

Production of *Thuja* (*T. standishii* x *T. plicata*) Using an Automated Micro-Irrigation System and Routine Leaching Fraction Testing in a Container Nursery¹

Jeff B. Million and Thomas H. Yeager²

Abstract

A web-based, container irrigation scheduling program (CIRRIG) based on routine Leaching Fraction (LF=drainage/applied) testing and real-time weather monitoring was evaluated for its effect on plant growth and water use of *Thuja* (*T. standishii* x *T. plicata*) 'Green Giant' in #15 [43 cm (17 inch)] containers in a commercial nursery in Florida. Independently-controlled irrigation zones each containing 830 plants were irrigated automatically with CIRRIG or with the nursery's traditional irrigation practice of a fixed daily rate. After 6 months, CIRRIG reduced the total volume of water applied by 51% [490 vs. 990 L/plant (129 vs. 262 gal/plant)] but reduced growth in plant height and width by 15% and 10%, respectively. Routine LF testing indicated that the target LF of 25% was likely too low for the coarse pine bark substrate and spray-stake irrigation system. In light of stricter consumptive use permitting of water by governmental agencies, technologies such as CIRRIG may allow nurseries to produce more plants with less water.

Index words: CIRRIG, evapotranspiration, growth, landscape plant, programmable logic controller, water use.

Species used in this study: *Thuja* Green Giant [*Thuja* (*T. standishii* x *T. plicata*) 'Green Giant'].

Significance to the Horticulture Industry

As water resources become more limiting to container nurseries, it is imperative that growers practice efficient irrigation to maximize profitability. The technology tested in this study involved routine leaching fraction testing coupled with real-time weather monitoring to automatically adjust daily irrigation run times in the field using a web-based irrigation scheduling program for container nurseries called CIRRIG. When the CIRRIG technology was implemented at a commercial container nursery and compared to the nursery's traditional irrigation practice, a water savings of 51% was achieved in the production of a micro-irrigated, trade #15 container-grown landscape plant. While the water savings provided minimal pumping cost savings on a per-container basis, a significant reduction in total water use may increase profitability by allowing nurseries to produce more plants with a given allotment of water granted by consumptive water use permits. Results indicated that additional research is necessary to determine what LF target levels will result in optimal growth with the least amount of water.

Introduction

Container nurseries are facing increased pressure from water management agencies to apply irrigation water efficiently (Majsztrik et al. 2017). The confined volume of substrate in containers provides limited water storage

capacity so that irrigation water is applied frequently, typically one to three times per day. Frequent irrigation places increased demand on applying efficient amounts of irrigation water to resupply water lost through evapotranspiration (ET) without excessive drainage and leaching of applied nutrients.

General strategies for objectively scheduling irrigation are based on evaluating the water deficit in the container prior to irrigation. One of these strategies entails directly measuring container water deficits using substrate moisture probes or sensors (Chappell et al. 2013, Coates et al. 2013, Lea-Cox et al. 2013, Niu et al. 2006, Warsaw et al. 2009) or by weighing containers (Prehn et al. 2010, Million et al. 2010, Sammons and Struve 2008). Another strategy is estimating water deficits using plant evaporation models (Beeson Jr. 2012, Grant et al. 2010, Million and Yeager 2015, Schuch and Burger 1997). The latter strategy has the advantage of not requiring hardware; however, the accurate estimation of water deficits using models has not been widely tested in commercial settings.

While the two general approaches have been found to be useful for determining the water status of the container substrate, critical additional information is needed to relate measured or estimated water deficits to efficient irrigation run times. For example, the capture of sprinkler irrigation water has been shown to be greatly affected by plant size, plant species and container spacing (Million and Yeager 2015). So, the actual amount of irrigation water captured by the container may be considerably different than that calculated solely by irrigation rate. For micro-irrigation, an efficient irrigation run time for a measured container water deficit can be affected by emitter placement, emitter flow rate, cyclic irrigation, container geometry, and substrate's physical properties (Bilderback and Fonteno 1987, Karam and Niemiera 1994, Lamack and Niemiera 1993). An irrigation strategy is needed that not only monitors pre-irrigation water deficits but also accounts for the ability of

¹Received for publication August 17, 2018. This research was supported by a grant from the Horticultural Research Institute (HRI). Its contents are solely the responsibility of the authors and do not necessarily represent the views of the HRI. The authors thank The Holly Factory personnel for their assistance. *Disclaimer* - Trade names, companies, and products are mentioned for informational purposes only and do not constitute an endorsement.

²Department of Environmental Horticulture, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611, jmillion@ufl.edu.

the irrigation system to resupply water to the container substrate.

A strategy for irrigation scheduling that accounts for irrigation system delivery is routine leaching fraction testing (Stanley 2012, Tyler et al. 1996a, Million and Yeager 2018). Leaching Fraction (LF) is the amount of container drainage divided by the amount of irrigation water applied to the container. When LF is measured routinely, irrigation run times can be adjusted to maintain a desired LF. Leaching fraction testing is post-irrigation and therefore directly monitors container drainage, which is generally undesirable and contributes to irrigation inefficiency and runoff.

Reducing LF can help conserve irrigation water and reduce leaching of applied nutrients. Day (2012) reported an annual reduction in irrigation water usage of 56% (74 vs. 167 million gallons/year) over a 4-year period after implementing LF testing at a Virginia container nursery. Associated reductions in the use of fertilizer, herbicide, and chlorine were also reported. Owen et al. (2008) reported that reducing the target LF from 20% to 10% reduced irrigation water use by 25% and drainage by 65%. Tyler et al. (1996a) found that reducing LF from 40-60% to <20% reduced irrigation water applied by 44% and NO₃-N leaching by 66%. In poinsettia production, reducing the target LF from 40% to 20% reduced irrigation water applied by 26% (Ku and Hershey 1991). During a 6-month period of production of ‘Nellie R. Stevens’ holly in 57 L (15 gal) containers, LF-guided micro-irrigation reduced water use by 60% compared to the nursery’s traditional irrigation practice (Million and Yeager 2018).

Daily adjustments to irrigation based on weather may provide additional means for improving irrigation efficiency using routine leaching fraction testing. If LF testing is conducted when weather conditions are conducive to high ET, and appropriate irrigation adjustments are made to achieve a desired LF based on those tests, then fixed daily irrigation amounts applied during the interval between LF tests should be sufficient in most cases. If, however, weather conditions become less conducive to high ET during the interval between LF tests, then fixed daily irrigation amounts are likely to be excessive and thus inefficient to some degree. Our strategy was to improve irrigation efficiency during the interval between LF tests by accounting for real-time weather affecting ET. To test this strategy we modified an existing web-based irrigation program called CIRRI (Million et al. 2012) to output irrigation run times based on LF testing and real-time weather that could be implemented automatically using programmable logic controller (PLC) software and hardware. The objective of this experiment was to evaluate this new technology in a commercial nursery by comparing the weather-based LF technology to the nursery’s traditional irrigation practice with regard to plant growth and water use.

Materials and Methods

LF Irrigation Technology. The LF irrigation technology used in this experiment included the software program CIRRI to generate irrigation run times and a PLC

LF Test Inputs	
LF Test Date:	2018-04-11 select 12 15 pm
LF Test Runtime:	8.0 minutes
Test LF:	23 %
Target LF:	30 %
Last changed: 2018-04-11 10:33:32	

Fig. 1. Example of how results of LF tests conducted approximately once every 3 weeks were input into CIRRI. CIRRI outputted real-time irrigation run times based on recent weather conditions relative to weather conditions associated with the LF test.

irrigation control system to automatically implement CIRRI-generated run times by controlling solenoid valves in the field. A brief description of each follows.

CIRRI (<http://www.bmptoolbox.org/cirri>) was designed for use in commercial container nurseries. One function of CIRRI was to acquire and manage weather data from a data-logging weather station (Vantage Pro Plus II; Davis Instruments, CA) located on-site. A Linux-based microcomputer (Raspberry Pi II; Adafruit Industries, New York City, NY) running WEEWX (www.weewx.com), a free, open-source weather program, acquired weather data logged every 5 sec from the weather station and parsed the weather data for four parameters used in ET calculations: minimum and maximum temperature, solar radiation, and rain. Weather data was stored in a MySQL database under the nursery’s user account on the CIRRI server housed in Gainesville, FL.

Another function of CIRRI was to create and manage multiple irrigation zones and to output daily irrigation run times for each zone based on zone inputs and weather data. For this trial, we selected “LF-micro” version which outputs irrigation run times based on routine LF testing in micro-irrigation production. Once a zone was created, certain inputs were assigned that typically remained unchanged or were infrequently changed for the duration of the crop: number of cycles per day, irrigation rate, container diameter, and weather station (if multiple stations at nursery). A second section of inputs is used for inputting LF test results (Fig. 1) including LF test date and time, LF irrigation run time (RT_{test}), measured LF (LF_{test}), and target LF (LF_{target}). Based on the LF test inputs, CIRRI calculated two LF test reference values, ET_{LF} and RT_{LF} , for making future irrigation calculations. ET_{LF} was the reference potential ET value (ET_o) calculated using the 24 hours of weather data collected previous to the LF test date and time. ET_o was calculated using a container-grown plant evaporation model described by Million et al. (2011), which uses a biased temperature maximum that accounts for the heating affect that occurs when growing plants in black containers on black ground cloth in spaced arrangements. RT_{LF} was the run time of the LF test adjusted for the target LF according to

$$RT_{LF} = (100\% - LF_{test}) \div (100\% - LF_{target}) \times RT_{test}.$$

Using the LF test reference values, daily irrigation run times (RT_{day}) were calculated just prior to irrigation

according to: $RT_{day} = ETo/ET_{LF} \times RT_{LF}$ where ETo is the potential ET calculated using the past 24 hours of weather data. In order to account for rain and multiple cycles during the day, an hourly water balance was calculated based on the distribution of solar radiation during the 24-hour period:

$$RT_{hour} = SR_{hr} \div SR_{day} \times RT_{day} - RT_{rain}$$

where RT_{hour} =hourly run time, SR_{hr} =hourly solar radiation, SR_{day} =past 24-hour solar radiation, and RT_{rain} = hourly rain converted to equivalent run time based on the irrigation application rate. RT_{hr} values calculated for each hour subsequent to the last irrigation were summed and ultimately output as the current irrigation run time. If a minimum run time of 2 minutes was not exceeded, then irrigation was cancelled and the deficit carried over to the subsequent irrigation cycle.

The PLC technology used to implement CIRRIG required various hardware and software. The microcomputer running the weather acquisition program also ran local JAVA agents that acquired output from CIRRIG and set timer values on the PLC (D0-DA06 with H0-ECOM100 communications module; Direct Logic, Atlanta, GA) for each test zone via an Ethernet connection on the local network. A cell modem and router (MBR95, Cradlepoint, Boise, ID) were used to create a local network connected to the internet. A graphical user interface program allowed the control and monitoring of all PLC activities locally or remotely.

Field Experiment. A field experiment was conducted at The Holly Factory (29.8°N, 82.5°W), a 28 ha (70 acre) container nursery producing primarily landscape shrubs and trees with spray-stake, micro-irrigation. The experimental site included six adjacent, independently-controlled irrigation test zones. Each test zone contained approximately 830 *Thuja* (*T. standishii* x *T. plicata*) ‘Green Giant’ in 43 cm (17 inch) top diameter containers (trade #15). Containers in each test zone were arranged in two sections of four rows each 91 m (300 ft) long. There was a 2.4 m (8 ft) alley between sections within a test zone and between adjacent tests zones. Containers were arranged in an offset pattern with a within-row spacing of 86 cm (34 inch) and a between-row spacing of 102 cm (40 inch). Water was supplied to each of the 8 rows of plants via 2.5 cm (1 inch) polyethylene pipe. Plastic tubing [0.32 cm (0.125 inch) inner diameter] supplied water from the 2.5 cm (1 inch) pipe to a single spray stake (Lime Green Groove Pot Stake®; 6.6 gal/hr at 20 psi; Maxijet, Dundee, FL) located at the perimeter of each container spraying inward. Water use was monitored by installing a 7.6 cm (3 inch) flowmeter (Flo-wise Totalizer; Senninger, Clermont, FL) upstream from the solenoid valve controlling each irrigation zone. Irrigation tests were conducted to determine irrigation rate and distribution of uniformity (DU) by collecting irrigation water from 16 emitters per zone during 10-minute irrigation cycles. Emitter flow rates averaged 27 L·hr⁻¹ (7.1 gal·hr⁻¹) and DU averaged 83%.

Thuja grown in 15 cm (6 inch) diameter containers (trade #1) were previously transplanted into the 43 cm (17

inch)-diameter containers (trade #15) on April 23, 2016, nine months prior to the start of the experiment on 6 Feb. 2017. The substrate was composed of 90% pine bark and 10% compost (Southeast Soils, Okahumpka, FL) containing a micronutrient supplement (Meg Iron V; Florikan, Sarasota, FL) at 2.1 lb·yd⁻³. Two controlled-release fertilizer applications were made to each container at planting: 50 g of 21-1.7-6.7 (Osmocote® 21-4-8, 12-14 month at 21 C; ICL Specialty Fertilizers, Dublin, OH) was sub-dressed on the side of the transplant root ball and 50 g 16-2.2-9.2 (POLYON® 16-5-11, 12-14 month at 21 F; Harrell’s, Lakeland, FL) top-dressed. A second top-dress application of 125 g was made to each container the week of January 2, 2017, one month prior to the start of the irrigation treatments. Plants were pruned for shape on March 13, 2017. All production activities were carried out by HF staff.

Three of the six test zones were irrigated according to The Holly Factory’s traditional practice (TP) and the other three using automated CIRRIG technology (CIRRIG). Both TP and CIRRIG were scheduled to irrigate once a day starting at 1215 HR. TP irrigation was a fixed rate of 10 min per day or 4.5 L per plant per day (1.2 gal per plant per day) until May 11 (day 94) and 15 min per day or 6.8 L per plant per day (1.8 gal per plant per day) from May 12 until the end of the experiment. At the nursery’s discretion, irrigation was turned off if rainfall was considered sufficient to offset irrigation needs. For the CIRRIG treatment, four plants per test zone were selected for routine LF testing. LF plants were placed on 43 cm (17 inch) diameter aluminum pizza pans placed on top of two 30 cm (1 ft) long pieces of 10.2 cm by 10.2 cm (4 in by 4 in) lumber. A 1.3 cm (0.5 in) diameter hole punched in the pizza pan allow for the collection of container drainage. An emitter from an adjacent container was placed in a pail to collect the amount of irrigation water applied. The average of the four LF measurements was entered in the CIRRIG program along with the associated irrigation run time and a target LF of 25%. The target LF was increased to 30% on June 27 (day 141) after observing declining water retention at 25%. LF tests were conducted approximately once every 3 to 4 weeks on days unaffected by rain or excessively cloudy conditions. The experiment lasted 197 days terminating on Aug 22, 2018 when plants were moved to another location at the nursery in preparation for sale.

Plant growth was monitored by tagging 16 plants per treatment block and measuring plant height and two perpendicular plant widths at the start and once every three weeks. Plant growth was the change in plant height and width from the start to the end of the experiment. Irrigation water applied to each test zone was monitored by taking weekly flowmeter readings. The experiment was analyzed as a randomized complete block design with three blocks and two irrigation treatments using Statistical Analysis System (SAS Version 9.4; Cary, NC). There were three replications per treatment for total water applied, and 48 replications per treatment for plant growth.

Table 1. Average daily air temperatures and solar radiation and total rain for monthly intervals at The Holly Factory nursery during the irrigation experiment.

Interval	Tmin ^y (C)	Tmax ^y (C)	Solar radiation ^z (MJ·m ⁻² ·d ⁻¹)	Rain (cm)
2/7/17 - 2/28/17	11	25	14	3
3/1/17 - 3/31/17	10	25	17	2
4/1/17 - 4/30/17	14	29	20	10
5/1/17 - 5/31/17	18	32	21	4
6/1/17 - 6/30/17	21	32	16	28
7/1/17 - 7/31/17	23	33	19	11
8/1/17 - 8/22/17	23	32	16	9

^zW·m⁻² = MJ·m⁻²·d⁻¹ × 11.57

^yTmin and Tmax were the average daily minimum and maximum temperatures, respectively. F = C × 1.8 + 32.

Results and Discussion

Weather during the experiment was typical of this North-Central Florida location (Table 1). By the middle of May daily low temperatures rarely fell below 21 C (70 F) and high temperatures were typically above 32 C (90 F). Solar radiation levels were highest in April and May when humidity was lower and skies clearer than subsequent summer months when humidity and cloud cover increased. An increase in convective storms during the summer months typically results in 16 to 20 cm (6 to 8 in) of rain per month, or double what we would normally expect in spring months. In this trial, lower than average rain fell in all months except June when 28 cm (11 in) was recorded.

Leaching fraction tests conducted for the CIRRIG treatment were generally higher than the target value of 25% (Fig. 2). The average LF for the 16 tests was 36% with only one testing date (June 1) giving a value <25%, the target LF. We attributed the high LF values to the coarse substrate and the scheduling of only one irrigation cycle per day. A cyclic irrigation schedule where irrigation is applied in two or more cycles per day has been shown to improve water retention and decrease drainage (Karam and Niemiera 1994, Tyler et al. 1996b). Despite high LF values, we often observed decreasing container weights

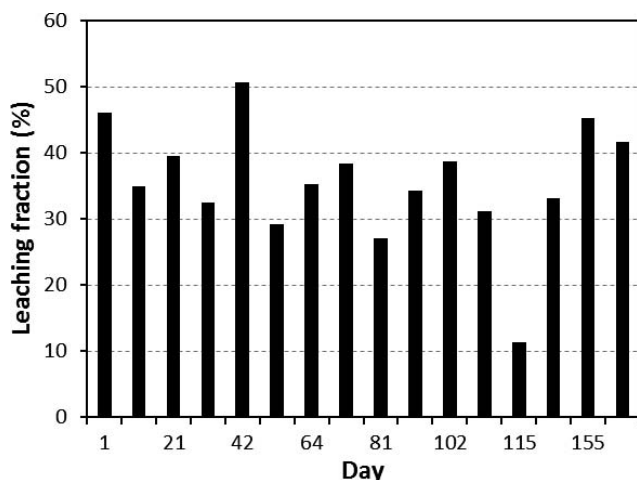


Fig. 2. Leaching fraction test results (n=4) used to guide CIRRIG-directed irrigation. The target LF was 25% (30% after day 141).

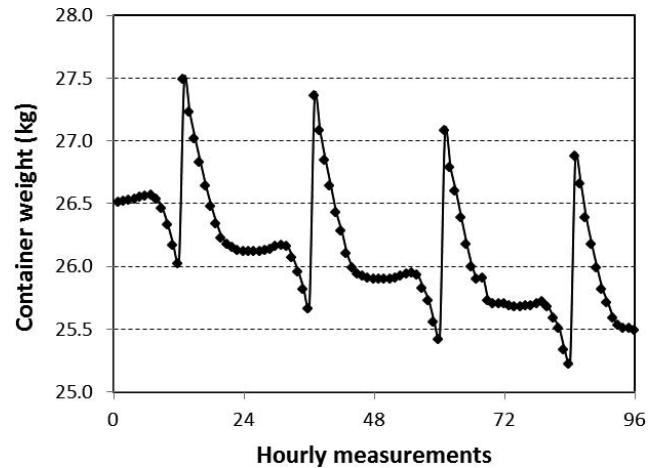


Fig. 3. Hourly container weight measurements for a CIRRIG-irrigated plant over a 4-day period (May 11-14).

over time. An example from a 4-day stretch of clear weather from May 11 to May 14 is given in Fig. 3. Decreasing container weights despite high LF was further evidence that the substrate was not efficiently retaining the irrigation water.

CIRRIG-directed irrigation applied less than 50% of the water applied by TP and this effect was consistent throughout the 197-day trial (Fig. 4). At the end of the experiment, CIRRIG reduced ($P < 0.01$) total irrigation water applied by $51 \pm 3\%$ [490 vs. 990 L per plant (129 vs 262 gal per plant); Table 2] compared to TP.

Although CIRRIG reduced irrigation water applied, plant growth was negatively affected during the second half of the experiment (Fig. 5). Plant growth of *Thuja* during the first 90 to 100 days was little affected by irrigation treatment. Subsequently, however, TP resulted in greater growth than CIRRIG, especially in May and June. There was little growth effect of irrigation treatments observed in July and August. By the end of the experiment,

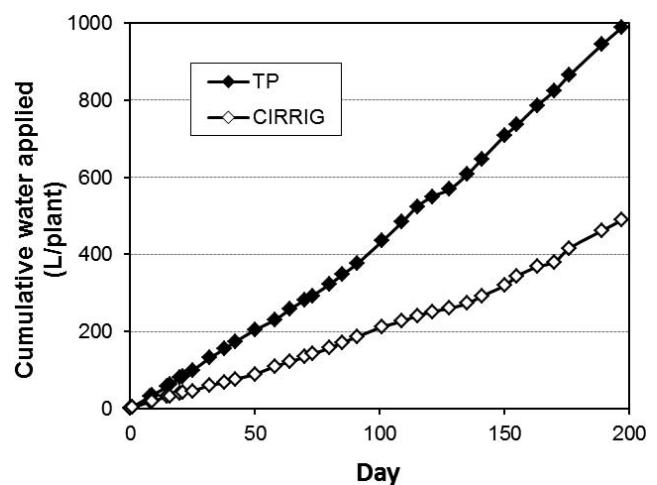


Fig. 4. Cumulative irrigation water applied to *Thuja* (*T. standishii* × *T. plicata*) ‘Green Giant’ produced in 43 cm (17 inch) diameter containers (trade #15) with The Holly Factory’s traditional irrigation (TP) or with CIRRIG technology. Each symbol represents a day flowmeter readings were taken (n=3). 1 gallon = 3.785 L.

Table 2. Plant growth and irrigation water applied to *Thuja* (*T. standishii* x *T. plicata*) ‘Green Giant’ grown in 43 cm (17 inch) diameter containers (trade #15) for 197 days with The Holly Factory’s traditional irrigation practice (TP) or with CIRRIG technology.

Irrigation practice	Plant growth ^y		Water applied ^z (L /plant)
	Height (cm)	Width (cm)	
TP	59	33	990
CIRRIG	51	30	490
Irrigation ^x	**	**	**
LSD _{0.05}	5	2	30

^zmeasured with flowmeters (n=3)

^ychange in plant height and width during the experiment (n=48)

^x1 inch = 2.54 cm; 1 gallon = 3.785 L

**significant at the $P < 0.01$ confidence level

plant height growth was reduced ($P < 0.01$) by 14% [59 vs. 51 cm (23 vs. 20 inch)] and plant width growth was reduced ($P < 0.01$) by 10% [30 vs. 33 cm (12 vs. 13 inch); Table 2]. Despite the 10-15% reduction in plant growth, *Thuja* plants irrigated with CIRRIG were of marketable size and appeared similar in quality to *Thuja* irrigated by TP.

Conducting this kind of experiment where each day entails implementing the irrigation treatment was a great learning experience. We learned some of the reasons why TP may have been applying more water than what was indicated by LF testing. One reason previously suggested was the coarseness of the substrate (90% pine bark), which may have required high irrigation rates (high LF) to maintain adequate substrate moisture levels. Another observation was that frequent mechanical issues with the main pump or water being directed to other areas of the nursery causing low water pressure resulted in many days when little or no water was delivered during scheduled times. High rates of irrigation may help container substrates with missed irrigations to “catch up” more rapidly than when irrigation is more conservative (low LF). Furthermore, skipped irrigation days resulting in lower pre-irrigation substrate moisture levels can exacerbate poor water retention of subsequent irrigations by increasing hydrophobic properties of the substrate. In a previous trial at The Holly Factory with Nellie Ray Stevens holly, LF testing to make periodic adjustments to irrigation resulted in plant growth and quality similar to the plant growth and quality using the nursery’s traditional fixed rate of irrigation, while using 50% less water (Million and Yeager 2018). In that experiment, daily adjustments to irrigation were not made with CIRRIG but remained fixed during the interval between LF tests. With that schedule, the additional water applied for days of low ET may have allowed for “catching up” but with lower overall amounts of irrigation water applied with CIRRIG relative to that applied using the nursery’s traditional practice.

A benefit of applying less irrigation water includes lower pumping costs. At The Holly Factory, the irrigation pumping cost basis was \$0.053 per 1000 L (\$0.20 per 1000 gal). In this trial total irrigation water applied was 990 and 490 L per plant (262 and 129 gal per plant) for TP and

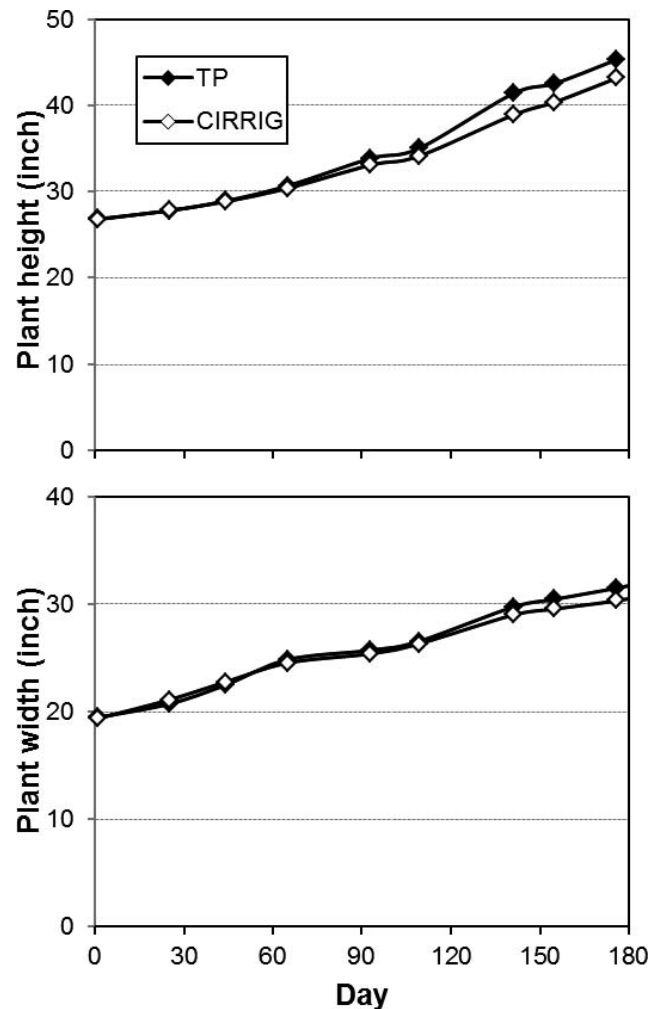


Fig. 5. Plant height and width of *Thuja* (*T. standishii* x *T. plicata*) ‘Green Giant’ produced in 43 cm (17 inch) diameter containers (trade #15) with The Holly Factory’s traditional irrigation practice (TP) or with CIRRIG technology (n=48). 1 inch = 2.54 cm.

CIRRIG, respectively. The savings of 500 L per plant (132 gal per plant) using CIRRIG equated to a savings of <\$0.03 per plant. At a market value of \$60 per plant, it is easy to see why even a reduction in water use of >50% provides minimal incentive to conserve water to reduce irrigation pumping costs. However, if consumptive use permits are limiting production by limiting a nursery’s allowable allotment of water, then reducing water consumption using CIRRIG technology may have significant, albeit unknown, impacts on nursery profitability.

Literature Cited

- Beeson, Jr., R.C. 2012. Development of a simple reference evapotranspiration model for irrigation of woody ornamentals. *HortScience* 47(2):264–268.
- Bilderback, T.E. and W.C. Fonteno. 1987. Effects of container geometry and media physical properties on air and water volumes in containers. *J. Environ. Hort.* 5(4):180–182.
- Chappell, M., S.K. Dove, M.W. van Iersel, P.A. Thomas, and J. Ruter. 2013. Implementation of wireless sensor networks for irrigation control in three container nurseries. *HortTechnology* 23:747–753.

- Coates, R.W., M.J. Delwiche, A. Broad, M. Holler. 2013. Wireless sensor network with irrigation valve control. *Computers and Electronics in Agric.* 96:13–22.
- Day, L. 2015. Evapotranspiration-based irrigation at Saunders Brothers Nursery. *Intl. Plant Propag. Soc.* 65:383–386.
- Grant, O.M., M.J. Davies, H. Longbottom, R. Harrison-Murray. 2010. Evapotranspiration of container ornamental shrubs: modelling crop-specific factors for a diverse range of crops. *Irrig. Sci.* 30:1–12.
- Karam, N.S. and A.X. Niemiera. 1994. Cyclic sprinkler irrigation and pre-irrigation substrate water content affect water and N leaching from containers. *J. Environ. Hort.* 12(4):198–202.
- Ku, C.S.M. and D.R. Hershey. 1991. Leachate electrical conductivity and growth of potted poinsettia with leaching fractions of 0 to 0.4. *J. Amer. Soc. Hort. Sci.* 116(5):802–806.
- Lamack, W.F. and A.X. Niemiera. 1993. Application method affects water application efficiency of spray stake-irrigated containers. *HortScience* 28(6): 625–627.
- Lea-Cox J.D., W.L. Bauerle, M.W. van Iersel, G.F. Kantor, T.L. Bauerle, E. Lichtenberg, D.M. King, and L. Crawford. 2013. Advancing wireless sensor networks for irrigation management of ornamental crops: an overview. *HortTechnology* 23(6):717–724.
- 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.* 228:151–177.
- Million, J.B., T.H. Yeager, and J.P. Albano. 2010. Evapotranspiration-based irrigation scheduling for reducing runoff during production of *Viburnum odoratissimum* (L.) Ker Gawl. *HortScience* 45(11):1741–1746.
- Million, J.B., J.T. Ritchie, T.H. Yeager, C.A. Larsen, C.D. Warner and J.P. Albano. 2011. CCROP - Simulation model for container-grown nursery plant production. *Scientia Horticulturae* 130(4):874–886.
- Million, J.B. and T.H. Yeager. 2018. Routine leaching fraction testing can reduce micro-irrigation water use in container nurseries. *South. Nursery Assn. Res. Proc.* 62:94–98.
- Million, J.B., and T.H. Yeager. 2015. CIRRI: weather-based irrigation management program for container nurseries. *HortTechnology* 25(4):528–535.
- Million, J.B. and T.H. Yeager. 2015. Capture of sprinkler irrigation water by container-grown ornamental plants. *HortScience* 50(3):442–446.
- Niu, G., D.S. Rodriguez, R. Cabrera, C. McKenney, and W. Mackay. 2006. Determining water use and crop coefficients of five woody landscape plants. *J. Environ. Hort.* 24(3):160–165.
- Prehn, A.E., J.S. Owen, Jr., S.L. Warren, T.E. Bilderback, and J.P. Albano. 2010. Comparison of water management in container-grown nursery crops using leaching fraction or weight-based on demand irrigation control. *J. Environ. Hort.* 28(2):117–123.
- Sammons, J.D. and D. K. Struve. 2008. Monitoring effective container capacity: a method for reducing over-irrigation in container production systems. *J. Environ. Hort.* 26(1): 19–23.
- Schuch, U.K. and D.G. Burger. 1997. Water use and crop coefficients of woody ornamentals in containers. *J. Amer. Soc. Hort. Sci.* 122:727–734.
- Stanley, J. 2012. Using leaching fractions to maximize irrigation efficiency. *Proc. International Plant Propagators' Society.* 62:331–334.
- Tyler, H.H., S.L. Warren, and T.E. Bilderback. 1996a. Reduced leaching fractions improve irrigation use efficiency and nutrient efficacy. *J. Environ. Hort.* 14(4):199–204.
- Tyler, H.H., S.L. Warren, and T.E. Bilderback. 1996b. Cyclic irrigation increases irrigation application efficiency and decreases ammonia losses. *J. Environ. Hort.* 14(4):199–204.
- Warsaw, A.L., R.T. Fernandez, B.M. Cregg, and J.A. Andresen. 2009. Water conservation, growth, and water use efficiency of container-grown woody ornamentals irrigated based on daily water use. *HortScience* 44:1308–1318.