HortScience 55(1):83–88. 2020. https://doi.org/10.21273/HORTSCI14402-19

Periodic Versus Real-time Adjustment of a Leaching Fraction-based Microirrigation Schedule for Container-grown Plants

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Additional index words. evaporation, *Podocarpus*, *Viburnum*, water use

***Abstract*. Two experiments were conducted to determine if a leaching fraction (LF)-guided irrigation practice with fixed irrigation run times between LF tests (LF_FX) could be improved by making additional adjustments to irrigation run times based on real-time weather information, including rain, using an evapotranspiration-based irrigation scheduling program for container production (LF_ET). The effect of the two irrigation practices on plant growth and water use was tested at three target LF values (10%, 20%, and 40%). For both *Viburnum odoratissimum* (Expt. 1) and *Podocarpus macrophyllus* (Expt. 2) grown in 36-cm-diameter containers with spray-stake microirrigation, the change in plant size was unaffected by irrigation treatments. LF_ET reduced water use by 10% compared with LF_FX in Expt. 2 but had no effect ($P < 0.05$) on water use in Expt. 1. Decreasing the target LF from 40% to 20% reduced water use 28% in both experiments and this effect was similar for both irrigation practices. For the irrigation system and irrigation schedule used in these experiments, we concluded that an LF-guided irrigation schedule with a target LF of 10% resulted in plant growth similar to one with a target LF of 40% and that the addition of a real-time weather adjustment to irrigation run times provided little or no improvement in water conservation compared with a periodic adjustment based solely on LF testing.**

Open-field production of 524,000 irrigated acres of horticultural plants in the United States used 205 billion gallons of water in 2013 and ≈50% of this water was pumped from groundwater sources (U.S. Department of Agriculture, 2014). Four states with large horticultural industries California, Florida, Oregon, and Texas used 60% of the 205 billion gallons of water. Water resources for irrigation are becoming increasingly limited so that technologies to conserve water are needed (Majsztrik et al., 2017).

Although sprinkler irrigation is used to produce plants in small containers (<28 cm diameter) in high densities, direct application of water using spray-stake irrigation is used to produce plants in larger containers that are placed in low densities. Compared with in-ground production, container production of plants with sprinkler irrigation is inherently inefficient, as containers occupy only a fraction of the production area even when closely spaced. Direct application of water to the container with spray-stake irrigation also can be inefficient, as typical water delivery rates for spray-stakes (15–40 cm/h) are much higher than for typical sprinkler systems (0.8–1.5 cm/h) so that small changes in irrigation run times can equate to large changes in application volumes and higher chances of overwatering (Million and Yeager, 2018b), particularly in bark-based substrates (Hoskins et al., 2014). Also, retention of water by the container substrate may be reduced at high application rates (Warren and Bilderback, 2005). Efficiency of spray-stake irrigation can be improved by using a cyclic irrigation schedule that applies water multiple times per day vs. a single application (Beeson and Haydu, 1995; Ruter, 1998).

Producing plants in large containers with spray-stake irrigation requires keen attention to detail if irrigation water is to be applied efficiently. To apply water efficiently, the irrigation system must be reliable, deliver water uniformly within the irrigation zone, and application rates should not vary greatly from one day to another. Even if the irrigation system delivers water consistently and uniformly, if irrigation needs within the irrigation zone vary due to nonuniform plant production conditions, such as varying plant species, stages of production, container sizes, container spacing patterns, and container substrates, efficient irrigation will be even more difficult to attain (Warren and Bilderback, 2005). Weather is another variable, as solar radiation, air temperature, and wind affect evapotranspiration (ET) rates and rain can reduce the irrigation demand (McCready et al., 2009). Beeson (2010) described the relationship between reference ET and actual ET based on plant canopy cover of the container production area.

The goal of efficient irrigation is to supply enough water for profitable production but not so much that unnecessary leaching occurs. One method for monitoring irrigation efficiency under a wide range of production conditions is to monitor the LF, the amount of leachate (container drainage) divided by the amount of irrigation water applied to the container. The LF can be routinely monitored and irrigation adjusted to achieve a desired LF. Stanley (2012) reported that implementing an LF monitoring program at a container nursery in Virginia reduced irrigation water use by >50%. For the largely sprinkler-irrigated nursery, a target LF of 10% was found to give good results throughout the nursery. Owen et al. (2009) reported that irrigation adjusted for a 20% LF with both pine bark-clay and pine bark-sand substrates did not return the substrate water content to container capacity. They reported a decrease in container weights of 0.6% to 0.8% per day if no rain occurred, indicating that over time and depending on the plant water needs, a water stress condition would occur unless additional irrigation water was applied, or rain received. Prehn et al. (2010) found that plants irrigated with a target LF of 20% produced similar-sized plants as those irrigated on-demand to maintain substrate moisture levels near container capacity. At a microirrigated container nursery, a target LF of 25% was found to be effective for a microirrigated container crop when irrigation was adjusted periodically (Million and Yeager, 2018a) but not when irrigation was adjusted daily based on ET and rain in the interval between LF tests (Million and Yeager, 2018b). The authors proposed that maintaining a fixed irrigation rate during the interval between LF tests may have allowed substrate moisture to "catch up" on days when the ET rate was less than the ET rate associated with the LF test day.

The objective of this study was to determine if the efficiency of an LF-based irrigation schedule could be improved with daily ET adjustments and if the improvement depended on the target LF value selected. Here, we describe two experiments, one with *V. odoratissimum* (L.) Ker Gawl. (Expt. 1) and one with *P. macrophyllus* (Thunb.) Sweet (Expt. 2), that monitored plant growth and water use as affected by irrigation schedule and the target LF.

Materials and Methods

Experimental site. Two experiments were conducted on the campus of the University of Florida in Gainesville (lat. 29.6°N, long. 82.3°W). The experimental site covered a 9.1- × 15.2-m area underlain with sandy fill and covered with black, industry-standard polypropylene ground cloth. A microirrigation system was installed that included a 4.8-cm-diameter header pipe that supplied

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Received for publication 24 July 2019. Accepted for publication 10 Oct. 2019.

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municipal well water to 18 lines of 1.9-cm-diameter polyethylene pipe each 7.7 m long. A solenoid valve and 103-kPa pressure regulator (15 psi PRL; Senninger, Clermont, FL) were installed at the head of each of the 18 lines so that each line could be controlled independently. Each line had nine spray-stake assemblies, eight of which were used to irrigate plants (one per plant) and one to collect total irrigation water applied. Each spray-stake assembly included a pressure compensating button (01WPCJ25; Netafim, Tel Aviv, Israel), a 1-m-long section of polyethylene tubing (0.64 cm diameter) and a down-spray emitter (CFd Black; Antelco, Longwood, FL) rated at 23 $L \cdot h^{-1}$ at 103 kPa. The water application rate of each emitter averaged 315 cm^3/min with a Distribution of Uniformity (Burt et al., 1997) of 98% when all 162 emitters were included in the test. A flush valve (5 psi Auto Flush; Maxijet, Dundee, FL) was placed at the end of each of the 18 lines. A total of 144 containers (18 lines × 8 containers per line) were placed in an equidistant pattern so that each plant was 0.91 m apart (center to center). The 18 lines were divided into three blocks of six lines (six irrigation treatments). The site had a uniform 2% to 3% slope with the header at the top and each line running downslope.

Expt. 1. Multiple-branched liner plants of *V. odoratissimum* were planted three per 36-cm-diameter container on 31 Aug. 2016. The spray-stake emitter was placed in the center of the three plants. The substrate was a 60:40 (by volume) pine bark:Florida sedge peat obtained from Hibernia Nursery located in Webster, FL. The substrate had a total porosity of 80%, a container capacity of 46% and a pore space at container capacity of 34%. The substrate was amended with a 17N–2.2P–8.3K controlled-release fertilizer (Polyon 9-month release at 21 °C; Harrell's, Lakeland, FL) at 9.5 $kg \cdot m^{-3}$, a 0N–0P–3.3K fertilizer with micronutrients (Harrell's) at 0.9 $kg \cdot m^{-3}$, dolomitic limestone at 4.2 $kg \cdot m^{-3}$, and gypsum at 1.2 $kg \cdot m^{-3}$. Containers were watered as needed until the experiment was started on 21 Jan. 2017. Irrigation was initially scheduled once a day at 1600 HR and then twice a day at 1115 HR and 1615 HR beginning 20 Mar. 2016. A 18N–2.6P–6.6K controlled-release fertilizer (Nutricote 270-d release at 25 °C; Florikan, Sarasota, FL) was surface-applied at 92 g/container on 20 Feb. 2017.

Plant growth was monitored by measuring plant height and plant width at experiment initiation and once every 2 to 3 weeks. Plant height was measured from the substrate surface to the uppermost foliage. Plant width was the average of two perpendicular measurements with one parallel to the irrigation pipe. All eight plants per treatment-block (24 per treatment) were measured. Plants were pruned for shape on 31 Mar. 2017 removing 2.4 ± 0.9 cm of height and 4.8 ± 2.4 cm of width.

The amount of irrigation water applied was determined by placing one emitter from each treatment-block in a 19-L pail with a notch cut underneath the lid, so the tubing would not crimp with the lid closed. The volume of water applied each week was determined by weighing to the nearest 0.01 kg. The trial was ended on 12 May 2017, 132 d after initiating irrigation treatments.

Expt. 2. Uniformly sized *P. macrophyllus,* five plants per 36-cm-diameter container, were obtained from Hibernia Nursery. Spray-stakes were inserted midway between the plants and container wall and angled toward the center. Very little spray was lost outside the container with this emitter placement. The container substrate was a 70:30 pine bark:Florida sedge peat amended with a 17N–2.2P–8.3K controlled-release fertilizer (Polyon 9-month release at 21 °C; Harrell's) at 10.7 $kg \cdot m^{-3}$, micronutrient blend (Micromax; ICL, Dublin, OH) at 0.9 $kg \cdot m^{-3}$, and dolomitic limestone at 4.7 $kg \cdot m^{-3}$. Irrigation treatments were initiated on 25 Oct. 2017. Irrigation was scheduled three times a day: 0815, 1115, and 1615 HR. No physical properties for this substrate were available.

Plant growth and water use were monitored as described for Expt. 1. Plants were pruned for shape on 13 Feb. 2018 by removing ≈8 ± 2 cm of height and 3 ± 1 cm of width, and again on 17 May 2018 by removing 3 ± 2 cm of height and 3 ± 2 cm of width. An 18N–2.6P–6.6K controlled-release fertilizer (Nutricote 270-d release at 25 °C; Florikan) was surface-applied 92 g/container on 13 Feb. 2018. The experiment was ended on 26 June 2018, 245 d after initiating irrigation treatments.

Irrigation treatments (Expt. 1 and Expt. 2). Each experiment included six irrigation treatments that were a factorial combination of two irrigation practices (LF_FX and LF_ET) and three target LF values (10%, 20%, and 40%). Both irrigation practices required LF tests to be conducted once every 1 to 3 weeks. For LF tests, the first, fourth, and seventh plant in each line were placed on 43-cm-diameter aluminum pizza pans with a 2.54-cm-high rim. The pans were elevated above the ground cloth using two pieces of lumber 10.2 × 10.2 cm. A 1.3-cm-diameter hole punched into the edge of the pan just inside the rim allowed container drainage to be collected by placing a tray under the drainage hole. The LF collection setups remained in test area for the duration of each experiment.

The LF_FX irrigation practice entailed only adjusting irrigation run times following an LF test date so that irrigation run times were fixed during the interval between LF tests. For each LF_FX treatment-block, the average LF of the three LF test plants was used to determine a new irrigation run time using Eq. [1]:

$$RT_{new} = RT_{test} * (100 - LF_{test}) / (100 - LF_{target}) \qquad [1]$$

where RT_{new} was the new adjusted irrigation run time, RT_{test} was the irrigation run time for the LF test, LF_{test} was the average test LF, and LF_{target} was the target LF.

The LF_ET irrigation practice entailed adjusting irrigation continuously using CIRRIG, an irrigation scheduling program designed for container nurseries (Million and Yeager, 2015). Nine zones corresponding to the nine LF_ET treatment-blocks were created in CIRRIG and an "LF-Micro" zone type was selected. This zone type used LF testing as a guide for irrigating microirrigated plants. After an LF test was completed, the average LF value of the three LF test plants and the date and time of the last irrigation cycle used in the LF test were input into CIRRIG. Based on these inputs and the treatment target LF, CIRRIG calculated two reference values, ET_{LF} and RT_{LF}, for making future irrigation calculations. ET_{LF} was the reference potential ET value (ETo) calculated using the 24 h of weather data collected before the input LF test date and time. ETo was calculated using a container-grown plant evaporation model (Million et al., 2011), which used a biased temperature maximum that accounted for the heating effect 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 Eq. [1]. Using the LF test reference values, daily irrigation run times (RT_d) were calculated just before irrigation using Eq. [2]:

$$RT_d = ETo / ET_{LF} \times RT_{LF} \qquad [2]$$

where ETo is the potential ET calculated using the past 24 h 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-h period with Eq. [3]:

$$RT_h = SR_h \div SR_d \times RT_d - RT_{rain} \qquad [3]$$

where RT_h = hourly run time, SR_h = hourly solar radiation, SR_d = past 24-hour solar radiation, and RT_{rain} = hourly rain converted to equivalent run time based on the irrigation application rate. RT_h values calculated for each hour after the last irrigation were summed and ultimately output as the current irrigation run time.

Irrigation control system. Irrigation for all treatments was controlled automatically using a programmable logic controller (PLC). We used a 16-outlet PLC (D0-DA06; Automation Direct, Atlanta, GA) with an optional eight-outlet module (D0-08TR; Automation Direct) to control the 18 valves. A communication module (HO-ECOM100; Automation Direct) allowed the PLC to be connected to the Internet via a local network created with a USB cellular modem with a static IP address and router (MBR1200b; Cradlepoint, Boise, ID). A graphical user interface developed at the University of Florida was used to select how each outlet on the PLC was controlled. For LF_FX treatments, a "Manual Default" option was selected that assigned a fixed irrigation run time for those valves. For LF_ET treatments, PLC outlets were assigned a CIRRIG zone. Once assigned, the PLC automatically acquired CIRRIG output at designated start times each day and set timer values for the corresponding outlets. A history of run times for both

LF_FX and LF_ET outlets was output by the PLC in a text file for record-keeping.

Statistical analysis. Expt. 1 and Expt. 2 were evaluated as randomized complete block experiments with three blocks and six irrigation treatments (two irrigation schedules × three target LF values). For total water applied, there was one replication per block. For change in plant height and change in plant width there were eight replications per block. Because the interaction effect between irrigation schedule and target LF for both water use and plant growth was insignificant ($P < 0.05$) in both experiments, mean separation for main effect means was by Fisher's least significant difference. All analyses were made using the PROC GLM procedure of Statistical Analysis System 9.4 (SAS Institute, Cary, NC).

Results and Discussion

Temperatures for Expt. 1 were mild during January and February with lows averaging 11 °C (–2 °C to 20 °C) with –2 °C recorded on 31 Jan. 2017 (Table 1). The mild temperatures resulted in the rapid growth of *V. odoratissimum* in February. Meaningful rain (>0.5 cm) fell on only 4 d during Expt. 1: 0.9 cm on 1 Jan., 2.0 cm on 7 Feb., 1.0 cm on 13 Mar., and 6.3 cm on 4 Apr. One purported advantage of LF_ET was to reduce irrigation amount depending on the amount and timing of rain. The lack of rain during Expt. 1 likely reduced this potential advantage.

Temperatures during Expt. 2 were typical for this location (Table 1). Minimum temperatures were <4 °C for 15 d in January and <0 °C for 9 of those 15 d. This cold period corresponded with minimal growth for *P. macrophyllus* during Jan. 2018. Only 24 cm of rain fell during the first 6 months of the experiment (Oct. 2017 to Mar. 2018) with only 9 d with rain >0.5 cm. May and June were rainy months with 20 d with rain >0.5 cm.

Table 1. Average daily minimum (T_{min}) and maximum (T_{max}) air temperatures, solar radiation, reference evapotranspiration (ETo) and total rain for monthly intervals during irrigation experiments in Gainesville, FL.

Month[z]	T_{min} (°C)	T_{max} (°C)	Sol. Rad. ($W \cdot m^{-2}$)	ETo (cm)	Rain (cm)
		Viburnum odoratissimum (Expt. 1)			
Jan. 2017	10	21	135	0.56	1
Feb. 2017	12	25	168	0.58	3
Mar. 2017	11	25	216	0.97	2
Apr. 2017	16	29	262	1.04	7
May 2017	16	31	292	1.17	0
		Podocarpus macrophyllus (Expt. 2)			
Oct. 2017	8	23	198	0.86	0
Nov. 2017	13	25	149	0.72	3
Dec. 2017	10	21	118	0.54	0
Jan. 2018	6	18	128	0.50	9
Feb. 2018	15	26	152	0.73	4
Mar. 2018	10	24	220	0.92	8
Apr. 2018	15	27	237	1.09	12
May 2018	20	30	222	1.09	19
June 2018	23	33	250	1.28	16

[z] Jan. 2017 (21–31 Jan.); May 2017 (1–12 May); Oct. 2017 (25–31 Oct.); June 2018 (1–26 June).

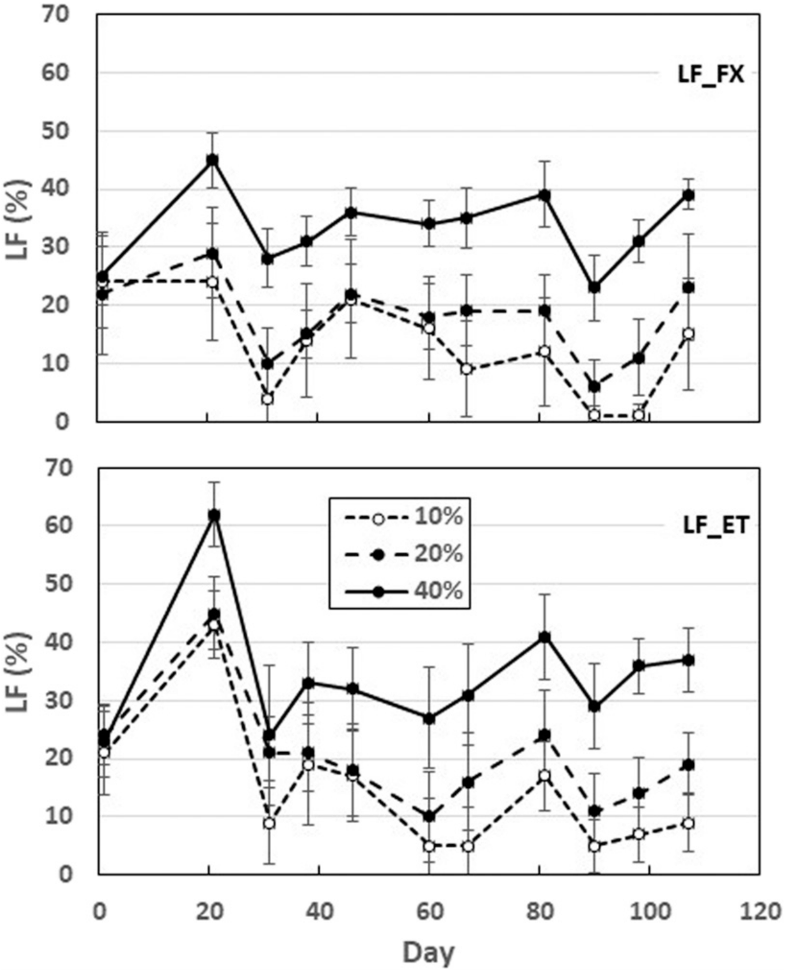

Fig. 1. Effect of irrigation practice and target leaching fraction (LF) (10%, 20%, or 40%) on measured LF with *Viburnum odoratissimum* in 36-cm-diameter containers (Expt. 1). Irrigation rates remained fixed (LF_FX; above) or were adjusted daily based on evapotranspiration rate and rain (LF_ET; bottom) between LF test dates. LF means (±SD) are the average of nine observations per LF test day. Day 0 = 21 Jan. 2017; Day 107 = 12 May 2017.

LF testing results for the two experiments are given in Fig. 1 (Expt. 1) and Fig. 2 (Expt. 2). For Expt. 1, initial LF testing resulted in an average LF of 23%. Overall, measured LF values agreed well with the target LF values during the experiment except for day 21 (10 Feb. 2017) when measured LF values were greater than the target values. For Expt. 2, initial LF testing resulted in an average LF of 61%. LF test values on day 12, the first LF test after initiating irrigation schedules, were greater than target values. Subsequent LF values for day 28 (22 Nov. 2017) and day 55 (19 Dec. 2017) agreed well with target values. Thereafter, irrigation practices had different effects on LF testing. LF_ET irrigation schedule resulted in high LF test values on day 91 (24 Jan. 2018) and day 114 (16 Feb. 2018), whereas LF_FX test LF values were only slightly higher than target values. This indicated that CIRRIG was overestimating ET and applied excess water during these colder winter days when growth was slow. In contrast, LF_FX irrigation schedule resulted in LF test values below targets for day 129 (3 Mar. 2018), day 159 (2 Apr. 2018), and day 175 (18 Apr. 2018), whereas LF_ET gave LF test values near target values. This spring period coincided with rapid plant growth and associated higher ET rates so that LF_FX irrigation schedule likely was not keeping up with increasing water demands. LF_ET compensated for increased ET rates and applied enough water to maintain reasonable target LF levels. From day 183 (26 Apr. 2018) until the end of the experiment, LF test values for both irrigation schedules agreed well with target LF values. This period coincided with stable weather patterns during late spring and early summer months.

Plant growth as indicated by changes in plant height and width was unaffected ($P < 0.05$) by irrigation practice or target LF for either Expt. 1 or Expt. 2 (Table 2). Similar plant growth indicated that all irrigation schedules were supplying enough water for optimal growth.

The primary objective of Expt. 1 and Expt. 2 was to evaluate whether an LF-based irrigation practice that applied real-time, ET-adjusted irrigation rates used less water than one with a fixed irrigation rate and whether there was an interaction between irrigation practice and target LF value. There was no interaction ($P < 0.05$) between irrigation practice and target LF for either Expt. 1 or Expt. 2 (Table 2), so the main effects of irrigation practice and target LF are discussed independently. LF_ET irrigation practice applied less water than LF_FX in Expt. 2 but not Expt. 1. For Expt. 2, LF_ET reduced the total amount of irrigation water 10% (255 vs. 283 L/plant) compared with LF_FX. Most of the water savings were observed during the last 6 weeks of Expt. 2 (Fig. 3) when frequent rains occurred (Table 1). Although LF_FX applied a constant irrigation amount, LF_ET accounted for these rains by either reducing the irrigation amount when rain was less than the ET-estimated water loss since the previous cycle or eliminating an irrigation cycle when rain exceeded the ET-estimated amount or irrigation water lost after the previous cycle.

Target LF affected water applied in both Expt. 1 and Expt. 2 (Table 2). Decreasing the target LF from 40% to 20% reduced the total amount of water applied by 28% (286 vs. 398 L/plant) in Expt. 1 and by 28% (246 vs. 342 L/plant) in Expt. 2. Reducing the target LF from 40% to 10% reduced the total amount of water applied 39% (242 vs. 398 L/plant) in Expt. 1 and 36% (220 vs. 342 L/plant) in Expt. 2. This reduction was like that reported by Tyler et al. (1996) who observed a 44% reduction in irrigation water when the LF for a 3.8-L sprinkler-irrigated ornamental plant was reduced from 40% to 60% to 0% to 20%. Decreasing the target LF from 20% to 10% reduced the total amount of water applied by 15% (242 vs. 285 L/plant) and 11% (220 vs. 246 L/plant) in Expt. 1 and Expt. 2, respectively. Nambuthiri et al. (2017) observed that a decrease in LF from 25% to 17% was associated with a 36% reduction in water

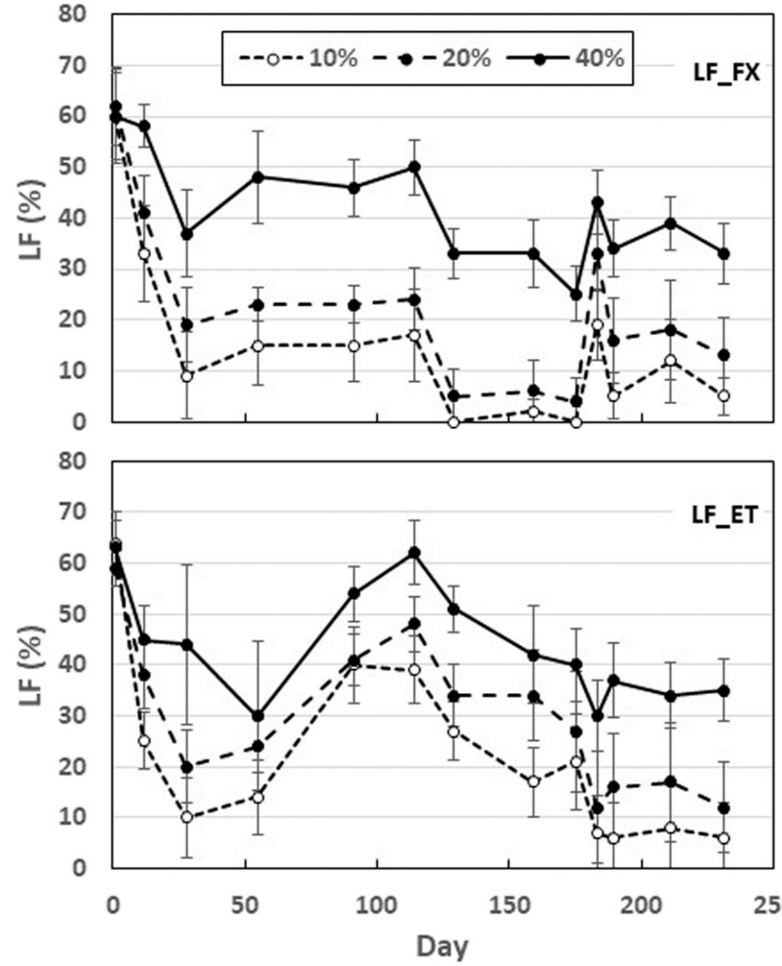

Fig. 2. Effect of irrigation practice and target leaching fraction (LF) (10%, 20%, or 40%) on measured LF with *Podocarpus macrophyllus* in 36-cm-diameter containers (Expt. 2). Irrigation rates remained fixed (LF_FX; above) or were adjusted daily based on evapotranspiration rate and rain (LF_ET; bottom) between LF test dates. LF means (±SD) are the average of nine observations per LF test day. Day 0 = 25 Oct. 2017; Day 231 = 26 June 2018.

Table 2. Effect of leaching fraction (LF) irrigation practice (IRR) and target LF (LF$_T$) on plant growth and irrigation water use of *Viburnum odoratissimum* (Expt. 1) and *Podocarpus macrophyllus* (Expt. 2) grown in 36-cm-diameter containers with spray-stake microirrigation. Irrigation rates remained fixed between LF test dates (LF_FX) or were adjusted daily based on evapotranspiration rate and rain (LF_ET). n = 24 for plant growth and n = 3 for water applied.

		V. odoratissimum			*P. macrophyllus*		
IRR	LF$_T$ (%)	Plant ht change^{z} (cm)	Plant width change^{z} (cm)	Water applied^{y} (L/plant)	Plant ht change^{z} (cm)	Plant width change^{z} (cm)	Water applied^{x} (L/plant)
LF_FX	10	45	41	245 (27)^{w}	41	40	235 (12)^{w}
	20	44	42	300 (31)	41	42	248 (79)
	40	47	42	409 (11)	39	41	365 (42)
LF_ET	10	45	41	239 (47)	39	41	204 (18)
	20	45	43	271 (32)	41	44	243 (50)
	40	46	43	386 (58)	41	43	319 (65)
Effect				$P > F$			
IRR		0.911	0.400	0.053	0.373	0.212	0.002
LF$_T$		0.421	0.389	<0.0001	0.356	0.219	<0.0001
IRR × LF$_T$		0.944	0.943	0.568	0.460	0.960	0.087

^{z}Initial plant height and width were 35 cm and 62 cm, respectively, for *V. odoratissimum* and 54 cm and 48 cm, respectively, for *P. macrophyllus*.

^{y}For LF$_T$ main effect, least significant difference 0.05 (LSD$_{0.05}$) = 47.

^{x}For IRR main effect, LSD$_{0.05}$ = 19; for LF$_T$ main effect, LSD$_{0.05}$ = 48.

^{w}Mean (SD).

applied to a 3.8-L sprinkler-irrigated ornamental plant.

The finding that plant growth in both experiments was unaffected by the low target LF value of 10% was surprising considering that higher LF values have been shown to be necessary to effectively resupply substrate water loss under nursery conditions (Million and Yeager, 2018b; Owen et al., 2009). Several factors may help explain why the low LF of 10% was effective in the current experiments. One is that production conditions for controlled irrigation experiments conducted at a research facility are typically less variable than for experiments conducted at a cooperating nursery. For example, the three plants we used for LF testing were used to guide irrigation of eight plants (including the three plants tested), whereas in a nursery three plants may be used to guide irrigation of hundreds of plants. The irrigation system with pressure-compensating emitters applied irrigation water uniformly and consistently, whereas in a nursery with large irrigated areas, irrigation water may be distributed less uniformly, and irrigation applications may be unpredictably skipped for a host of reasons. We used a medium-flow, down-spray emitter in a container that represented the smaller size of the range of containers that are microirrigated. This likely resulted in more efficient retention of irrigation water than would have occurred using the same spray-stake in a larger container. Although we cannot be confident that a target LF of 10% will be effective in a nursery, the two experiments demonstrate that a target LF of 10% using an LF-directed irrigation schedule can produce a quality plant with an efficient irrigation delivery system.

The use of CIRRIG to adjust irrigation based on potential ET rate had no benefit in reducing the total amount of irrigation water applied in Expt. 1 and had a minor effect in Expt. 2. The 10% reduction in water use in Expt. 2 was largely due to adjustments for rain rather than adjustments for ET rate. McCready et al. (2009) found that a rain cutoff sensor saved 7% to 30% of water compared with a fixed irrigation schedule with no sensor. When comparing LF_ET with LF_FX, LF_ET reduced irrigation on days when ET was lower than the reference ET associated with a given LF test but increased irrigation when it exceeded the reference ET. Table 3 shows that during Expt. 2 the irrigation amount for LF_FX was greater than for LF_ET approximately the same number of days as LF_ET increased irrigation amount over LF_FX (99 vs. 97 d). On days when LF_FX irrigation amounts exceeded those of LF_ET, ETo averaged 0.71 cm, whereas on days when LF_ET was greater than LF_FX, ETo averaged 1.00 cm. Greatest differences were observed in May when LF_FX irrigated more than LF_ET on 18 d resulting in a savings of 41 min of irrigation (169 vs. 128 min). During May, ETo for days when LF_FX irrigated more than LF_ET was 0.82 but when the two treatments applied the same amount, ETo was 1.39 cm. At the end of the experiment, the net result was a reduction of 74 min or 9% (776 vs. 850 min) using LF_ET schedule compared with LF_FX. The effect of this difference on average LF cannot be determined as we did not continuously monitor LF. However, because plant growth was similar for the two irrigation schedules, no apparent biological advantage was awarded either irrigation treatment. Based on the results of these two experiments, the use of CIRRIG to improve water savings of an LF-guided irrigation program by automatically making real-time ET and rain adjustments cannot be justified unless manual adjustments for rain are not effectively made by irrigation managers. A container nursery found that although automated irrigation scheduling with CIRRIG reduced water usage and associated pumping costs, much greater cost savings were achieved by reducing the labor that would normally be required for substrate moisture sampling and manual adjustment of irrigation controllers (Million and Yeager, 2019). Greater cost savings in reduced labor compared with decreased water use also were found by Belayneh et al. (2013) for a sensor-based, automated irrigation system.

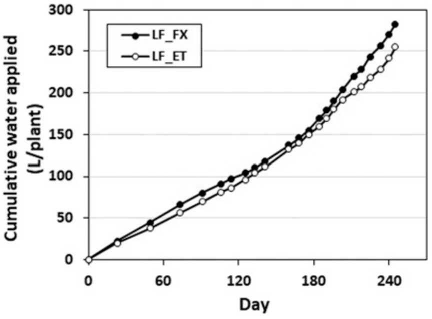

Fig. 3. Main effect of irrigation practice on cumulative water applied to *Podocarpus macrophyllus* grown in 36-cm-diameter containers from 25 Oct. 2017 to 26 June 2018 (Expt. 2). Between leaching fraction test dates, irrigation amounts remained fixed (LF_FX) or were adjusted daily based on evapotranspiration rate and rain (LF_ET). Means were averaged over target LF values of 10%, 20%, and 40% (n = 9).

Table 3. The number of days when the irrigation amount for a fixed irrigation schedule (FX) between leaching fraction tests was greater than, less than, or equal to the amount using a leaching fraction–based irrigation schedule that made real-time adjustments based on evapotranspiration and rain (ET). The corresponding reference evapotranspiration values (ETo) and total irrigation time (Irrig) for each condition are also given. *Podocarpus macropyllus* in 36-cm-diameter containers were microirrigated three times per day (Expt. 2).

	No. of days			ETo (cm)			Irrig (min)	
Month^z	FX>ET	FX<ET	FX=ET	FX>ET	FX<ET	FX=ET	FX	ET
Nov. 2017	15	6	9	0.71	0.71	0.74	85	76
Dec. 2017	16	9	6	0.45	0.65	0.58	81	71
Jan. 2018	12	14	5	0.42	0.56	0.53	75	68
Feb. 2018	4	17	7	0.54	0.82	0.66	61	68
Mar. 2018	8	18	5	0.70	1.05	0.83	93	102
Apr. 2018	13	13	4	0.92	1.24	1.15	129	116
May 2018	18	9	4	0.82	1.51	1.39	169	128
June 2018	13	11	2	1.13	1.45	1.30	157	147
Total	99	97	42	0.71	1.00	0.90	850	776

^{z}Irrigation treatments started 25 Oct. 2017 and end 26 June 2018.

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