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Cyclic Irrigation Reduces Container Leachate Nitrate-nitrogen Concentration

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Abstract. **Two experiments were conducted to evaluate the effects of cyclic irrigation on leachate NO_3-N concentration, container leachate volume, total effluent volume, and growth of *Ilex crenata* Thunb. 'Compacta'. In Expt. 1, container leachate volume was reduced 34% when 13 mm of water was applied in three cycles compared to continuous irrigation of 13 mm per unit time. Forty-nine percent less container leachate volume was collected from a continuous application of 8 mm than from that of 13 mm water. In Expt. 2, container leachate volume was reduced 71% when 6 mm was applied in a single application over 30 minutes compared to 13 mm applied continuously for 1 hour. Total effluent was reduced by 14% and 10% in Expts. 1 and 2, respectively, when 13-mm irrigation was applied in three cycles compared to one continuous irrigation. Container leachate NO_3-N concentrations from cyclic irrigation were generally less than leachate NO_3-N concentrations from continuous irrigation treatments. The percentage of applied N leached as NO_3-N ranged from 46% when 13-mm irrigation was applied in three cycles to 63% when 13-mm irrigation was applied in a single cycle. Leachate NO_3-N concentration was reduced as irrigation volume was reduced from 13 to 6 mm in Expt. 2. Percentage of applied N leached as NO_3-N was 63%, 56%, and 47% when 13-mm irrigation was applied in one, two, and three cycles, respectively, compared to 19%, 16%, and 15% when 6-mm irrigation was applied in one, two, and three cycles, respectively. 'Compacta' holly shoot and root growth were minimally affected by cyclic irrigation or irrigation volume.**

Successful production of container-grown ornamentals requires adequate nutrients and water in the container medium. Most soilless media, consisting of a high percentage of pine bark, have a low capacity for retaining nutrients and water, and large irrigation quantities result in significant nutrient loss, particularly NO_3-N (Rathier and Frink, 1989).

Several cultural methods have been evaluated to improve NO_3-N management in container nurseries (Cox, 1985; Jarrell et al., 1983; Niemiera, 1991; Rathier and Frink, 1989; Stewart et al., 1981). Recently, two commercial nurseries reported a reduction in irrigation volume applied and subsequent irrigation runoff with cyclic irrigation (Daughtry, 1990; Whitesides, 1989). Cyclic irrigation comprises two phases: 1) the operating phase of the irrigation system and 2) the phase in which the irrigation is off (Karmeli and Peri, 1974). To our knowledge, no research has been conducted to determine the influence of overhead cyclic irrigation. We conducted two experiments to evaluate the effects of cyclic, overhead irrigation on container leachate and runoff volume, NO_3-N concentration leached from the container, and plant growth of *Ilex crenata* 'Compacta' holly.

Materials and Methods

Apparatus. Water collection modules were constructed to collect container leachate and runoff from the growing areas. Modules were 0.25 m deep, 1.2 m wide, and 2.4 m long (Fig. 1). The module base was 1.9-cm-thick, pressure-treated plywood, with a funnel installed in one corner to route container leachate to a container outside the module. A second 1.9-cm-thick plywood sheet was placed on support beams (2.5 × 5.0 mm) near the top of the pressure-treated side boards. All joints were caulked and painted to prevent leakage. Sixteen holes, 15 mm in diameter and spaced ≈18 mm apart, were cut in the top plywood sheet, and 2.3-liter nursery containers were recessed about two-thirds of the depth of the container. The containers were suspended in the top sheet of plywood, which allowed container leachate to drain into the module base for collection. A second funnel was installed in one corner of the top plywood sheet to route bed runoff to a collection container outside the module. Modules were supported at a 5% slope by 20 × 20 × 41-mm concrete blocks.

In Expt. 1, the design was a randomized block design with three replications of each irrigation treatment and 16 plants per replication (module). Experiment 2 was a completely randomized design in a 2 × 3 factorial (2 irrigation volumes × 3 irrigation cycles). Each experimental unit (module) had three replications, with 16 plants at each irrigation treatment with a split-plot of two fertilizer rates.

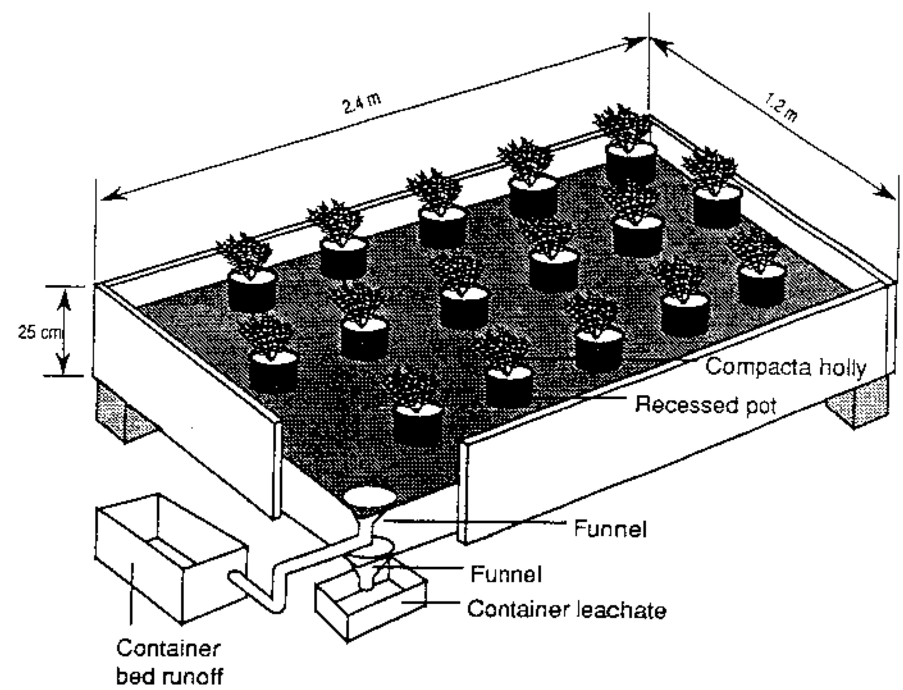

Fig. 1. Water collection module.

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Plant and media preparation. Uniform liners of 'Compacta' holly in 480-mm^3 pots were repotted into a 3 pine bark : 1 peat (v/v) medium in 2.3-liter containers on 26 Mar. 1991 (Expt. 1) and 12 May 1992 (Expt. 2). Medium was amended with (kg·m^{-3}) 1.2 gypsum, 3.6 dolomitic limestone, and 0.9 minor elements (Micromax; Grace-Sierra, Milpitas, Calif). In Expt. 1, 17N–3.1P–10K controlled-release fertilizer (Osmocote; Grace-Sierra) was incorporated at 8.3 kg·m^{-3} into the medium before potting. A second fertilizer application of 12N–2.6P–4.9K (Parker Fertilizer Co., Sylacauga, Ala.) at 5 g/pot was topdressed on 21 Aug. 1991. In Expt. 2, controlled-release fertilizer at two rates was incorporated into the medium before potting (in kg·m^{-3}): 7.1 [low fertilizer (LF)] and 9.5 [high fertilizer (HF)] of 17N–3.1P–10K. Plants in the LF and HF treatments were topdressed on 14 Sept. 1992 with 17N–3.1P–10K at 18 and 24 g/pot, respectively.

Table 1. Irrigation treatments (Expts. 1 and 2).

Irrigation cycle[z]	No. cycles[y]	Cycle duration (min)	Total irrigation vol (mm)
		Expt. 1	
1C13	---	60	13
2CY13	2	30	13
1C8	---	40	8
2CY8	2	20	8
		Expt. 2	
1C13	---	60	13
2CY13	2	30	13
3CY13	3	20	13
1C6	---	30	6
2CY6	2	15	6
3CY6	3	10	6

[z]1C13, one continuous cycle with 13-mm irrigation; 2CY13 and 3CY13, two and three cycles, respectively, with 13-mm irrigation; 1C8, one continuous cycle with 8-mm irrigation; 2CY8, two cycles with 8-mm irrigation; 1C6, one continuous cycle with 6-mm irrigation; 2CY6 and 3CY6 two and three cycles, respectively, with 6-mm irrigation.
[y]All cyclic treatments had a 1-h resting phase between irrigation cycles.

Particle size distribution of the medium was determined by sieving oven-dried medium through U.S. standard sieves no. 1/4, 4, 7, 18, 35, 60, and 140 with openings of 6.4, 4.75, 2.8, 1.0, 0.5, 0.25, and 0.106 mm, respectively. Based on percentage of dry medium weight, medium particles >4.75, between 4.75 and 1.0, and <1.0 mm were 28%, 60%, and 12%, respectively, in Expt. 1 and 32%, 58%, and 10%, respectively, in Expt. 2.

Medium pore space and water-holding capacity were determined from Gessert (1976) and Whitcomb (1979) procedures. Physical properties for medium in Expt. 1 were 60% total porosity, 22% airspace, and 38% water-holding capacity. In Expt. 2, medium had 58% total porosity, 22% airspace, and 36% water-holding capacity. Cation exchange capacities (CEC) were 259 and 375 meq per container (45 and 48 meq per 100 g medium) for Expts. 1 and 2, respectively.

Irrigation treatments. Plants were hand-watered to saturation at potting, weighed (container mass), placed in the collection modules, and watered with overhead impact sprinklers (model 20BADJ; Rain Bird Sales, Glendora, Calif.). Irrigation was applied to all treatments at 0.9 liter·s^{-1}. The average daily irrigation applied at container nurseries in Alabama is ≈15 mm and ranges from 6 to 22 mm (Fare et al., 1992). To model irrigation volumes used in nurseries, two irrigation volumes (13 and 8 mm) were applied as a continuous application (1C13 and 1C8, respectively) or as two cyclic applications (2CY13 and 2 CY8, respectively) (Table 1). Irrigation was applied to all treatments when container medium in the 1C13 treatment was estimated at 70% to 80% of container capacity. Irrigation was applied between 0700 and 1200 HR.

In Expt. 2, plants were irrigated when the container medium for each treatment reached 80% of container capacity as determined by container mass. Two plants from each treatment and replication were weighed each afternoon (1600 HR) to determine weight loss. Irrigation application was based on weight loss from container mass at potting. Irrigation was applied the following day between 0500 and 1100 HR. Two irrigation volumes (13 and 6 mm) were applied as a continuous application (1C13 and 1C6, respectively) or as two (2CY13 and 2CY6, respectively) or three (3CY13 and 3CY6) cyclic applications (Table 1).

Tempe pressure cells (Soilmoisture Equipment Corp., Santa Barbara, Calif.) were used to develop a soil moisture release curve. Based on the curve, ≈40% to 50% of the total water volume was not available to plants (data not shown). Thus, irrigation was applied when ≈33% to 40% of the available water was lost via evapotranspiration. One plant per treatment per replication was harvested (fresh and dry shoot and root weights were recorded) during the middle of each experiment to recalibrate for container mass due to plant growth.

Water analysis. After one irrigation each week, container leachate and irrigation runoff (irrigation water that fell between the pots) volumes were measured 1 h after applying irrigation. Leachate was collected on days 1, 3, 5, 10, 45, 60, 90, 120, 150, 180, and 210 in Expt. 1 and days 1, 3, 5, 10, 20, 30, 60, 90, 100, 121, 123, 126, 130, 140, 150, and 180 in Expt. 2. Leachate samples were filtered and refrigerated at 4C. Within 4 weeks, leachate samples were analyzed for NO_3-N and NH_4-N with a Wescan ammonia analyzer (model 360; Alltech Associates, Deerfield, Ill.).

Plant harvest. Plants were grown outdoors in full sun for 210 and 180 days in Expts. 1 and 2, respectively. At termination, shoot growth was analyzed by determining a growth index {[height + width 1 + width 2 (perpendicular to width 1)]/3}. Shoots were cut at soil level, oven-dried at 57C, weighed, and analyzed for total N by a semimicro Kjeldahl method. Root growth was determined by transversely dividing the root ball into three 5-cm increments. In each section, roots were separated from the container medium, washed, and scanned on a Comair root length scanner (Commonwealth Aircraft, Melbourne, Australia). Root samples were oven-dried at 57C and weighed. Roots in the three sections were combined to determine total length and dry weight. In both experiments, additional 'Compacta' holly plants were potted and placed on a conventional growing bed with gravel covering. Data collected from these plants were similar to data collected from 'Compacta' holly grown in the water collection modules. Thus, only data from the module are reported.

Table 2. Effects of irrigation method and volume on container leachate and total effluent in the water collection module and growth of 'Compacta' holly (Expt. 1).

Irrigation cycles[z]	Container leachate (liters)[y]	Total effluent (liters)[y]	Growth index (mm)[x]	Shoot dry wt (g)
1C13	3.5	30.1	32.2	76.3
3CY13	2.3	25.9	35.0	66.0
1C8	1.8	21.7	31.7	69.8
3CY8	1.1	18.5	31.0	62.5
Significance				
Cyclic	0.0001	0.0001	0.005	0.002
Irrigation volume	0.0001	0.0001	0.001	0.031
Cyclic × irrigation	0.2070	0.2433	0.001	0.428
Contrast				
1 cycle vs. 3 cycles with 13 mm	---[w]	---	0.001	---
1 cycle vs. 3 cycles with 8 mm	---	---	0.223	---

[z]1C13, one continuous cycle with 13-mm irrigation; 3CY13, three cycles with 13-mm irrigation; 1C8, one continuous cycle with 8-mm irrigation; 3CY8, three cycles with 8-mm irrigation.
[y]Container leachate and total effluent (container leachate plus irrigation runoff) were collected from each module (16 containers) after each irrigation event.
[x]Growth index = [height + $width_1$ + $width_2$ (perpendicular to $width_1$)]/3.
[w]Dash denotes contrast not tested due to nonsignificant interaction.

Results and Discussion

Container leachate. During Expt. 1, container leachate volume (per pot per irrigation application) was reduced by 34% when 13 mm of water was applied in three cycles instead of in one continuous irrigation (Table 2). Using 8 rather than 13 mm of water reduced container leachate by ≈50% at each irrigation application (90 to 179 ml/pot). Plants receiving treatment 3CY8 had the least container leachate volume, averaging 67 ml/pot over all sampling dates.

In Expt. 2, fertility treatment had no effect on container leachate volumes; consequently, fertilizer treatment subplots were combined for analysis. Container leachate volumes were reduced by 18% when 13 mm of water was applied as cyclic irrigation (2CY13 and 3CY13) compared to 13 mm applied as continuous irrigation (Table 3). There were similar leachate volumes collected from plants grown with treatments 2CY13 and 3CY13. With 6 mm of water, container leachate volumes were reduced 32% with cyclic irrigation (2CY6 and 3CY6) compared to continuous irrigation (1C6). Leachate volume was 50% less with three cyclic applications compared to two cyclic applications.

Irrigation runoff in these tests consisted of water that fell between the containers in the water collection module. These modules present an empirical situation because the typical container bed allows some irrigation water to infiltrate the soil. All runoff water was collected from the modules, so our irrigation runoff values are high compared to those in an actual nursery.

Effluent. Total effluent (container leachate and irrigation runoff) from the module was ≈30 liters when 13 mm of water was applied in a 1-h continuous application (1C13) (Table 2). This amounts to 1 mm of water (77% of the volume applied) or >100,000 liters of effluent/ha per irrigation application. Total effluent was reduced by 14% when irrigation was applied in three cycles (3CY13) compared to one continuous application (1C13). When continuous irrigation volume was 8 mm rather than 13 mm, total effluent was reduced by 28%.

Table 3. Effects of irrigation method and volume on container leachate and total effluent in the water collection module (Expt. 2).

Irrigation cycles[z]	Container leachate (liters)[y]	Total effluent (liters)[y]
1C13	3.1	30.5
2CY13	2.7	27.4
3CY13	2.4	27.5
1C6	0.9	15.0
2CY6	0.8	13.7
3CY6	0.4	12.5
Significance		
Cyclic	0.0001	0.0001
Irrigation volume	0.0001	0.0001
Cyclic × irrigation	0.4374	0.0001
Contrasts		
1 cycle vs. 2 and 3 cycles with 13 mm	0.0063	0.0001
2 cycles vs. 3 cycles with 13 mm	0.2874	0.9023
1 cycle vs. 2 and 3 cycles with 6 mm	0.0061	0.0377
2 cycles vs. 3 cycles with 6 mm	0.0022	0.0029

[z]1C13, one continuous cycle with 13-mm irrigation; 2CY13 and 3CY13, two and three cycles, respectively, with 13-mm irrigation; 1C6, one continuous cycle with 6-mm irrigation; 2CY6 and 3CY6, two and three cycles, respectively, with 6-mm irrigation.
[y]Container leachate and total effluent (container leachate plus irrigation runoff) were collected from each module (16 containers) after each irrigation event.

In Expt. 2, total effluent was reduced 10% when continuous irrigation (1C13) was compared to cyclic irrigation (2CY13 and 3CY13). Continuous irrigation with 6 mm of water, rather than 13 mm, resulted in 51% less total effluent. When the continuous application (1C6) was compared to two and three cycles (2CY6 and 3CY6), total effluent was reduced by 13%. About 9% less total effluent was collected from 3CY6 than from 2CY6.

Nitrate-nitrogen leachate. Leachate volumes were used for subsequent calculations of NO_3-N leached from containers. Only results from Expt. 2 will be discussed because 80% to 90% of the N leached was in the form of NO_3-N. Also, in Expt. 1 (1991), high rainfall (73.9 cm) occurred during April and May; thus, irrigation was not applied as frequently as during normal conditions, resulting in inconsistent NO_3-N and NH_4-N concentrations in container leachate.

Based on NO_3-N concentrations from the sampling dates and the estimated levels from weekly container leachate volumes, leachate NO_3-N loss was ≈133 mg/pot for the growing season from the HF continuous irrigation (1C13) treatment (Table 4). This indicates that ≈63% of the total applied N was leached as NO_3-N. Nitrate-nitrogen loss was reduced 11% when 13 mm of water was applied in two and three cycles (2CY13 and 3CY13), compared to one continuous application. Cox (1985), Jarrell et al. (1983), and Niemiera (1991) reported NO_3-N leached can be ≤50%, 64%, and 45% of applied N, respectively, with conventional irrigation.

Nitrate-nitrogen leached with HF was reduced ≈53% (63 vs. 133 mg/pot) when irrigation volume was 6 mm (1C6) rather than 13 mm (1C13 in Expt. 2) (Table 4). The amount of NO_3-N leached was reduced 29% with 6-mm cyclic irrigation treatments (2CY6 and 3CY6) compared to one continuous application (1C6).

Table 4. Effects of irrigation method and volume on estimated cumulative NO_3-N leached from containers in the collection module (Expt. 2).

Irrigation cycles[y]	Estimated cumulative NO_3-N leached (mg/pot)[z] HF[x]	LF[w]
1C13	133	89
2CY13	129	80
3CY13	108	70
1C6	63	34
2CY6	52	28
3CY6	37	24

[z]The milligrams per pot of NO_3-N leached was calculated from concentrations from the 16 sampling dates and container leachate volume. Cumulative NO_3-N leached was interpolated from the irrigation frequency between sampling dates and, therefore, not amenable to statistical analysis. A total of 88 irrigations were applied.
[y]1C13, one continuous cycle with 13-mm irrigation; 2CY13 and 3CY13, two and three cycles, respectively, with 13-mm irrigation; 1C6, one continuous cycle with 6-mm irrigation; 2CY6 and 3CY6, two and three cycles, respectively, with 6-mm irrigation.
[x]HF = high fertility, 9.5 $kg{\cdot}m^{-3}$.
[w]LF = low fertility, 7.1 $kg{\cdot}m^{-3}$.

The percentage of leachate NO_3-N with LF followed a trend similar to HF (Table 4). Nitrate-nitrogen loss was ≈89 mg/pot in the 1-h continuous irrigation treatment (1C13). This loss indicates ≤69% of the total applied N was leached as NO_3-N.

Cyclic irrigation treatments (2CY13 and 3CY13) had ≈16% less NO_3-N loss with LF than with continuous irrigation (1C13). About 64% less NO_3-N was leached from pots receiving the LF rate with 6-mm irrigation compared to pots receiving 13-mm irrigation.

These data indicate that regardless of the fertilizer rate used in plant production, leachable NO_3-N depends on the applied irrigation volume and the amount of container leachate. For example, with 1C13, ≈63% of N leached as NO_3-N with HF and ≈69% with LF. When irrigation was applied in two cycles (2CY13), ≈61% of N leached as NO_3-N in the HF treatment and 62% in the LF treatment. When 6 mm of water was applied in three cycles (3CY6), ≈18% of the N leached as NO_3-N in the HF treatment and 19% in the LF treatment.

Plant growth. In Expt. 1, the 'Compacta' holly growth index and shoot dry weights were higher when plants were irrigated with 13 mm than with 8 mm (Table 2). The cyclic treatment resulted in a higher shoot-growth index than the noncyclic treatment at 13 mm.

In Expt. 2, cyclic irrigation and irrigation volume had no effect on the growth index or on shoot dry weight (data not shown). Plants grown with the HF rate had a significantly higher growth index (38.6 vs. 34.7 mm) and higher shoot dry weights (42.7 vs. 38.5 g) than plants grown with the LF rate. All cyclic irrigation, fertility rate, and irrigation volume treatment interactions were nonsignificant at $P \leq 0.05$.

The difference in plant response in the two experiments was related to soil moisture when irrigation treatments were applied. During Expt. 1, irrigation treatments were applied when soil moisture was estimated to be between 70% and 80% of container capacity. In Expt. 2, irrigation applications were applied when soil moisture was at 80% of container capacity based on weight loss. Because soil was maintained at a higher moisture level in all treatments in Expt. 2, plant response to cyclic irrigation was similar to continuous irrigation.

Root growth was not influenced by cyclic irrigation or irrigation volume in Expt. 1 (data not shown). Typically, more root dry weight was produced in the upper third of the container than the middle or lower third in all irrigation treatments. There were no differences among treatments for total root dry weight.

In Expt. 2, irrigation volume had little effect on root growth. Plants grown with cyclic irrigation produced 268 m/plant total root length compared to 326 m/plant with noncyclic irrigation (significant at $P \leq 0.05$). Plants grown with HF had less root length (289 vs. 353 m/plant) but more root dry weight (11.0 vs. 9.7 g/plant) than plants grown in the LF treatments (significant at $P \leq 0.05$). All cyclic irrigation, irrigation volume, and fertility treatment interactions were nonsignificant at $P \leq 0.05$.

Foliar N concentration was not influenced by cyclic irrigation or irrigation volume in either experiment (data not shown). But, in Expt. 2, the foliar N concentration was higher in plants with HF (37 $g \cdot kg^{-1}$) than in plants grown with LF (32 $g \cdot kg^{-1}$). Foliar N levels were in an acceptable range for both treatments (Gilliam and Smith, 1980).

Our data indicate that quality 'Compacta' holly plants can be grown with irrigation volumes lower than those traditionally applied and that using this procedure can result in container leachate volume reduction. Furthermore, if irrigation is applied in two or three cycles, container leachate volume will be reduced, which results in less NO_3-N leached than in traditional continuous irrigation. Also, the HF fertilizer treatments produced plants 10% larger than those under LF, but at the same time had 19% more NO_3-N leached. With the current environmental concerns regarding water quality in container production, cyclic irrigation is a desirable management practice to reduce NO_3-N loss in container production.

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