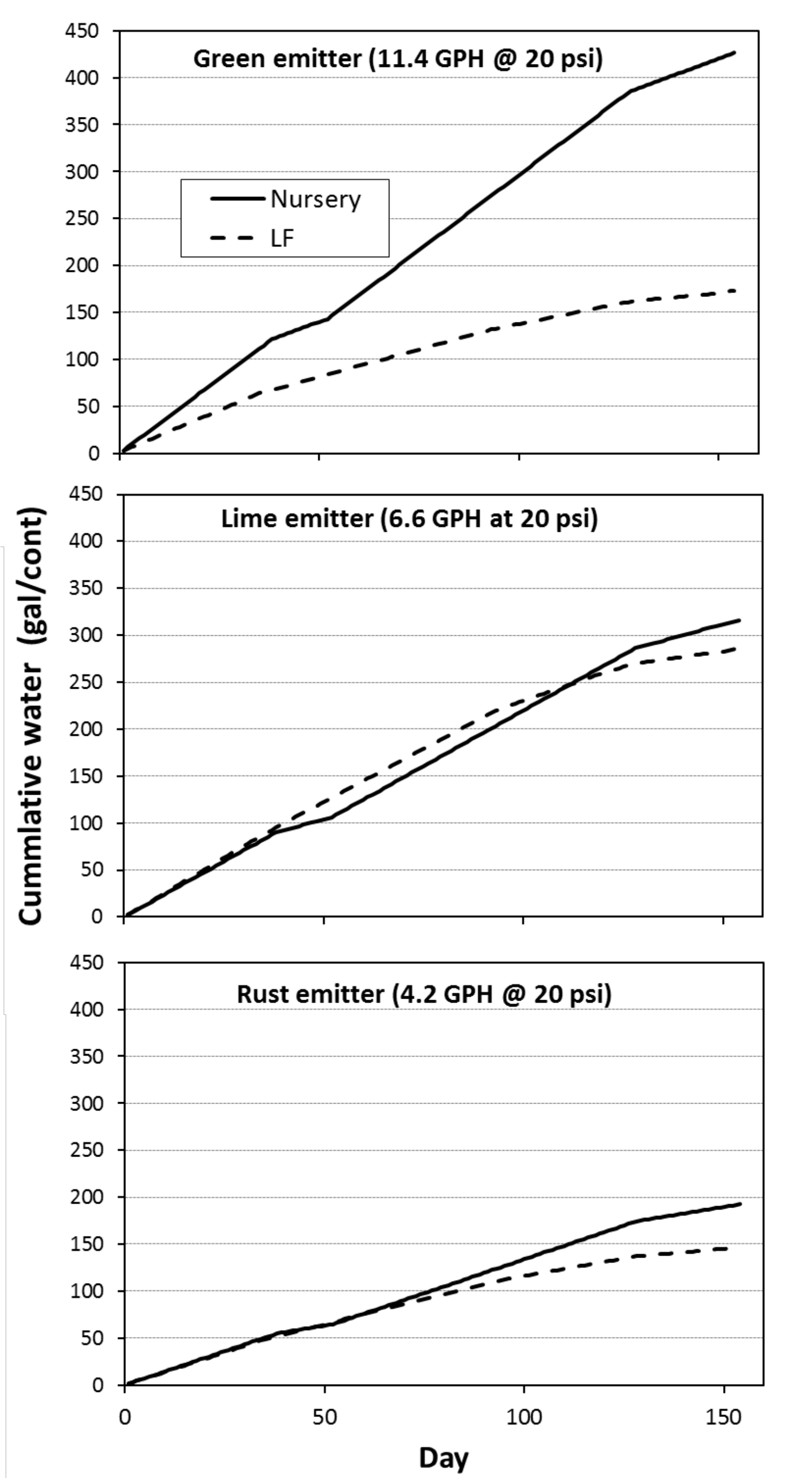

Fig. 1. Cumulative irrigation water applied to 'Nellie R. Stevens' holly in 15-gallon containers using the nursery's traditional irrigation practice or a leaching fraction (LF) irrigation schedule. GPH=gallons per hour

Clean WateR^3: Helping Growers Save Water and Money

Sarah A. White

E-143 Poole Agricultural Center
Department of Plant and Environmental Sciences
Clemson University, Clemson, SC 29634-0310

swhite4@clemson.edu

Index Words: Irrigation control, fertilizer management, treatment technologies, water footprint, carbon footprint

Significance to the Industry: Access to quality sources of water for irrigation is increasingly limited. To stay in business over the coming years, growers will need to develop alternative sources of water (e.g., recycled water) or the capacity to recycle water. The Clean WateR^3 team (cleanwater3.org) is developing information resources and tools growers can use to help make decisions related to optimizing use of water and fertilizer, managing and remediating runoff, and costs and benefits associated with recycling water.

Nature of Work: Fresh water resources are precious and limiting in many areas of the United States. Even in areas of the U.S. where water is not considered a limited resource, competition for and scrutiny of current uses of water resources are increasing. Use of recycled water for nursery and greenhouse crop production may serve to reduce stress on potable water resources, enhance consumer perception of industry reputation for water conservation, and support continued producer economic viability over coming years. Producers' use of recycled water resources for irrigating crops is limited by (A) concerns related to contaminant (e.g., disease, pesticide, and salt) presence and crop health, and (B) the cost of infrastructure changes required to use the resource.

Twenty-two research and extension faculty from 9 universities, 11 collaborating growers, and 6 advisory board members from across the U.S. make up the Clean WateR^3 (R^3 = Reduce, Remediate, Recycle) team. In 2014, our team received NIFA-USDA Specialty Crop Research Initiative funding to:

(A) Develop a suite of online tools that present information related to water management in a manner beneficial to the producer decision process. These data are supported by economic analysis of water management strategies [life cycle inventory (water footprint and carbon footprint)] and crop loss assessments.
(B) Reduce contaminant loading into recycled water sources via installation of treatment technologies and alteration of water management strategies.
(C) Evaluate treatment technology capacity to remediate plant diseases, pesticides, and nutrients from irrigation runoff.

These outputs support the project's long-term impacts of (A) ensuring that water does not limit economic sustainability of nursery and greenhouse producers; (B) helping growers reduce water use, adopt treatment technologies to clean water, and incorporate water reuse at their operation; and (C) conserve valuable water resources and reduce the environmental impact of irrigation runoff.

Results and Discussion: Research conducted by the Clean WateR^3 team is delineated within four areas: understanding the system, reduce, remediate, and recycle. Each area is critical for creating a holistic, systems-based approach for managing water at producer facilities. The ultimate priority for each research area involves getting relevant, quality information to growers so they have tools with which to make informed management decisions. Growers can access information on a variety of water-related topics online at cleanwater3.org.

Understanding the system: To confidently make recommendations about changes in practice, we need to have a better understanding of the many components within a complex system and how they interact. Clean WateR^3 team members have:

- Installed nursery pads at their research facilities and are modeling in three dimensions as well as quantifying how water moves onsite – both surface runoff and water that percolates through the bed, and
- Determined: (A) how water moves through container substrates, (B) barriers to grower adoption and retention and how to present information so it is understood and implemented, (C) how to market reduced water use and conservation during production to end consumers, and (D) the economics of production practices related to water (1, 2).

Reduce: Reducing runoff via optimizing irrigation application methodology and timing is an important task, as managing water during irrigation may help reduce water use, fertilizer leaching, and plant disease pressure. Clean WateR^3 team members have:

- Engineered substrates for better water relations and refined parameters for quality
- Helped growers apply water efficiently when needed by the crop (sensor vs. timed irrigation)
- Identified factors that reduce pesticide losses from nursery production areas

Remediate: Once irrigation runoff exits the production area, it is critical to manage the contaminants it carries. Clean WateR^3 team members are developing and evaluating capacity of treatment technologies to remove nutrients, pesticides, and diseases from runoff (3, 4). Nutrient remediation technologies include floating treatment wetlands, vegetative buffers, filter socks, and woodchip bioreactors. Pesticide remediation technologies include: woodchip bioreactors and granular activated carbon filters. Plant disease remediation technologies include floating treatment wetlands, vegetative buffers, woodchip bioreactors, slow sand filters, and ozone. For each contaminant, the timing, scalability, and efficacy of treatment technologies are being quantified - along with the economics of their adoption and use.

Recycle: Clean WateR^3 team members have worked with growers to help them develop water recycling systems (5) and also evaluated the return on investment for installing water recycling infrastructure. In the future, information gained from understanding the system, reducing water use, and remediating production runoff will combine to inform decisions related to water recycling. Our mission is to provide growers with research-based information sufficient to evaluate the merits of investing in recycling water and to selecting production and irrigation strategies, treatment options, and infrastructure enhancements that are suited for their operation.

Acknowledgements: This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2014-51181-22372. Special thanks to all Clean WateR^3 researchers, advisory board members, students, and technicians.

Literature Cited:

1. Ingram, D. L., C.R. Hall, and J. Knight. 2016. Carbon footprint and variable costs of production components for a container-grown evergreen shrub using life cycle assessment: an east coast United States model. HortScience 51:989-994.
2. Ingram, D.L., C.R. Hall, and J. Knight. 2017. Comparison of three production scenarios for *Buxus microphylla japonica* 'Green Beauty' marketed in a #3 container on the west coast using life cycle assessment. HortScience 52:357-365.
3. Majsztrik, J.C., R.T. Fernandez, P.R. Fisher, D.R. Hitchcock, J. Lea-Cox, J.S. Owen, Jr., L.R. Oki, and S.A White. 2017. Water use and treatment in container-grown specialty crop production: a review. Water Air Soil Pollut. 228(4):151.
4. Oki, L.R., L.L. Nackley, and B. Pitton. 2016. Slow sand filters: a biological treatment method to remove plant pathogens from nursery runoff. Acta Horticulturae 1140:139-144. DOI: 10.17660/ActaHortic.2016.1140.30.
5. Pitton, B.J.L., L.R. Oki, D.L. Haver, and G.E. Johnson. 2017. Recycling Nursery Water. Amer. Nursery. Sept.:20-23.

Comparison of On-demand and Conventional Irrigation Regimes for 'Silver Dollar' Hydrangea Grown Outdoors in Biochar Amended Pine-bark

Nastaran Basiri Jahromi[1], Forbes Walker[1], Amy Fulcher[2], James Altland[3] and Wesley Wright[1]

[1]Biosystems Engineering and Soil Science Department, University of Tennessee
[2]Department of Plant Sciences, University of Tennessee
[3]USDA Technology Application Unit, Wooster, OH

nbasirij@vols.utk.edu

Index Words: Automatic irrigation system, nursery crops, overhead sprinkler systems, plant physiology-based irrigation, substrate physical properties-based irrigation

Significance to Industry: Controlling irrigation using automated timers or by manually operated systems are the most common irrigation scheduling methods in container production systems. Using a fixed irrigation rate in timer-based or manual systems can result in over- or under-watering, an increase in crop vulnerability to disease, a decrease in nursery crop growth due to human error and an increase in leachate. Developing management practices that make more efficient use of irrigation is important for improving the sustainability of nursery crop production.

Nature of Work: Improving irrigation efficiency can be achieved by scheduling irrigation based on estimated crop water use rather than relying on periodically adjusting irrigation volume based on perceived water needs (1). Irrigation scheduling can increase water use efficiency (2) by applying the appropriate amount of water only when needed to support plant growth and avoiding over or under-watering (3). Amendments such as biochar, a carbon-rich by-product of pyrolysis, can reduce substrate pore size by nesting between the larger particles of pine bark. This reduction in substrate pore size could increase the amount of available water and improve irrigation efficiency and plant growth (4). The objective of this research was to evaluate the impact of a hardwood biochar and on-demand irrigation scheduling on plant water use and biomass gain of container-grown 'Silver Dollar' hydrangea.

The outdoor experiment was initiated on 15 June 2017 at University of Tennessee in Knoxville. The treatments were arranged in a 2×3 factorial with two substrates (100% pine bark amended with biochar at 0% or 25% by volume) and three irrigation schedules (conventional irrigation, substrate physical properties-based and plant physiology-based irrigation system). The experiment was a randomized complete block design with three replications and eight subsamples. Data were subjected to analysis of variance using mixed models (SAS v9.4, Cary, NC). 'Silver Dollar' hydrangea rooted cuttings (Griffith Propagation Nursery Inc. Watkinsville, GA) were transplanted into 7.6 L plastic containers on 5 May 2017 which were filled with pine bark and amended with 0% or 25% by volume of hardwood biochar (Proton Power Inc., Lenoir City, TN). One week after transplanting, plants were top-dressed with medium rate, 40 g per container, of 18N-2.6P-9.9K controlled release fertilizer with micronutrients (Osmocote Classic, Everris, Marysville, OH). A wetting agent (Aquagro L, Aquatrols, Paulsboro, NJ) was applied as a drench of 600 mg L^{-1} to ensure even wetting of the substrate. Eight plants were placed in the center of each irrigation zone. Border plants of the same species were spaced around the perimeter of the containers in the experiment to mitigate edge effects.

Substrate moisture levels were monitored with moisture sensors (GS1, Decagon Devices Inc. Pullman, WA) connected to a data logger (CR1000, Campbell Scientific Inc. Logan, UT) with a multiplexer (AM16/32, Campbell Scientific Inc.). A 16-channel relay controller (SDM-CD16AC, Campbell Scientific Inc.) was used to operate solenoid valves. Each probe was calibrated for each of the two substrates at three moisture levels to determine volumetric water content (VWC). There were three sensors per irrigation and biochar rate combination. When the average VWC estimated by the three sensors dropped below the irrigation set point, the data logger was programmed to supply power to the valve controlling irrigation to those containers. Eighteen independently controlled, square irrigation plots were constructed from 1.9 cm PVC pipe. Irrigation was applied by four overlapping sprinklers (Toro® 570 Shrub Spray, The Toro Co., Riverside, CA) per irrigation plot. Each emitter provided 5.5 L h^{-1}. Emitters were mounted on 1.3 cm diameter risers at a height of 66 cm. There were three replicates of each irrigation system and biochar rate combination for a total of eighteen plots. The irrigation run time of each plot was individually calculated based on the lower set points, upper irrigation set points and the flow rate of each plot.

Plants were hand watered until the roots reached the container sidewall. Once the roots reached the sidewall, plants were irrigated by one of the three automatic irrigation systems. An irrigation schedule based on the soilless substrate moisture characteristic curve for each of the two substrates was developed via the evaporative method (Hyprop, UMS, Munich, Germany) and applied irrigation when the volumetric water content corresponding to a substrate water potential of -0.1 bar, generally considered the highest tension for plant available water, was reached. A second irrigation scheduling regime was based on the relationship between photosynthetic rate and substrate moisture content and actuated irrigation at the volumetric water content that was expected to maintain photosynthesis at 90% of the predicted maximum photosynthetic rate. The traditional industry approach to irrigation, delivering 1.8 cm (0.7 inches) of water in one event each day served as the control.

Growth index was 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 portions of plants were harvested and hand-washed of substrate. Plant shoots and leaves were dried at 55 °C until there was no change in mass and then weighed to obtain dry weight at initiation and termination of the experiment. Water use efficiency (WUE) per plant was estimated as (increase in dry weight (g) /total irrigation volume applied (L) over the eight weeks). Leachate was captured with drip pans on three plants per irrigation zone. The leachate pans were shielded from the overhead irrigation by an inverted 7.6 L plastic container with the bottom removed.

Results and Discussion: Plant physiology-based irrigation used less water than the two other irrigation systems while still meeting the needs of the crop. The total amount of water used over the 13-week experiment was reduced by 15% in plant physiology-based irrigation compared to the conventional irrigation (Table 1). There were no differences in the total water used between the substrate physical properties-based and the conventional irrigation system.

Total leachate volume was lower in both on-demand irrigation systems compared to the conventional irrigation. It was 27% lower in plant physiology-based and 31% lower in substrate physical properties-based irrigation scheduling. Estimating plant water use by measurements tied to the physiological status of the plant can conserve water and minimize leachate (5). Plants were under short periods of low VWC in on-demand irrigation system (6), which reduced the channeling and the volume of leachate. The tendency of water to channel through the substrate increased when applied to dry substrate. Channeling may increase water and dissolved fertilizer leaching (7).

Although the total water use was unaffected or lower in on-demand irrigation systems, plant biomass and growth index were higher in on-demand irrigation systems compared to the traditional industry practice of applying 1.8 cm of water per day (Table 1). The on-demand irrigation system prevented the over- or under-watering that happen with traditional irrigation (8). Moisture deficit in traditional irrigation might approach or exceed the water buffering capacity and result in a soil water content in which little to no water is available to plants.

Water use efficiency was greater in on-demand irrigation systems. It increased by 40% in plant physiology-based and substrate physical properties-based irrigation scheduling systems compared to the conventional irrigation (Table 1). Conserving water and promoting maximal crop growth maximized WUE. Conservative irrigation schedules that applied the appropriate amount of water as it was needed by the plants increased the water use efficiency over the traditional industry practice of applying 1.8 cm of water per day. Similar results are also reported in other studies (1, 2). Moderate moisture deficit in on demand irrigation system improved water use efficiency by reducing the water use and leachate volume without a negative effect on plant growth (6).

Total irrigation applied, water use efficiency and total leachate volume were not affected by biochar amendment rate. The effect of biochar depends on type of feedstock, the pyrolysis conditions, and the ecosystem or cropping systems to which biochar is applied (9).

Substantial water savings were achieved without a decrease in growth using a plant physiology based-irrigation system, which selected irrigation set points based on photosynthetic rate and volumetric water content relationship. This system also mitigated leaching. The nursery industry can adopt this system in order to increase water savings potential or expand production on existing and/or limited water supplies. This research demonstrated that on-demand irrigation scheduling with a physiological-basis or substrate physical properties-basis could be an effective approach to increase water use efficiency for container-grown nursery crops without negatively affecting plant growth.

Literature Cited

1. Van Iersel, M.W., M. Chappell, and J.D. Lea-Cox. 2013. Sensors for Improved Efficiency of Irrigation in Greenhouse and Nursery Production. HortTechnology. 23: 735–746.
2. Regan, J. M. 1999. Nursery irrigation scheduling, p. 1-8. Proc. 2nd Annu. Nursery Growers short course. Wilsonville, Ore.
3. Nemali, K.S., and M.W. van Iersel. 2006. An automated system for controlling drought stress and irrigation in potted plants. Scientia Horticulturae 110: 292–297.
4. Caron, J., D.E. Elrick, R. Beeson, and J. Boudreau. 2005. Defining critical capillary rise properties for growing media in nurseries. Soil Science Society of America Journal 69: 794–806.
5. Fulcher, A.F., J.W. Buxton, and R.L. Geneve. 2012. Developing a physiological-based, on-demand irrigation system for container production. Scientia Horticulturae 138: 221–226.
6. Nambuthiri, S., E. Hagen, A. Fulcher and R. Geneve. 2017. Evaluating a Physiological-based, On-demand Irrigation System for Container-grown Woody Plants with Different Water Requirements. HortScience 52: 251–257.
7. Hoskins, T.C., J.S. Owen, and A.X. Niemiera. 2014. Water Movement through a Pine-bark Substrate during Irrigation. HortScience. 49: 1432–1436.
8. Warren, S.L., and T.E. Bilderback. 2005. More plant per gallon: Getting more out of your water. HortTechnology 15: 14–18.
9. Sohi S., E. Lopez-Cape, E. Krull, and R. Bol. 2009. Biochar, climate change and soil: A review to guide future research. CSIRO Land and Water Science Report series, ISSN: 1834-6618, 56 pp.

Table 1. Total irrigation applied per container (L), total leachate volume (L), final dry weight (g), final growth index (cm) and water use efficiency (g L^{-1}) for *Hydrangea paniculata* ‘Silver Dollar’ plants in substrates amended with 0% or 25% by volume of hardwood biochar over a 13 week experiment.

Irrigation system	Total irrigation applied per container (L)	Total leachate volume (L)	Final dry weight (g)	Final growth index (cm)	Water use efficiency ($g{\cdot}L^{-1}$)
Conventional	52.8a	24.4a	96.9b	55.7b	1.0b
Substrate physical	54.1a	16.9b	117.9a	60.6a	1.4a
Plant physiology	45.0b	17.7b	111.5a	59.2a	1.4a
P-value	0.0358	0.0069	0.0272	0.0324	0. 0442

Means in each column followed by the same letter were not significantly different (α = 0.05).