Use of Routine Leaching Fraction Testing to Guide Irrigation at a Container Nursery[1]

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Abstract

Efficient irrigation during container plant production is difficult to achieve as irrigation is scheduled daily or multiple times per day to maintain an adequate supply of water in the limited substrate volume. Leaching fraction (container drainage/water applied) testing is one strategy to monitor and adjust irrigation to limit excessive container drainage. We compared an automated irrigation schedule based on routine leaching fraction testing and weather (LFI) with a nursery's traditional irrigation practice (TIP). Compared to TIP, LFI reduced water applied in four of five sprinkler-irrigated trials without a notable growth affect; LFI increased water applied in a fifth trial but plant growth was also increased. Compared to TIP, LFI reduced water applied in all three micro-irrigated trials but also reduced growth in one of the trials. LFI reduced water applied by an average of 21% [57.8 vs. 73.1 $kL \cdot ha^{-1} \cdot d^{-1}$ (15,300 gal/acre/day) or \$3,000 $ha^{-1}yr^{-1}$ (\$1,200/acre/year) at a pumping cost of \$0.53/kL (\$0.20/1000 gal). We concluded that the greater economic benefit of water savings was to provide increased capacity for additional production under consumptive water use limitations rather than to reduce the unit cost of production.

Index words: automation, evapotranspiration, sprinkler, micro-irrigation, weather.

Species used in this study: Leyland cypress, *Cupressus × leylandii* A.B. Jacks. and Dallim., Parson juniper, *Juniperus squamata* Gordon 'Expansa Parsonii', crape myrtle, *Lagerstroemia indica* L. × *fauriei* Koehne 'Natchez', Indian hawthorn, *Raphiolepis indica* (L.) Lindl., sweet viburnum, *Viburnum odoratissimum* Ker Gawl.

Significance to the Horticulture Industry

Methods for applying irrigation water efficiently are needed for production of container-grown plants. This study conducted at a cooperating nursery compared an automated, irrigation control system based on leaching fraction testing and real-time weather, with the nursery's traditional method of subjectively rating moisture of substrate core samples for adjusting irrigation. Results indicated that significant water savings (5-50%) can be achieved with the automated system. However, due to the low cost of pumping water relative to the price of the marketable product, we concluded that the greater economic benefit of reduced irrigation water applied was to provide increased capacity for additional production under consumptive water use limitations rather than to reduce the unit cost of production.

Introduction

Frequent irrigation is needed to maintain adequate substrate moisture levels for production of landscape plants in containers. Management strategies are needed to help growers make objective decisions on when and how much water to apply so that profitable production can be maintained with minimal water use and associated detrimental effects of agrichemical leaching. Much research has evaluated irrigation scheduling strategies that rely on assessing pre-irrigation substrate moisture either with sensors (Belayneh et al. 2013, Hagen et al. 2014, Nambuthiri et al. 2014, Pershey et al. 2015) or by weighing (Million et al. 2010, Prehn et al. 2010). For on-demand irrigation control, threshold values can be set to turn on and off irrigation valves. For fixed-time irrigation schedules, irrigation run times can be set that bring the pre-irrigation water content back to container capacity or, for deficit irrigation, to a predetermined water deficit level (Sammons and Struve 2008, Welsh and Zajicek 1993). Alternatively, irrigation can be automatically stopped once a threshold moisture level is reached as determined by sensors (Belayneh et al. 2013) or weighing (Prehn et al. 2010). A more indirect approach is estimating pre-irrigation water deficits with evapotranspiration models (Baille et al. 1994, Beeson, Jr. 2005, Million et al. 2015, Schuch and Burger 1997). Evapotranspiration models for irrigation scheduling have not been widely adopted by the industry and this is likely due in part to the wide range of plant production conditions (e.g., species, container size, container spacing, stage of plant growth, plant size) that exist in the nursery at any given time.

An alternative irrigation strategy, and one that was tested in this study, is to adjust irrigation run times based on the amount of leachate (container drainage) that occurs. The amount of leaching can be described with the leaching fraction (LF), the amount of leachate collected divided by the amount of irrigation water applied to the container. When conducted routinely, irrigation run times can be adjusted to a target LF according to:

$$\text{New run time} = \text{LF test run time} \times (100\% - \text{Test LF}) \div (100\% - \text{Target LF}).$$

For sprinkler-irrigated crops, the target LF is typically 10-15% (FDACS 2014) while higher target LF values of 25-30% have been needed for micro-irrigated crops in nursery settings (Million and Yeager 2018, Owen et al.

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2007). Micro-irrigation in outdoor container nurseries typically entails the use of spray-stake emitters that apply water directly to each container. Higher target LF values for micro-irrigated crops may be due in part to spray stake application rates that can be 10X higher than typical sprinkler application rates, reducing the ability of the substrate to retain the applied water. Also, spray stake irrigation rarely applies water uniformly over the substrate surface so that downward water movement can occur rapidly, resulting in leachate being observed in as little as 60-90 sec (Hoskins et al. 2018).

While periodic adjustments to irrigation run times can be made with LF testing and substantial water savings observed (Stanley 2012), there is potential to improve irrigation efficiency further by making additional adjustments during the interval between LF tests according to real-time weather affecting evapotranspiration, as well as accounting for rain that can reduce the irrigation requirement. Using this strategy, Million and Yeager (2020) reported an additional water savings of 10% in a micro-irrigation experiment with Podocarpus (*Podocarpus macrophyllus* L.) in 26.5-L (7 gal) containers but no water savings in a similar experiment with sweet viburnum.

While research has demonstrated that new irrigation scheduling strategies can work well in controlled experiments, there are few reports where these strategies have been tested or adopted by container nurseries. The objective of our study was to implement an automated, LF-based irrigation scheduling program at a commercial nursery in central Florida and compare water use and plant growth with the nursery's traditional irrigation practice. A companion study with similar objectives and methods was conducted at another container nursery in central Florida around the same time (Million and Yeager 2019). The primary differences between the two studies were the species tested, sizes of production areas, and LF testing scheduling/management.

Materials and Methods

LF Irrigation Technology. The LF irrigation technology used in these experiments included the software program CIRRIG (Univ. of Florida, Gainesville, FL, www.bmptoolbox.org/cirrig) to generate irrigation run times and a programmable logic controller (PLC) irrigation control system to automatically implement CIRRIG-generated run times by controlling solenoid valves in the field. A brief description of each follows.

CIRRIG was designed for use in commercial container nurseries. One function of CIRRIG in this study was to acquire and manage weather data from two data-logging weather stations (Vantage Pro Plus II, Davis Instruments, Hayward, CA) located on-site. One station was in a sprinkler-irrigated production area and the other in a micro-irrigated area. A Linux-based microcomputer (Raspberry Pi 2, Adafruit Industries, New York City, NY) running WEEWX, (www.weewx.com), a free, open-source weather program, acquired weather data logged every 5 s 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 CIRRIG server housed in Gainesville, FL.

Another function of CIRRIG 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. Once a zone was created, certain inputs were assigned that remained unchanged or were infrequently changed for the duration of the crop: number of cycles per day, irrigation rate, container diameter, and weather station. A second section of inputs was used for inputting LF test results 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, CIRRIG calculated two LF test reference values, ET_{LF} and $RT_{LF,}$ for future irrigation calculations. ET_{LF} was the reference potential ET value (ETo) calculated using the 24 hours of weather data collected prior to the LF test date and time. ETo was calculated using a container-grown plant evaporation model described by Million et al. (2015), 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 immediately before irrigation according to a simple linear adjustment:

$$RT_{day} = ETo/ET_{LF} \times RT_{LF},$$

where ETo is the potential ET calculated using the past 24 hours of weather data. 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-hr 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-hr 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 after the last irrigation were summed and ultimately outputted as the current irrigation run time. If a minimum run time was not exceeded, then the irrigation was cancelled, and the deficit carried over to the subsequent irrigation cycle.

The PLC irrigation control system used to implement CIRRIG required various hardware and software. The microcomputer running the weather acquisition program also ran JAVA (Oracle Corp., Austin, TX) programs that acquired output from CIRRIG and set timer values on a PLC (D0-06DA or D0-06DD2 with a H0-ECOM100 communications module, Direct Logic, Atlanta, GA) for each test zone via an Ethernet connection on the local network. Because of the remote location, a cellular modem with a static IP address and router (MBR95, Cradlepoint, Boise, ID) were used to create a local network connected to the internet. A graphical user interface program developed

Table 1. Non-replicated trials conducted at a container nursery to compare automated LF technology with the nursery's traditional irrigation practice with regards to plant growth and water use. Average daily minimum (T_{min}) and maximum (T_{max}) air temperatures and solar radiation and total rain were recorded on-site. One cm = 0.394 in; C*1.8+32 = F.

Trial[z]	Plant common name	Container diameter (cm)	Start date	End date	T_{min}/T_{max} (C)	Solar radiation ($W \cdot m^{-2}$)	Rain (cm)
S1	Sweet viburnum	25.4	11 Sep. 2015	28 Mar. 2016	16/25	139	53
S2	Crape myrtle	27.9	23 Sep. 2015	20 Jun. 2016	16/27	188	74
S3	Indian hawthorn	25.4	6 Jul. 2016	31 Mar. 2017	17/28	183	60
S4	Sweet viburnum	25.4	6 Jul. 2016	21 Feb. 2017	18/28	180	56
S5	Parson juniper	25.4	8 May 2017	30 Apr. 2018	18/28	188	137
M1	Leyland cypress	43.2	16 Sep. 2015	15 Mar. 2016	16/25	157	43
M2	Leyland cypress	43.2	16 Feb. 2016	21 Feb. 2017	18/29	203	104
M3	Leyland cypress	43.2	4 May 2017	22 Feb. 2018	19/28	181	121

[z]Trial designation: S=sprinkler-irrigated, M=micro-irrigated.

at the Univ. of Florida allowed the control and monitoring of all PLC activities locally or remotely. The micro-irrigated area had no electrical power, so we used a 12VDC battery to run all electronics including a DC-powered PLC (D0-06DD2, Automation Direct, Direct Logic, Atlanta, GA) and DC-latching solenoids.

Field trials. Eight side-by-side, non-replicated trials comparing an automated, LF-based irrigation scheduling program to the nursery's traditional irrigation practice were conducted at Cherrylake, a 730-ha (1,800 acre) container nursery located in Groveland, Florida (Lat. 28.8°N, Long. 81.8°W, elev. 21-30 m). Cherrylake produces trees and shrubs in a wide range of container sizes in black plastic containers placed on conventional black, woven polypropylene ground cloth. Shrubs were mainly produced in smaller containers [≤ trade 11.4 L (3 gal)] with sprinkler irrigation while trees were grown in larger containers [≥ trade 26.5 L (7 gal)] with spray-stake micro-irrigation. Five trials were conducted with sprinkler-irrigated shrubs and three experiments with micro-irrigated trees during a 3-yr period (Table 1). The plants tested included sweet viburnum, crape myrtle, Indian hawthorn, Parson juniper, and Leyland cypress. The substrate for micro-irrigated trials with trade 57 L (15 gal) containers was 60% pine bark [2 cm (3/4-inch sieve)] and 40% Florida peat (volume basis). The total porosity, air space and water-holding capacity for this mix were 56%, 35%, and 21%, respectively. For sprinkler-irrigated trials with trade 11.4 L (3 gal) containers the substrate was 60% pine bark, 30% Florida peat, and 10% sand. The total porosity, air space and water-holding capacity for this mix were 56%, 28%, and 28%, respectively.

The sprinkler zones used wobbler sprinklers [Excel-Wobbler with grey #9 nozzles rated at 9.5 $L \cdot min^{-1}$ (2.5 $gal \cdot min^{-1}$) at 138 kPa (20 psi), Senninger, Clermont, FL] on 1.2 m (4 ft) risers. Micro-irrigated zones used two different types of spray-stake emitters. A down-spray emitter [Max-Cone Down Fan Black rated at 21 $L \cdot h^{-1}$ (5.5 $gal \cdot min^{-1}$) at 103 kPa (15 psi); Maxijet, Dundee, FL] was used for trials M1 and M2 and a fan-spray emitter [Spot Spitter Tall Light Green rated at 20 $L \cdot h^{-1}$ (5.3 $gal \cdot h^{-1}$) at 103 kPa (15 psi); Primerus, Encinitas, CA) for M3.

Each trial used common procedures. Water use was monitored with flowmeters (Sensus, Raleigh, NC) installed in each of the test zones. Irrigation tests were conducted to relate irrigation output per container to the change in water flowmeter readings. For these tests, irrigation water was collected in 20-40 containers per zone during a typical irrigation cycle. During each trial, flowmeter readings were taken once or twice each week to monitor irrigation water applied to each crop.

Plant growth was monitored by labeling 16 similar-sized plants in each test zone. Plant height and width were measured at the start and then once every two weeks until the trial was terminated. Plant height was measured from the top of the substrate to the uppermost foliage, and plant width was the average of two perpendicular width measurements. Trials were terminated when the nursery began selling plants out of either one of the test zones. Plant canopy growth was calculated as the change in plant height and width from the start to the end of each trial. For crape myrtle (S2), stem caliper was measured on all five stems per container at the height of 84 cm (33 in).

The two irrigation practices compared in each trial were Cherrylake's traditional irrigation practice (TIP) and automated CIRRIG technology based on ET and LF testing (LFI). For TIP, a nursery employee took substrate core samples 1-2 times a week and rated substrate moisture by a feel test. If the moisture was rated as too high, staff would manually shut off the valve for one or more cycles. If the substrate moisture level was rated low, staff would contact the production manager to increase the irrigation amount. In micro-irrigated areas, once a week staff manually opened valves to check the overall irrigation system, including pipes, tubing, and clogged emitters. This manual irrigation system check was carried out in both TIP and LFI test zones and the water applied was supplemental to the normal irrigation schedule. For LFI, irrigation was controlled automatically with PLC technology. LF tests were conducted by nursery staff approximately once every 2-4 weeks depending on time of year and weather. Staff were instructed to conduct LF tests during normal weather conditions and not following significant rain events. Four to six plants were selected for LF testing per test zone. For sprinkler trials, LF test plants were placed in a tight-fitting pail that allowed leachate to be collected without reabsorption. Container assemblies were weighed before and after irrigation to determine the total amount of water applied. After removing the plant,

Table 2. **Effect of irrigation practice on irrigation water use at a wholesale container nursery. An automated irrigation schedule based on routine leaching fraction testing and weather (LF) was compared to the nursery's traditional irrigation practice (TIP) in side-by-side, unreplicated trials. One cm = 0.394 in; 1 L = 0.264 gal; 1 ha =2.471 ac.**

Trial[z]	Plant common name	Irrig. rate[y]	Test zone (ha)	Plants (no.)	Plant density (no./ha)	Days	Water applied ($kL \cdot ha^{-1} \cdot d^{-1}$)		
							LF	TIP	LF/TIP
S1	Sweet viburnum	0.84	0.22	8400	38,450	200	68.8	72.4	0.95
S2	Crape myrtle	0.81	0.11	4700	44,680	271	44.6	64.9	0.69
S3	Indian hawthorn	0.84	0.016[x]	1400	83,050[w]	258	49.9	73.8	0.67
S4	Sweet viburnum	0.84	0.028[x]	2560	83,050[w]	230	81.8	93.7	0.87
S5	Parson juniper	0.71	0.10/0.06 [v]	3520/1990 [v]	37,810	357	63.0	50.4	1.25
M1	Leyland cypress	13.6	0.13	900	6750	181	42.1	52.9	0.79
M2	Leyland cypress	20.8	0.13	900	6750	371	29.4	83.8	0.35
M3	Leyland cypress	22.3	0.13	900	6750	301	54.5	103.9	0.52

[z]Trial designation: S=sprinkler-irrigated, trade 3-gal container; M=micro-irrigated, trade 15-gal container.

[y]Irrigation rate [cm/h for sprinkler trials (S) and L/h for micro-irrigation trials (M)].

[x]Weighted average; 0.009 ha before spacing on Day 112 (10 Oct. 2016) and 0.038 ha after spacing.

[w]Weighted average; 129,200 plant/ha before spacing on Day 112 (10 Oct. 2016) and 38,300 plant/acre after spacing.

[v]Paired test zones of unequal area but with the same plant density.

leachate was poured into a tared container to determine leachate volume. The average of the 4-6 LF measurements was inputted into CIRRIG along with the test date and time. For micro-irrigated trials, LF test plants were placed on 43-cm-diameter (17 in) aluminum pizza pans with 2.5-cm-high (1-in-high) rims that were raised 9 cm (3.5 in) above the ground on pieces of lumber. One 1.3 cm-diameter hole was punched near the perimeter of the pan to allow leachate to drain into a collection pan for weighing. If needed, slope was created with shims to improve drainage out of the pizza pan. To determine the amount of irrigation water applied to the container, an adjacent emitter was placed into a 15 L (4 gal) pail. A slot cut out of the rim allowed the tubing to pass into the pail with a lid on the pail. Leachate and irrigation water applied were collected and summed over all scheduled irrigation cycles in a 24-h period to arrive at one LF value per LF test plant. As with sprinkler LF testing, the average of the LF measurements was inputted into CIRRIG by Cherrylake staff. LF test setups with plants on the pizza pans were left in the LFI test zone throughout each trial. All weights were recorded to the nearest 0.01 kg (0.02 lb) using a portable bench scale (ES30R, Ohaus, Parsippany, NJ). LFI start times were within 30 min of TIP start times. For sprinkler irrigated trials, irrigation was scheduled once daily typically at dawn or pre-dawn so that staff could enter fields by 0800 HR. For micro-irrigated trials, two or three cycles per day were scheduled depending on the time of the year. A target LF value of 15% was used for sprinkler-irrigated trials and 25% (M1, M2) or 30% (M3) for micro-irrigated trials.

The trials were not replicated, so we could not conduct a statistical analysis of the irrigation practice effect on irrigation water applied and plant growth. Water applied was expressed on a $L \cdot ha^{-1} \cdot d^{-1}$ ($gal \cdot ac^{-1} \cdot d^{-1}$) basis as each trial had different container densities and lengths of time. Container densities and lengths of time for each trial are also provided so that the reader could calculate equivalent volumes of water applied per container.

Results and Discussion

Sprinkler trials. Compared to TIP, use of LFI decreased the amount of irrigation water applied in S1-S4 trials and increased water applied in S5 (Table 2). The use of LFI decreased water use by 5%, 31%, 33%, and 13% for S1, S2, S3, and S4, respectively. For these four trials where LFI reduced irrigation water applied, plant growth was either not greatly affected (S1, S2, and S4) or was increased (S3) with LFI compared to TIP (Table 3), indicating that reduced irrigation did not negatively affect growth. For S3, the increase in Indian hawthorn growth with LFI was primarily observed during the trial's final two months (February and March), which coincided with an early spring flush. During this 2-month period, LFI applied 60% more water than TIP (66 vs. 41 cm) while applying 43% less water (122 vs. 175 cm) during the previous 7-months. This indicated that TIP likely provided insufficient water for optimum growth during the early spring period of S3.

In contrast to trials S1-S4 where the use of LFI decreased water use, the use LFI increased irrigation water applied by 25% compared to TIP in trial S5 (Table 2). Increased water applied using LFI in S5 occurred predominantly during the final 3-months of the trial, which coincided with spring months (February-April). During this 3-month period, the use of LFI increased water use 82% [91 vs. 50 cm (36 vs 20 in)], during the previous 9-months LFI increased water use only 3% [134 vs. 130 cm (53 vs. 51 in)] versus TIP. During the final 3-month period, the use of LFI increased the change in height and width of Parsoni juniper plants 1.0 cm (0.4 in) and 4.6 cm (1.8 in), respectively. Over the entire trial, the use of LFI increased the change in height and width of Parsoni juniper plants 1.7 cm (0.7 in) and 10.5 cm (4.1 in) compared to TIP (Table 3).

Leaching fraction test results for sprinkler trials are given in Table 4. The average LF values for the five trials ranged from 7% to 18%; the target LF was 15%. For Parsoni juniper (S5), LF test values were always below the target LF of 15% indicating that the use of LFI was not applying excessive water despite applying 25% more than

Table 3. Effect of irrigation practice on plant growth for seven side-by-side, un-replicated trials at a container nursery. An automated irrigation schedule based on routine leaching fraction testing and weather (CIRRIG) was compared to the nursery's traditional irrigation practice (TIP). One cm = 0.394 in; 1 mm = 0.0394 in.

Trial[z]	Plant	Plant height change (cm)			Plant width change (cm)		
		LF	TIP	LF/TIP	LF	TIP	LF/TIP
		Mean (SD)[y]			Mean (SD)[y]		
S1	Sweet viburnum	25 (3)	26 (2)	0.96	22 (2)	23 (2)	0.96
S2	Crape myrtle	-	-	-	4.8 (0.7)[x]	4.8 (0.8)[x]	0.99
S3	Indian hawthorn	15 (5)	10 (3)	1.67	20 (4)	11 (3)	1.80
S4	Sweet viburnum	18 (6)	20 (4)	0.92	11 (6)	7 (4)	1.35
S5	Parson juniper	10 (4)	8 (5)	1.22	72 (8)	61 (8)	1.17
M1	Leyland cypress	73 (23)	69 (20)	1.07	50 (9)	46 (8)	1.09
M2	Leyland cypress	114 (16)	140 (16)	0.81	64 (7)	72 (5)	0.90
M3	Leyland cypress	95 (10)	82 (16)	1.17	43 (7)	41 (5)	1.06

[z]Trial designation: S=sprinkler-irrigated, 11.4 L (trade 3-gal) container; M=micro-irrigated, 57 L (trade 15-gal) container.

[y]SD=standard deviation (n=16)

[x]Change in stem caliper (mm).

that applied using TIP. LF test results during two of the trials are given in Fig. 1 (S2) and Fig. 2 (S3) to show how LF tests varied with seasonal changes. For crape myrtle (S2), very wide fluctuations in results were observed. Initially during the fall, LF values were at or below the target values of 15%. However, during the late fall and winter months, LF values increased dramatically. For this crop, two factors played a role in making LF testing highly variable. One is that the crop canopy is aggressively pruned on a routine basis to promote root and stem growth. Canopy pruning results in reduced evapotranspiration and so water loss through canopy is reduced immediately after pruning. Secondly, as fall and winter months arrive, ET rates decline due to shorter days, lower solar radiation levels, and cooler temperatures. It is common for LF values to increase during late fall and winter months if irrigation amounts are not reduced in proportion to ET rates. In contrast, in spring months when ET rates increase with longer days and warmer temperatures and plants exhibit a spring growth flush, it is common for irrigation amounts to lag water demand so that LF values are often low. This can be seen for Indian hawthorn (Fig. 2), where LF values began increasing during the winter months. Generally, more consistent LF test results were observed for S3, which did not exhibit the "yo-yo" effect to the same degree observed for crape myrtle with its vigorous pruning schedule (Fig. 1). We concluded that for 'Natchez' crape myrtle, a more frequent LF testing schedule would be recommended for this crop, including the need to test crops immediately after pruning.

Table 4. Target and measured leaching fraction (LF) values routinely measured in test zones irrigated with CIRRIG, a LF and weather-based irrigation scheduling program.

Trial[z]	Plant	LF (%) Target	Mean[y]	Min[y]	Max[y]	No.[x]
S1	Sweet viburnum	15	18	2	42	13
S2	Crape myrtle	15	18	0	74	23
S3	Indian hawthorn	15	15	3	29	18
S4	Sweet viburnum	15	8	1	21	13
S5	Parson juniper	15	7	4	9	9
M1	Leyland cypress	25	31	6	64	14
M2	Leyland cypress	25	23	2	58	23
M3	Leyland cypress	30	36	14	66	13

[z]Trial designation: S=sprinkler-irrigated, 11.4 L (trade 3-gal) container; M=micro-irrigated, 57 L (trade 15-gal) container.

[y]Mean, minimum and maximum values (average of four plants per LF test date) for LF tests conducted 1X every 3-4 weeks

[x]Number of LF test dates.

Micro-irrigation trials. Leaching fraction-based irrigation resulted in substantial water savings compared to the nursery's typical irrigation practice for all three of the micro-irrigation trials. Irrigation water applied using LFI was 21%, 65%, and 48% less than TIP for M1, M2, and M3, respectively (Table 2). While Leyland cypress growth in M1 and M3 was similar for the two irrigation schedules, the use of LFI reduced canopy growth 10-20% in M2 (Table 3). Routine LF testing during M2 indicated that 11 of 23 tests resulted in values below the target of 25% (Fig. 3). Consistent LF values below the target of 25% provide evidence that water stress conditions reducing plant canopy growth likely occurred in M2. Due to reduced growth in M2, we increased the target LF from 25% to 30% for M3.

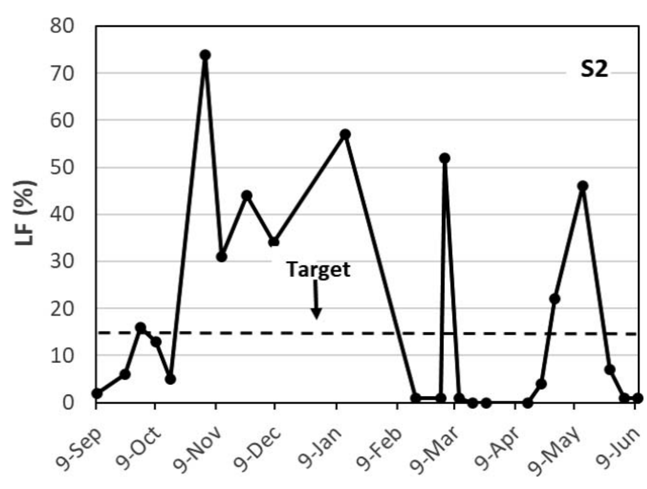

Fig. 1. Leaching fraction tests (LF) during production of crape myrtle in 25.4 cm (trade 3 gal) containers irrigated with a LF and weather-based schedule (S2). Means represent the average LF of 4-6 containers.

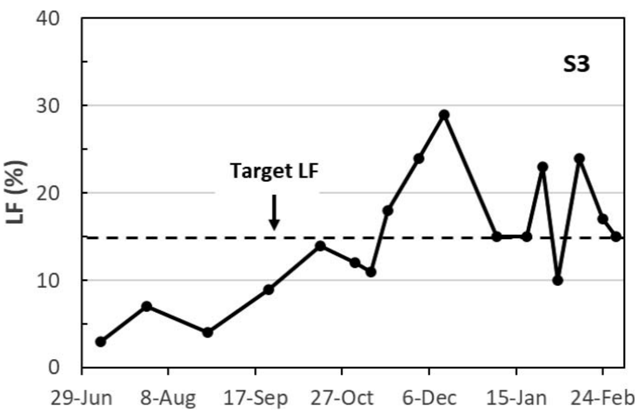

Fig. 2. Leaching fraction tests (LF) during production of Indian hawthorn in 25.4 cm (trade 3 gal) containers irrigated with a LF and weather-based schedule (S3). Means represent the average LF of 4-6 containers.

Routine LF testing in M3 resulted in average LF of 36% (Table 4), with a minimum value of 14% in June (Fig. 4). The result was that plant growth in M3 was not reduced despite a reduction in water use of 48% using LFI compared to TIP.

Nursery staff, for the most part, did a good job of following through on LF testing but as this was new to the staff, several issues were observed from time to time. One issue that occasionally arose was recording zero leachate for one or more plants during a routine test. Although zero leachate might result when the volume of irrigation water applied was just enough to bring substrate moisture up to an acceptable level without leaching, it likely indicated an under-watered condition. Furthermore, a continued deficit could have resulted in the development of hydrophobic substrate properties, further exacerbating the under-watering problem. When adjusting irrigation using one or more test plants that gave a value of 0%, we recommend that follow-up LF testing be conducted as soon as possible to ensure irrigation adjustments have corrected the situation. A second issue was the timing of LF tests. Nursery staff often have fixed schedules for accomplishing tasks. We

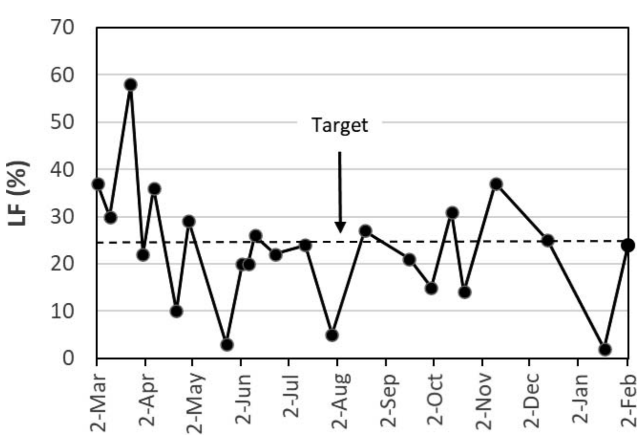

Fig. 3. Leaching fraction tests (LF) during production of Leyland cypress in 43 cm (trade 15-gal) containers irrigated with a LF and weather-based schedule (M2). Means represent the average LF of four containers.

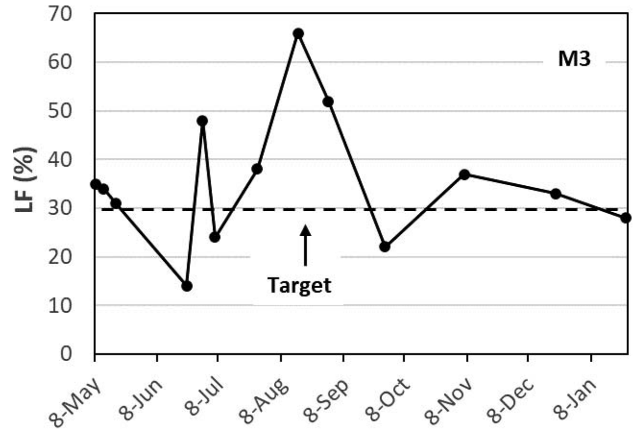

Fig. 4. Leaching fraction tests (LF) during production of Leyland cypress in 43 cm (trade 15 gal) containers irrigated with a LF and weather-based schedule (M3). Means represent the average LF of four containers.

recommend that LF testing be done on days with normal or above normal ET. With a fixed schedule for LF testing, there is a chance the weather will not be optimal. Also, frequent rains during summer afternoons and evenings can ruin prepared LF tests, creating additional problems for maintaining a consistent routine LF schedule.

Results of the eight demonstration trials showed that a LF-directed irrigation practice can decrease irrigation water use by 5-50%. If M2 results are disregarded because plant growth was negatively affected by LFI, average irrigation savings for the other seven trials averaged 21% (57.8 vs. 73.1 $kL{\cdot}ha^{-1}{\cdot}d^{-1}$). This result was equivalent to 21,100 vs. 26,700 $kL{\cdot}ha^{-1}{\cdot}y^{-1}$. Based on yearly electrical bills and metered pumps at Cherrylake, irrigation pumping costs at the nursery averaged $0.53 per kL. Using this cost rate, the average savings using LFI vs. TIP would be $3,000 per hectare per year. Equivalent savings on a per-container basis would be $0.05 for the sprinkler-irrigated crops at 57,000 plants per hectare and $0.45 for the micro-irrigated crops at 6,700 plants per hectare. These cost savings are minor considering that common sprinkler-irrigated plants sell for $5-15 and micro-irrigated plants for $50-150. While a 21% average reduction in water use does not have a major impact on the unit cost of production, if consumptive water use restrictions imposed by water-governing bodies are limiting, the 21% reduction in water use may provide for additional capacity. Reduced irrigation run times can also allow for more flexibility in the nursery's irrigation scheduling.

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