Leaching Fraction-based Microirrigation Schedule Reduced Water Use but Not N and P Loss during Production of a Container-grown Shrub

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Abstract. Irrigation that decreases the leaching fraction (LF; leachate/water applied) has been shown to reduce fertilizer N and P leaching during the production of sprinkler-irrigated, container-grown plants; however, little research involving outdoor production of microirrigated plants in large containers has been conducted. Two microirrigation schedules based on routine leaching fraction testing were compared to determine their effects on water use and leaching losses of N and P during the production of Dwarf Burford holly in 36-cm-diameter (trade #7) containers. Applied irrigation water and leachate were collected continuously and sampled weekly during the 12-month experiment. An irrigation schedule adjusted once every 1 to 3 weeks to a target LF of 20% resulted in the application of 36% less water (383 vs. 597 L/plant) and 43% less leachate (255 vs. 445 L/plant) than a schedule adjusted to a target LF of 40%; plant growth was unaffected ($P > 0.05$). Irrigation schedules had no effect ($P > 0.05$) on cumulative N and P leaching losses, which were attributed in large part to rain. Average leaching losses of N and P were 15.2 and 2.2 g per container (210 and 30 kg·ha⁻¹·year⁻¹), respectively. Both N and P leaching losses represented 35% of the 43.5 g N and 6.3 g P applied per container in two controlled-release fertilizer applications. The results support the best management practice of scheduling irrigation based on routine LF testing to reduce irrigation water use but not reduce N and P leaching.

Outdoor production of plants in containers requires frequent irrigation to compensate for the limited water storage capacity of confined substrate volumes (Beeson, 2007; Warren and Bilderback, 2005). Frequent irrigation of container-grown plants places great demand on water managers to apply water efficiently at each application to avoid excessive leaching. This is particularly true for microirrigated, spray-stake production in which the water application rates (e.g., 15–40 cm·h⁻¹) are typically 10- to 25-times higher than for those of sprinkler-irrigated production (e.g., 0.8–1.5 cm·h⁻¹). Although cyclic irrigation is a common practice to improve

water retention of microirrigated container substrates (Beeson and Haydu, 1995; Karam and Niemiera, 1994), scheduling irrigation in multiple cycles with shorter run times results in fractions of 1 min being the difference between supplying an adequate amount of water vs. an excessive amount (Million and Yeager, 2019).

One measure of irrigation efficiency is the LF, which is the amount of leachate divided by the amount of water applied to the container. If sufficient water is being supplied to sustain plant growth, then an irrigation schedule that maintains a lower LF will use less water and result in less leachate. Nambuthiri et al. (2017) used an on-demand sprinkler irrigation schedule that reduced the LF from 25% to 17%, resulting in a 35% reduction in irrigation water applied and a 65% reduction in leachate volume. Tyler et al. (1996) found that reducing the LF from 46% to 31% reduced the irrigation volume by 49% and leachate volume by 63%. Irrigation management that targets a low LF with routine LF testing significantly reduced water use at a container nursery (Stanley, 2012). Compared with the nursery's traditional irrigation practice, irrigation adjustment based on routine LF testing reduced irrigation volumes applied

during six of seven nonreplicated trials at a Central Florida container nursery, with greater water savings for microirrigated vs. sprinkler-irrigated crops (Million and Yeager, 2019). Routine LF testing targeting a LF of 20% vs. 40% reduced the irrigation volume 28% during each of two experiments without affecting plant growth (Million and Yeager, 2020).

Reducing the volume of leachate has been shown to reduce leaching losses of applied N and P from containers. Tyler et al. (1996) reported that the N leaching loss was reduced 53% after 55 d and 19% after 100 d when the leachate volume was reduced by 63%. Warsaw et al. (2009) found an irrigation schedule that reduced the leachate volume by 66% to 79% also reduced NO₃-N leaching by 38% to 59% and P by 46% to 74%. During a column leaching study, Niemiera and Leda (1993) found that increasing the leaching fraction from 20% to 40% increased N leaching by 61%. Fare et al. (1994) reported that reducing sprinkler irrigation from 1.3 cm/d to 0.6 cm/d reduced the leachate volume 75% and leachate NO₃-N 36% to 46%; plant growth was unaffected. These aforementioned studies, except for that by Tyler et al. (1996), involved small containers (≤3.8 L) and sprinkler irrigation. Surprisingly, the effect of irrigation schedules on fertilizer N and P leaching during plant production in large containers with microirrigation has not been well-investigated (Zhu et al., 2005).

The objective of this study was to evaluate the impact of irrigation schedules that target a low or high LF on irrigation water applied, plant growth, and N and P leaching during the production of container-grown landscape plants with spray-stake microirrigation.

Materials and Methods

The experiment was conducted outdoors on the campus of the University of Florida in Gainesville (lat. 29.6°N, long. 82.3°W). The gently sloped (1% to 2%) site was covered with black industry-standard polypropylene ground cloth. The site's microirrigation system consisted of eight individually controlled irrigation lines. The six interior lines irrigated experimental plants and the outside lines irrigated border plants. The six experimental lines were in a randomized block design with two irrigation treatments [target LF of 20% (LF20) or target LF of 40% (LF40)] and three blocks. Each irrigation line had nine spray-stake assemblies, eight of which were used to irrigate plants (one per container) and one was placed in a 15-L pail to continuously collect irrigation water. Each spray stake assembly included a pressure compensating button (01WPCJ25; Netafim, Tel Aviv, Israel), a 1-m-long section of polyethylene tubing (diameter, 0.64 cm), and a down-spray emitter (CFD Black; Antelco, Longwood, FL) rated at 23 L·h⁻¹ at 103 kPa. A flush valve (5 psi Auto Flush; Maxijet, Dundee, FL) was placed at the end of each of the eight lines. Irrigation tests indicated

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very high uniformity ($DU = 98\%$) and an average application rate of $322 \pm 6 \text{ cm}^3/\text{min}$. Of the eight containers per line, the outer two served as borders. Of the six interior plants per line, three were used for routine LF testing and three were used for continuous leachate collection; all six were used to

monitor plant growth. Each of the six interior plants per line was placed on an elevated aluminum pizza pan with a drain hole for routine LF testing or continuous leachate collection. The 64 containers ($8 \text{ lines} \times 8 \text{ containers}$) were placed in an equidistant pattern with a container spacing (center-to-

center) of 0.91 m (13,800 containers per hectare).

Irrigation was scheduled three times (cycles) per day: 1100, 1400, and 1700 HR. On 3 Nov. 2019, cycle start times were changed to 1000, 1230, and 1500 HR due to the daylight savings time change. Irrigation was automatically controlled using a programmable logic controller (PLC) (D0-DA06; Automation Direct; Atlanta, GA) connected to the internet. Hourly weather data (solar radiation, minimum and maximum temperatures, and rain) from a weather station (Vantage Pro 2 Plus; Davis Instruments, Hayward, CA) located on-site were automatically uploaded to a University of Florida server running CIR-RIG, a container irrigation program developed at the University of Florida that interfaced with the PLC (Million and Yeager, 2020). The PLC was programmed to automatically cancel an irrigation cycle if the amount of rain received after the previous cycle exceeded the scheduled amount of irrigation water to apply.

The daily amount of water to apply was based on LF testing conducted once every 1 to 3 weeks using three plants per line. A 2-week testing interval was planned, but shorter intervals were sometimes needed to follow-up the irrigation adjustments made when LF test values were significantly different from target values. LF tests were only conducted on days when weather conditions provided normal evapotranspiration (ET) rates. Test intervals more than 2 weeks occurred when weather conditions were not conducive to LF testing for a given 2-week interval. During LF testing, a pan was placed under the drain hole of the pizza pan to collect leachate over a 24-h period (all three cycles). Except for a small opening for collecting drainage, pans were covered to minimize evaporation of the leachate. The amount of irrigation water applied during the same 24-h period was determined by weighing the irrigation collector pail before and after the LF test. The volume of irrigation water applied by each line was used in the calculations for each of the three LF measurements per line. The average LF of the three test containers per line (LF_1) and the run time (RT_1) were used to calculate a new irrigation run time (RT_2) based on the target LF (LF_2) of 20% or 40% according to the following equation: $RT_2 = RT_1 \times (100\% - LF_1) / (100\% - LF_2)$. The new run time was divided equally between the three cycles. After each test, the new LF-adjusted run time remained constant until the following LF test was conducted.

Fig. 1. Dwarf Burford holly plant size [(height + width) / 2] measured once every 2 weeks from 7 Mar. 2019 through 8 Mar. 2020. Irrigation adjustments to target a leaching fraction of 20% or 40% had no effect ($P > 0.05$) on plant canopy growth.

Fig. 2. Routine leaching fraction (LF) test results conducted once every 1 to 3 weeks to adjust irrigation to a target LF of 20% or 40%. Means ($\pm$ SD) for each of the 30 test dates were the average of nine LF test plants per target LF treatment. The final LF test was performed on 2 Mar. 2020 (week 52).

Table 1. Effect of target leaching fraction on water applied and leachate N and P. Leachate was continuously collected and sampled weekly during 12 months of production of Dwarf Burford holly in 36-cm containers at a density of 13,800 containers per hectare. Spray-stake microirrigation was adjusted once every 1 to 3 weeks to target leaching fraction (LF) values of 20% or 40%. Controlled-release fertilizer supplied 43.5 g N and 6.33 g of P per container, 65% of which was preplant-incorporated and 35% of which was surface-applied 28 weeks after planting.

Target LF (%)	Irrigation water (L/container)	Leachate (L/container)	Leachate loss (g/container)		Leachate concn ² (mg·L ⁻¹)	
			N	P	N	P
20	383	255	15.0	1.94	59.0	7.61
40	597	445	15.4	2.38	34.6	5.35
P value	0.027	0.017	0.529	0.140	0.029	0.073

²Volume-weighted.

Fig. 3. Weekly volume (mean $\pm$ SD) of irrigation water applied from 7 Mar. 2019 through 8 Mar. 2020 (week 53) as affected by routine irrigation adjustment to target a leaching fraction of 20% or 40%.

Fig. 4. Weekly total rain, average daily minimum (T_{min}) and maximum (T_{max}) temperatures, and average solar radiation associated with weekly leachate collections.

For continuous leachate collection, leachate from three containers per line was directed into a PVC pipe apparatus that directed the combined leachate into 50-L tubs buried in the ground. Strips of black polyethylene sheeting were taped around the lower portion of each container to form a “skirt” over the pizza pan to prevent rain from directly entering the leachate collec-

tion apparatus. At the end of each week, volumes of leachate and irrigation water were measured by weighing to the nearest 0.01 kg. After measuring the leachate volume, one 250-mL leachate sample was taken from each collection tub. An irrigation water sample was also taken from one of the irrigation collector pails. Weekly leachate and water samples were filtered and stored at 4 °C until they were submitted to the University of Florida’s Environmental Water Quality Laboratory (<https://arl.ifas.ufl.edu>) within 4 d of sampling. Leachate samples were analyzed for NO_3^- -N, total Kjeldahl N, and total P. We only report N, which was the sum of NO_3^- -N and total Kjeldahl N. The total amounts (mg per container) of N and P leached each week were calculated by multiplying leachate N and P concentrations ($\text{mg}\cdot\text{L}^{-1}$) by the volume of leachate collected (L per container per week).

The experiment was started on 7 Mar. 2019. Two Dwarf Burford holly (*Ilex cornuta* ‘Burfordii Nana’) starter plants obtained from Hibernia Nursery (Webster, FL) were transplanted to 36-cm-diameter (trade #7; 700 series; Haviland Plastic Products, Haviland, OH) containers filled with a substrate composed of a volume of 70% pine bark, 20% Florida peat, and 10% leaf compost (Oldcastle, Lakeland, FL). The substrate was amended with dolomitic limestone at $4.2\text{ kg}\cdot\text{m}^{-3}$ and a micronutrient blend (Micro-max; ICL, St. Louis, MO) at $0.89\text{ kg}\cdot\text{m}^{-3}$. The volume of substrate in each container was 21 L, with a substrate total porosity of $80 \pm 3\%$ and container capacity of $46 \pm 3\%$. A 18N–2.3P–6.6K controlled-release fertilizer (Nutricote Total 18–6–8, 270-day release at 25 °C; Florikan, Sarasota, FL) was incorporated at the label-recommended medium rate of 157 g per container (28.3 g N/container and 4.1 g P/container). Fertilizer was weighed for each container to ensure that each container received the correct amount.

Transplants were uniformly watered-in manually to avoid drainage, and containers were set out in the experimental area. Containers were irrigated for 1 min three times per day until 12 Mar., when the first weekly leachate collection was performed. The first LF test was conducted on 12 Mar., and the results were used to initiate treatment irrigation schedules beginning on 13 Mar.

Plant growth was monitored by measuring plant height and plant width at experiment initiation and once every 2 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. Plant size was the average of plant height and width. Plants were lightly tip-pruned for shape approximately once per month. As indicated by low leachate N concentrations ($<10\text{ mg}\cdot\text{L}^{-1}$), the same fertilizer was reapplied to the surface of containers on 16 Sept. 2020 (week 28) at 85 g per container, which is the label-recommended medium rate for a top-dress application. The top-dress fertilizer was distributed in a broad band around the entire perimeter of the substrate surface.

The final leachate collection was performed on 9 Mar. 2020. The final day of irrigation was 8 Mar. 2020, resulting in a total of 368 d of irrigation from which leachates were collected. Weekly volumes of irrigation and leachate were totaled along with the associated amounts of N, and P. Volume-weighted concentrations of N and P ($\text{mg}\cdot\text{L}^{-1}$) were calculated by dividing the total amounts leached (mg per container) by the total leachate volume (L per container). Plant growth was the change in plant height and width from the start of the experiment to 9 Mar. 2020. Experimental data were analyzed as a randomized complete block design with two irrigation treatments and three blocks using the Proc GLM procedure of Statistical Analysis System 9.4 (SAS Institute, Cary, NC). There was one replication per treatment-block for irrigation and leachate response variables and six replications per treatment-block for plant response variables.

Results

Plant growth. The changes in plant height and plant width after 12 months of growth were unaffected ($P > 0.05$) by irrigation treatment. The pattern of Burford holly canopy growth is provided in Fig. 1. The effect of approximately monthly tip-pruning was similar for both irrigation treatments, with only the week 12 pruning resulting in no net growth from the previous measurement at week 10. After a 4-week period of little canopy growth following the early March planting, plant canopy growth was steady until late October, when plants became dormant. Canopy growth did not resume by the end of the experiment in early March of the following spring.

LF testing. Routine LF testing of 30 d during the 12-month experiment resulted in

Fig. 5. Volume of leachate collected weekly from 7 Mar. 2019 through 8 Mar. 2020 (week 53) during outdoor production of Dwarf Burford holly in 36-cm-diameter containers. Spray-stake microirrigation was adjusted once every 1 to 3 weeks to target LF values of 20% or 40%.

Fig. 6. Average potential evapotranspiration rate for leaching fraction test days (ET_{o_LF}) compared with the average potential evapotranspiration for all days before the next leaching fraction (LF) test (ET_o). Routine LF tests were conducted once every 1 to 3 weeks, with irrigation adjustments based on LF tests remaining constant between LF tests.

averages (mean $\pm$ SD) of $22 \pm 10\%$ and $40 \pm 9\%$ for LF20 and LF40 irrigation schedules, respectively. In general, LF test values for LF20 were in the range of 10% to 30%, whereas LF values for LF40 were in the range of 30% to 50% (Fig. 2). The up-and-down pattern of LF during the first 6 months coincided with the spring and early summer months, when plants were rapidly growing and ET rates were increasing with longer days and high temperatures. Adjustments to irrigation based on LF testing tended to

overcompensate when LF test results were lower than the target values, so that subsequent LF test values were $\approx 25\%$ higher than the target LF values. For LF20, the test LF was very low (3%) on 5 Sept. 2019 (week 26). This test date followed 1 week of clear days, during which solar radiation averaged $254 \text{ W}\cdot\text{m}^{-2}$ and the potential ET averaged $1.3 \text{ cm}\cdot\text{d}^{-1}$, which were much higher than the corresponding values of $133 \text{ W}\cdot\text{m}^{-2}$ and $0.7 \text{ cm}\cdot\text{d}^{-1}$, respectively, during the previous week.

Irrigation water and leachate volume.

The total volume of irrigation water applied after 12 months was decreased by 36% for LF20 vs. LF40 (Table 1). Weekly water use peaked at the end of September (week 30), when the plant size was greatest (Fig. 3), little rain occurred, and weather was conducive to high ET rates (Fig. 4). The increase in water use from planting until peak was relatively constant until week 13 (early June); after that time, frequent rain reduced the irrigation requirement so that weekly irrigation water use did not increase much until rain became less frequent in September (Fig. 3). After the peak in late September, water use decreased steadily until December; at that time, it remained relatively constant throughout the winter months. The decrease in water use after the September peak was due to lower potential ET rates associated with shorter days and cooler temperatures.

The total leachate volume collected after 12 months was decreased by 43% for LF20 vs. LF40 (Table 1). The weekly leachate volume varied greatly due to rain (Fig. 5). For weeks with little or no rain, the leachate volume started at 2 L per container in Mar. 2019, peaking to 4 L per container in Sept. 2019. Rain resulted in dramatic increases in leachate volume for weeks 9, 14 to 16, 18, 21, 24 to 25, 32 to 34, 37, 41, and 42, with peak weekly leachate volumes of 16 to 19 L per container. Rain was estimated to add 155 L of water per container (assuming 100% of rain enters the container). This amount represented 42% and 24% of the total volume of irrigation water applied for LF20 and LF40, respectively. If the estimated contribution of rain was added to the volume of irrigation applied, then the overall LF was estimated to have been 49% and 55% for LF20 and LF40, respectively. These results indicate that rain was a major factor in determining the amount of leachate that occurred despite the automatic cancelling of irrigation when rain exceeded the cycle's irrigation amount.

There were 21 weeks with little or no rain ($<0.25 \text{ cm}$ of rain per week). For those 21 weeks, LF values based on weekly leachate and irrigation water collection averaged 34% and 52%, respectively, for LF20 and LF40. The observed LF values higher than the targeted LF values when little or no rain occurred were expected because LF testing used to adjust irrigation was purposely conducted on days with normal ET rates to insure adequate irrigation for the remaining days. Because irrigation remained constant between LF test days, LF values higher than the target would likely occur on days when the potential ET rate was lower than the potential ET rate on the day of the LF test. This is evident when the average daily potential ET (ET_o) during the interval between LF tests is plotted against the ET_o of the day of the LF test (ET_{o_LF}) (Fig. 6). During the 12-month experiment, the ET_o averaged 83% of ET_{o_LF} . There were 269 d when the ET_o was lower than the ET_{o_LF} and 94 d when the ET_o was higher or equal to the ET_{o_LF} . Days when the ET_o was less than the

ET_o-LF were common during the period from June through October, when cloudy and rainy conditions were more prevalent than they were in spring.

Nutrient leaching. Irrigation water contained low concentrations of N and P. The mean $\pm$ SD concentrations of N and P in the 53 weekly water samples were 0.36 ± 0.20 and 0.0044 ± 0.0040 mg·L⁻¹, respectively. The total contributions of N in irrigation water during the experiment were 0.14 and 0.21 g

per container for LF20 and LF40, respectively. The total contributions of P in irrigation water were 0.0017 and 0.0026 g P per container for LF20 and LF40, respectively. These amounts were negligible compared with the 43.5 g N and 6.33 g of P per container that were applied during the two fertilizer applications.

Total leaching losses of N and P were unaffected ($P < 0.05$) by irrigation treatments (Table 1) despite the 43% decrease in leach-

ate volume that resulted for LF20 vs. LF40. Leaching losses of NO₃-N represented 97% and 95% of N for LF20 and LF40, respectively (data not provided). The average N loss for the two irrigation treatments was 15.2 g per container or 35% of the 43.5 g of N applied. The average total P leachate loss for the two irrigation treatments was 2.2 g per container or 35% of the 6.33 g of P applied during the two fertilizer applications. Equivalent N and P losses were 210 and 30 kg·ha⁻¹·year⁻¹, respectively.

The impact of rain on the leachate volume explains, in part, why N and P leaching losses for the two irrigation practices were not different. As previously mentioned, rain-adjusted LF estimates of 49% and 55% for LF20% and LF40%, respectively, indicated that both irrigation schedules resulted in high leaching pressure despite the reduced overall leachate volume observed for LF20%. Weekly losses of N (Fig. 7) revealed that ≈ 10 g N or two-thirds of the total N loss during the experiment occurred during the first 16 weeks. During this first 16-week period, ≈ 6 g N per container were lost during 3 weeks with significant rain: week 9 = 1.6 g N leached with 4.1 cm of rain; week 14 = 2.5 g N leached with 9.1 cm of rain; and week 15 = 1.8 g N leached with 8.1 cm of rain. Because NO₃-N is a highly leachable form of N and represented 96% of N in leachate, it is not surprising that rain had such a major influence on N leaching. Weekly leachate P loss (Fig. 7) exhibited a similar effect of rain, except that significant leaching did not occur until 3 months after planting, with a maximum weekly loss of P not occurring until week 24. Leachate P loss was greater ($P < 0.05$) for LF40 vs. LF20 for weeks 8, 10 to 12, 27, 29, and 30 with little or no rain. However, leachate P loss was greater ($P < 0.05$) for LF20 for week 42 when 7 cm of rain fell. We attributed the greater leachate P loss for LF20 during week 42 to rain leaching P that had previously accumulated more in LF20 than in LF40 when leaching was unaffected by rain.

A closer evaluation of the effect of rain on leachate N and P was performed by sorting data into five categories based on the amount of rain received each week (Table 2). Differences in leachate volume, leachate N, and leachate P between LF20 and LF40 were greatest when little or no rain (<0.25 cm) fell and diminished as weekly

Fig. 7. Weekly leaching losses of N and P during the 12-month outdoor production of Dwarf Buford holly in 36-cm-diameter containers. Spray-stake microirrigation was adjusted once every 1 to 3 weeks to target LF values of 20% or 40%. Controlled-release fertilizer supplied 43.5 g N and 6.33 g of P per container, 65% of which was preplant-incorporated and 35% of which was surface-applied 28 weeks after planting. For total P, significant weekly differences ($P < 0.05$) due to irrigation treatment are denoted with an asterisk.

Table 2. Effect of rain on leachate losses of N and P during 12 months of outdoor production of Dwarf Buford holly in 36-cm-diameter containers. Leachate was continuously collected and sampled weekly. Spray-stake microirrigation was adjusted once every 1 to 3 weeks to target leached fraction (LF) values of 20% or 40%. Controlled-release fertilizer supplied 43.5 g N and 6.33 g of P per container, 65% of which was preplant-incorporated and 35% of which was surface-applied 28 weeks after planting.

Weekly rain (cm)	Weeks	Rain (cm)	Leachate vol. (L/container)			Leachate N (g/container)			Leachate P (g/container)		
			LF20	LF40	LF20/LF40	LF20	LF40	LF20/LF40	LF20	LF40	LF20/LF40
<0.25	21	1	53	123	0.43	1.8	2.5	0.72	0.17	0.35	0.49
0.25–1.27	8	7	25	55	0.45	1.5	2.0	0.75	0.11	0.21	0.52
1.27–2.54	9	17	41	72	0.57	1.8	2.0	0.90	0.22	0.30	0.73
2.54–3.81	7	23	48	78	0.62	1.4	1.5	0.93	0.34	0.42	0.81
>3.81	8	58	89	118	0.75	8.4	7.5	1.12	1.10	1.11	0.99
Total	53	106	255	445	0.58	15.0	15.4	0.97	1.94	2.38	0.85

Fig. 8. Weekly leachate concentrations of N and P during the 12-month outdoor production of Dwarf Burford holly in 36-cm-diameter containers. Spray-stake microirrigation was adjusted once every 1 to 3 weeks to target LF values of 20% or 40%. Controlled-release fertilizer supplied 43.5 g N and 6.33 g of P per container, 65% of which was preplant-incorporated and 35% of which was surface-applied 28 weeks after planting.

rain increased. Compared with LF40, LF20 reduced the leachate volume by 57% when weekly rain was <0.25 cm, but only by 25% when weekly rain was >3.81 cm. Similarly, leachate N loss was reduced by 28% when weekly rain was <0.25 cm, but it was increased by 12% when weekly rain was >3.81 cm. We attributed this 12% increase in leachate N loss for LF20 to the leaching of N that accumulated in LF20 substrate during previous weeks with little rain. Reducing the target LF from 40% to 20% reduced leachate P by 51% when weekly rain was <0.25 cm but only by 1% when weekly rain was >3.81 cm. These results clearly show that any effect that a reduced target LF had on reducing leachate N and P loss during periods of little or no rain was lost or minimized when rain occurred.

The overall volume-weighted leachate concentration of N at the end of the 12-month experiment was 71% higher for LF20 than for LF40, respectively (Table 1). Volume-weighted concentrations of P were not significantly different for the two irrigation treatments. Leachate N concentrations for both irrigation treatments were highest during weeks 8 to 16, with a

maximum value of $254 \text{ mg}\cdot\text{L}^{-1}$ observed for LF20 at week 8 (Fig. 8). Leachate P concentrations were highest during weeks 14 to 24, with a maximum value of $21 \text{ mg}\cdot\text{L}^{-1}$ observed for LF20 at week 24 (Fig. 8).

Discussion

The primary objective of this experiment was to evaluate the effect of reduced leachate volume on leachate loss of applied N and P. By following a routine LF testing procedure and adjusting irrigation to target a LF of 20% vs. 40%, we observed a 43% decrease in leachate volume with the application of 36% less irrigation water. Because Dwarf Burford holly growth was unaffected, the results supported the best management practice of using LF testing to guide irrigation to conserve water (FDACS, 2014). Assuming sufficient irrigation water was retained by the substrate to sustain optimal plant growth, by definition, a lower LF would be expected to result in less leachate volume. However, we did not expect that reducing the leachate volume would not reduce leachate N and P loss because most

research has reported otherwise. Tyler et al. (1996) reported that an irrigation schedule that targeted a LF of 20% vs. 40% reduced the leachate volume by 63% and leaching losses of $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, and P by 66%, 62%, and 57%, respectively. To eliminate the effect of rain on leaching, the researchers did not include leachate data for 32 d of the 100-d experiment if daily rain was >0.13 cm. However, when the results included rain days, a target LF of 20% vs. 40% reduced leaching losses of $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, and P by 10%, 27%, and 0%, respectively. This supports our conclusion that rain has a major factor in N and P leaching in outdoor production. An often-cited study by Fare et al. (1994) reported that when irrigation was reduced from 13 to 6 $\text{mm}\cdot\text{d}^{-1}$ for a sprinkler-irrigated container crop, the leachate volume was decreased by 74% and the leachate loss of $\text{NO}_3\text{-N}$ was decreased by 59% (average of three cyclic irrigation treatments and high fertilizer rate). During their experiment (Expt. 2), samples obtained for nutrient analyses were based on intermittent daily samples instead of continuously collected leachate samples. As a result, sampling days likely did not include days of significant rain that may have provided different results than would have occurred if samples were taken from continuously collected leachate. Warsaw et al. (2009) reported that irrigation schedules that reduced leachate volume by 66% to 79% also reduced $\text{NO}_3\text{-N}$ leaching by 38% to 59% and P by 46% to 74%. As in the latter study, these results were based on sampling only 2 d per month so that reported irrigation schedule effects were not based on cumulative leachate collection and were likely based on only days with no rain. For our experiment, rain represented 42% and 24% of the total amounts of irrigation water applied with LF20 and LF40 so that despite targeting and achieving low LF values on non-rain days, rain resulted in overall LF values of 49% and 55%, respectively. We concluded that rain minimized the potential benefit of a low LF irrigation schedule for reducing leachate N and P losses. Because the experiment was conducted outdoors, similar results would not be expected for comparable production under cover. Finally, we concluded that the value of adjusting irrigation based on routine LF testing as an irrigation best management practice is supported more by water conservation than by reduced fertilizer N and P leaching.

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