Timing of Low Pressure Irrigation Affects Plant Growth and Water Utilization Efficiency[1]

Stuart L. Warren and Ted E. Bilderback[2]
Department of Horticultural Science
North Carolina State University, Raleigh, NC 27695

Abstract

Pine bark based substrates, commonly used in the southeastern United States for container nursery crop protection, have low moisture retention properties; therefore, daily irrigation during the growing season is required to maximize plant growth. Current guidelines state that irrigation should occur during the early morning hours (before 1000 HR). However, limited research indicated that multiple application of water each day resulted in significantly more growth compared to early morning application. The objective of these studies was to evaluate the effects of irrigation timing on plant growth, photosynthesis, water utilization efficiency, and substrate temperature. In experiment 1, the daily total volume of irrigation required to maintain 0.4 leaching fraction (LF) in the early morning application (0300, 0500, and 0700 HR) was divided into three equal parts and applied at the following times: 0300, 0500, and 0700 HR; 1200, 1500, and 1800 HR; 0900, 1200, and 1500 HR; and 0500, 1200, and 1900 HR. In experiment 2, the daily total volume of irrigation to maintain 0.15 LF within each timing was divided into three equal parts and applied at the following times: 0200, 0400, and 0600 HR; 0600, 0900, and 1200 HR; 1200, 1500, and 1800 HR; and 0600, 1200, and 1800 HR. Irrigation applied at 1200, 1500, and 1800 HR produced 57% and 69% greater total plant dry weight in experiments 1 and 2, respectively, compared to plants irrigated during early morning hours. Root:top ratio was unaffected by irrigation timing. In both experiments, irrigation applied at 1200, 1500, and 1800 HR had higher water utilization efficiency compare to irrigation applied at 0300, 0500, and 0700 HR or 0600, 0900, and 1200 HR. In experiment 2, plants irrigated at 1200, 1500, and 1800 HR maintained higher rates of net CO_2 assimilation and stomatal conductance, and lower substrate temperatures from 1800 to 2200 HR compared to plants irrigated at 0300, 0500, and 0700 HR or 0600, 0900, and 1200 HR.

Index words: irrigation volume, irrigation management, *Cotoneaster dammeri* 'Skogholm', leaching fraction, photosynthesis, stomatal conductance, container temperature, container production, cyclic irrigation.

Significance to the Nursery Industry

Irrigation timing had a significant affect on plant growth, container temperature, and water utilization efficiency. Plants that were irrigated 1200, 1500, and 1800 HR significantly outperformed plants irrigated during early morning hours. Decreases in plant growth appear to be related to increases in diurnal water stress over the course of the growing season. Growers should avoid letting the container substrate dry out by late afternoon. Our data suggests that growers may want to investigate irrigating at times other than early morning.

Introduction

Production of high quality plants requires proper irrigation management. Pine bark based substrates, commonly used in the southeastern United States for container nursery crop protection, have low moisture retention properties; therefore, daily irrigation during the growing season is required to maximize plant growth. Current 'best management practices' state that irrigation should occur during the early morning hours (before 1000 HR) to reduce potential of wind blowing the irrigation water from the targeted area and to reduce evaporation of irrigation water (18). A recent survey of Alabama nurseries reported that most nurseries (> 60%) are following this recommendation (4). However, Keever and Cobb (8) reported irrigation during the day (1300 HR or split application at 1000 and 1500 HR) reduced substrate and canopy temperature and enhanced top and root growth of *Rhododendron* x 'Hershey's Red' compared to irrigation at 2000 HR. Although, Keever and Cobb stated that the timing of irrigation to achieve maximum growth is not known, their results suggested that a single application applied 2 to 4 hr before maximum air temperature or split application at 1000 and 1500 HR was beneficial. Beeson (1), working with four woody ornamentals, also reported increased growth when irrigation was applied during the day in contrast to early morning (0600 HR) irrigation. However, he attributed the increased growth to lower daily accumulated water stress. Unfortunately, the times of irrigation during the day were not reported. Thus, irrigating during the day may increase growth by reducing heat load and minimizing water stress in the later part of the day. Few studies have determined if irrigation timing affects water usage and water utilization efficiency (2).

Much research has focused on increasing irrigation application efficiency. Cyclic irrigation, where the daily water allotment is applied in a series of cycles comprised of an irrigation and a resting interval (7, 12), can improve irrigation application efficiency [(irrigation volume applied – volume leached) ÷ volume applied] by 25% to 38% (4, 9, 15).

Limited research examining irrigation volume has been completed (6, 17). Simply reducing irrigation volume without regards to the plant's needs can lead to stomatal closure, reduced photosynthesis, and subsequent loss of plant growth (6, 9). Tyler et al. (17) reported a leaching fraction (LF) (irrigation volume leached ÷ irrigation volume applied) of 0.4 maximized growth of *Cotoneaster dammeri* 'Skogholm'. However, Groves et al. (6) reported a LF of 0.15 maximized growth of 'Skogholm' cotoneaster, a LF of 0.3 was required

[1]Received for publication January 16, 2002 ; in revised form May 16, 2002. This research was funded, in part, by the North Carolina Association of Nurserymen, Raleigh, NC, and the Virginia Nursery and Landscape Association, Christiansburg, VA. Special thanks to William Reece and Mary Lorscheider for technical assistance.

[2]Professors.

to maximize growth of *Rudbeckia fulgida* 'Goldsturm'. Growers need additional techniques to improve irrigation and water utilization efficiency. Ideally, to be quickly adopted, these new tools should involve minimum changes to their current production systems. One technique may be irrigation timing. Therefore, our objective was to evaluate the effects of irrigation timing on plant growth, photosynthesis, water utilization efficiency, and substrate temperature.

Materials and Methods

Experiments were conducted in 1999 and 2000. In both experiments rooted cuttings of *Cotoneaster dammeri* 'Skogholm' were potted into 3.8 liter (#1) containers in a pine bark:sand (8:1 by vol) substrate amended with 0.9 kg/cu m (2 lbs/cu yd) dolomitic limestone. Each plant was fertilized at potting with 5.0 g N (0.18 oz) from 17N–2.2P–8.2K (17–5–10, 5–6 month, Pursell Technology, Sylacauga, AL). Plants were grown in a plant production area subdivided into 16 separate plots that allowed for collection of all irrigation water leaving each plot. Plots were 8 × 1 m (25 × 3 ft) with a 2% slope. Twenty containers were placed in each plot for a total of 80 containers in each treatment. Both experiments were in a randomized complete block design with 4 replications and were conducted for 100 days at the North Carolina State University Horticulture Field Laboratory, Raleigh.

In 1999, the volume of irrigation to maintain 0.4 LF in the early morning application (treatment A below) was applied to all treatments (Table 1). The total daily volume of water was divided into three equal parts and applied at the following times:

A. 0300, 0500, and 0700 HR (early morning)
B. 1200, 1500, and 1800 HR (PM)
C. 0900, 1200, and 1500 HR (midday)
D. 0500, 1200, and 1900 HR (all day).

Leaching fraction was monitored daily and irrigation volume was adjusted weekly to maintain 0.4 LF in the early morning treatment (0300, 0500, and 0700 HR). Total irrigation volume applied per container, total volume leached per container, and average LF for the entire study period are reported in Table 1.

In 2000, the daily total volume of irrigation to maintain a 0.15 LF within each treatment was divided into three equal parts and applied at the following times:

A. 0200, 0400, and 0600 HR (early morning)
B. 0600, 0900, and 1200 HR (AM)
C. 1200, 1500, and 1800 HR (PM)
D. 0600, 1200, and 1800 HR (all day)

Leaching fraction was monitored daily and irrigation volume was adjusted weekly. Total irrigation volume applied per container, total volume leached per container, and average LF for the entire study period are reported in Table 1. In both studies, irrigation was applied via pressure compensated spray stakes {Acu-Spray Stick; Wade Mfg. Co., Fresno, CA [rate of application 200 ml/min (0.3 in/min)]}.

In 2000, substrate temperatures were measured in two locations in one container in every replication (total of 8 thermocouples/treatment) for the entire study. Two copper-constantan thermocouples were positioned in the substrate halfway down the container profile 2.5 cm (1 in) from the container wall on both the northern and southern exposure. Thermocouples were connected to a 23X micrologger via a AM-32 multiplexer (Campbell Scientific, Logan, UT). Temperature data were recorded every 5 min and averaged over each 60-min interval. Maximum, minimum, and average temperature along with time of maximum, and time of minimum were recorded every 60 min. Substrate temperatures were averaged over exposure before analysis.

For both studies, at treatment initiation (Day 0), 10 plants were harvested and separated into tops (aerial tissue) and roots. Tops and roots were dried at 65C (150F) for 5 days and weighed. At harvest, tops (aerial tissue) from five randomly chosen containers per plot (total of 20 containers/treatment) were removed. Roots were placed over a screen and washed with a high pressure water stream to remove substrate. These plants were handled as previously described to determine initial top and root dry weight. In 2000, diurnal measurements of net CO_2 assimilation (A) and stomatal conductance (g_s) were made on July 20 and August 17, 2000, on one plant from each replication (4 plant/treatment), using a portable photosynthesis system containing a LI-6200 computer and LI-6250 gas analyzer (LI-COR, Lincoln, NE). A diurnal measurement event consisted of measurements during late morning between 1030 to 1130 HR, at midday from 1300 to 1400 HR and late afternoon from 1600 to 1700 HR. Readings were made on the terminal 8 cm (3.2 in) of growth. A 0.25-liter curvette was used for measurements. PPF values average 1250 ± 143, 1655 ± 75, and 1134 ± 45 $\mu mol \cdot s^{-1} \cdot m^{-2}$ for 1030 to 1130 HR, 1300 to 1400 HR, and 1600 to 1700 HR, respectively.

Table 1. Effect of irrigation timing on total irrigation volume applied per 3.8-liter container, total irrigation volume leached per 3.8-liter container, and average experiment leaching fraction (LF).

Irrigation timing		Volume applied (L)	Volume leached (L)	Leaching fraction[z]
			1999	
Early morning	(0300, 0500, and 0700 HR)	39.6	15.1	0.38
Midday	(0900, 1200, and 1500 HR	39.6	7.5	0.19
PM	(1200, 1500, and 1800 HR)	39.6	9.9	0.25
All day	(0500, 1200, and 1900 HR)	39.6	9.9	0.25
			2000	
Early morning	(0200, 0400, and 0600 HR)	18.7	3.6	0.19
AM	(0600, 0900, and 1200 HR)	26.4	4.0	0.15
PM	(1200, 1500, and 1800 HR)	27.5	3.3	0.12
All day	(0600, 1200, and 1800 HR)	26.4	3.2	0.12

[z]Leaching fraction = irrigation water leached ÷ irrigation water applied, averaged for the entire 100 day study period.

Table 2. Effect of irrigation timing on dry weight and root:top ratio of *Cotoneaster dammeri* 'Skogholm', 1999.

Irrigation timing	Dry weight (g) Top	Root	Total	Root:top[z]
Early morning	31.9c[y]	4.6b	36.6c	0.14a
Midday	46.6ab	6.2ab	52.8ab	0.15a
PM	49.9a	7.6a	57.5a	0.13a
All day	42.6b	6.4a	50.0b	0.15a

[z]Root:top = root dry weight ÷ top dry weight.

[y]Means within columns followed by the same letter or letters are not significantly different as determined by LSD, $P = 0.05$

Table 3. Effect of irrigation timing on dry weight and root:top ratio of *Cotoneaster dammeri* 'Skogholm', 2000.

Irrigation timing	Dry weight (g) Top	Root	Total	Root:top[z]
Early morning	60.7d[y]	12.8b	73.5c	0.21a
AM	80.3c	18.0a	98.3b	0.22a
PM	103.5a	20.7a	124.2a	0.20a
All day	91.0b	19.7a	110.7b	0.22a

[z]Root:top = root dry weight ÷ top dry weight.

[y]Means within columns followed by the same letter or letters are not significantly different as determined by LSD, $P = 0.05$.

Data were subjected to analysis of variance procedures (ANOVA) (15). Treatments means were separated by LSD, $P = 0.05$. The following variables were determined: total plant dry weight = top dry weight + root dry weight; water utilization efficiency = irrigation volume retained in substrate ÷ total plant dry weight (liters of water required to produce 1 g plant dry weight); and root:top ratio = root dry weight ÷ top dry weight.

Results and Discussion

Leaching fraction and dry weight. In 1999, LF averaged 0.38, 0.19, 0.25, and 0.25, for early morning, midday, PM, and all day treatments, respectively (Table 1). Irrigation applied in the PM and midday produced 56% and 46% greater top dry weight, respectively, compared to early morning irrigation (Table 2). Plants irrigated with PM also had greater top dry weight compared to the all day application (0500, 1200, and 1900 HR). Similarly, Keever and Cobb (8) reported that irrigation applications during the day (1300 HR, or a split application of 1000 and 1500 HR) increased top growth compared to irrigation applied at 2000 HR. Root dry weight increased 65% when irrigated with PM (1200, 1300, and 1600 HR) compared to early morning. Plants irrigated with midday, PM, and all day irrigation had similar root dry weights. Statistically, total plant dry weight had the same results as top growth. Root:top ratio was unaffected by irrigation timing illustrating that top and root dry weight responded similarly to irrigation timing (Table 2).

In 2000, LF averaged 0.19, 0.15, 0.12, and 0.12, for early morning, AM, PM, and all day, respectively (Table 1). Irrigation applied PM had significantly greater top dry weight compared to all other irrigation timings (early morning, AM, and all day) (Table 3). Root growth results were similar to 1999, i.e., AM, PM, and all day had similar root dry weights. In addition, root:top ratio was unaffected by irrigation timing (Table 3). These data combined with results from Keever and Cobb (8) and Beeson (1) support the hypothesis that plant growth can be increased significantly if irrigation is applied in the PM. In general, plants irrigated with PM produced the heaviest plants with the greatest water utilization efficiency which is in contrast to the current recommendation of irrigating during early morning. These studies suggest that if presumable sufficient daily irrigation is applied only during early morning hours, growth will be significantly reduced compared to plants irrigated later in the day.

Water utilization efficiency. In 1999 and 2000, PM and midday had higher water utilization efficiency requiring 0.6 liters and 0.3 liters per g of plant dry weight compared to 0.7 liters and 0.4 liters per g of plant dry weight for early morning and AM irrigation (Table 4). This is an increase of 17% and 33%, respectively. Even though it required more water to maintain the LF for PM and midday treatments compared to early morning and AM (Table 1), PM and midday produced a gram of plant dry weight with less water.

Photosynthesis and stomatal conductance. Results from July 20 and August 17, 2000, were similar, so only data from August 17 are presented. At 1100 HR, plants irrigated with PM and all day had 47% higher rates of A compared to early

Table 4. Effect of irrigation timing on water utilization efficiency[z]

Irrigation timing	Experiment 1999	2000
	liters	
Early morning	0.7a[y]	0.4a
AM	0.7a	0.4a
PM	0.6b	0.3b
Midday	0.6b	0.3b

[z]Water utilization efficiency = liters water ÷ g dry weight.

[y]Means within columns followed by the same letter or letters are not significantly different as determined by LSD, $P = 0.05$.

Table 5. Effect of irrigation timing on net CO_2 assimilation (A) and stomatal conductance (g_s) of *Cotoneaster dammeri* Skogholm', 2000.

Irrigation timing	CO_2 assimilation ($\mu mol \cdot CO_2 \cdot m^{-2} \cdot s^{-1}$) Time 1100	1330	1630
Early morning	5.9b[z]	5.4b	4.0c
AM	5.5b	4.6b	4.2bc
PM	8.7a	6.5ab	7.6a
All day	8.4a	7.5a	6.0ab
	Stomatal conductance ($mol \cdot m^{2} \cdot s$)		
Early morning	0.12b[z]	0.13b	0.08c
AM	0.11b	0.12b	0.11bc
PM	0.28a	0.16ab	0.20a
All day	0.24a	0.22a	0.16ab

[z]Means within columns followed by the same letter or letters are not significantly different as determined by LSD, $P = 0.05$.

morning and AM (Table 5). Since plants irrigated early morning and AM had received the total daily water volume (all three cycles), the lower A rate was unexpected. Compared to 1100 HR measurements, A of all treatments decreased at 1330 HR. This is probably due to increased canopy and substrate temperature. Martin et al. (11) working with containerized *Magnolia grandiflora* 'St. Mary' in Florida reported a similar decline in midday A levels attributing the decline to increasing container and air temperature. Only plants irrigated all day had significantly greater A than early morning and AM at 1330 HR. This may reflect the two irrigation cycles all day (0600 and 1200 HR) had received by 1330 HR compared to the one cycle (1200 HR) that PM had received. Thus, plants irrigated PM may have had reduced A due to limited water availability. At 1630 HR, A levels of plants irrigated early morning, AM, and all day decreased compared to 1330 HR suggesting increasing water and temperature stress. However, plants irrigated with PM had increased A measurements compared to 1330 measurements. At 1630 HR, plants irrigated with PM had 86% higher rates of A compared to early morning and AM. Both AM and all day treatments had water applied at 1200 but this does not appear to be sufficient to maintain A levels through 1630 HR. Plants irrigated PM received additional water at 1500 HR which appeared to maintain A. Beeson (1) reported the greatest differences in shoot water potential between plants irrigated early morning and plants irrigated throughout the day occurred in mid- to late afternoon. Generally by 1300 HR plants irrigated early morning had lower water potential with the difference becoming more pronounced by 1600 HR.

Compared to A, g_s had similar trends suggesting that differences in stomatal conductance were regulating A (Table 5). At low to moderate levels of water stress, most reductions in CO_2 assimilation are due to stomatal closure (3). At 1100 HR, plants irrigated with PM and all day had significantly higher g_s levels compared to early morning and AM. At 1330 HR, all day was still significantly higher that early morning and AM, whereas by 1630 HR only PM was significantly higher than early morning and AM.

Substrate temperature. Substrate temperatures recorded on August 16 and 17, 2000, are presented as typical temperatures with sunny to partly cloudy sky conditions (Fig. 1). With the exception of time of daily maximum temperature, containers irrigated with early morning and AM treatments had similar temperature profiles. The time of daily maximum for containers irrigated early morning occurred at 1630 HR [43.8C (111F)], whereas the daily maximum for AM was 1730 HR [42.8C (109F)]. Thus, data for AM are not presented. Time of daily maximum and maximum temperature for containers irrigated PM and all day were similar [1530 HR, 40.2C (104F)]. Martin et al. (11) working with a pine bark:peat:sand substrate (3:1:1 by vol) in Florida reported maximum container temperatures of 45C (113F) from 1715 to 1745 HR. Containers irrigated early morning had significantly lower temperatures at 0600, 0700, and 0800 HR compared to PM however, the differences were small. Container temperatures irrigated with PM and all day had significantly lower temperatures from 1800 to 2200 compared to early morning for most days. Compared to early morning, daily

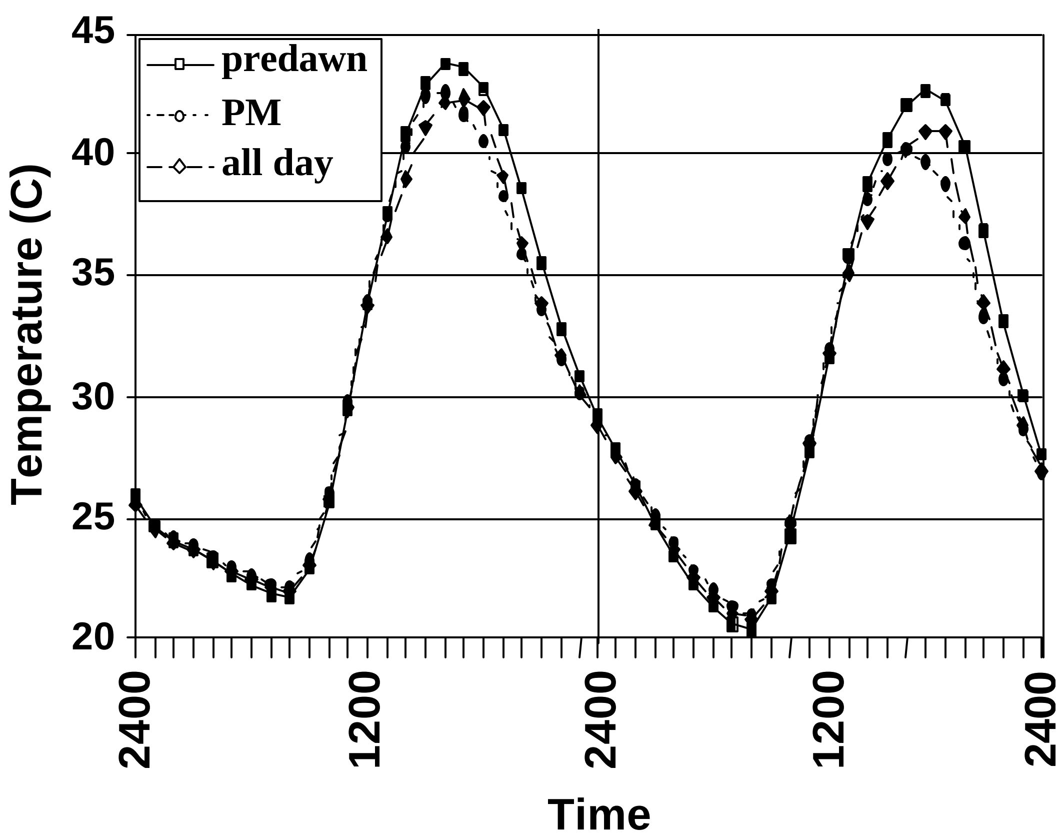

Fig. 1. Effect of irrigation timing on substrate temperatures measured August 16 and 17, 2000.

maximum temperatures for PM were usually significantly lower by 2C to 3C (3.6F to 5.4F). This difference in temperature in combination with available water could have a significant impact on A (14). Martin et al. (11) reported a 50% increase in caliper growth of *Magnolia grandiflora* 'St. Mary' when maximum temperature was reduced by 3C (5.4F) [48C to 45C (118F to 113F)].

Irrigation timing had a significant affect on plant growth, A, g_s, water utilization efficiency, and container temperature. Plants that were irrigated with PM significantly outperformed plants grown with early morning irrigation. Decreases in plant growth appear to be related to increases in diurnal water stress over the course of the growing season. Moderate water stress over long periods was more detrimental to dry matter accumulation than severe stress for short periods in *Eucalyptus* (13). As always, growers should try new techniques under their nursery conditions before making sweeping changes. In addition, this research was conducted with spray stakes, research is needed to determine if similar results are obtained with overhead irrigation.

Literature Cited

1. Beeson, R.C. 1992. Restricting overhead irrigation to dawn limits growth in container grown woody ornamentals. HortScience 27:996–999.

2. Beeson, R.C. and J. Haydu. 1995. Cyclic microirrigation in container-grown landscape plants improves plant growth and water conservation. J. Environ. Hort. 13:6–11.

3. Chaves, M.M. 1992. Effects of water deficits on carbon assimilation. J. Expt. Bot. 42:1–16.

4. Fain, G.B, C.H. Gilliam, K.M. Tilt, J.W. Olive, and B. Wallace. 2000. Survey of best management practices in container production nurseries. J. Environ. Hort. 18:142–144.

5. Fare, D.C., C.G. Gilliam, and G.J. Keever. 1994. Cyclic irrigation reduces container leachate nitrate-nitrogen concentration. HortScience 29:1514–1517.

6. Groves, K.M., S.L. Warren, and T.E. Bilderback. 1998. Irrigation volume, application and controlled-release fertilizers: I. Effect on plant growth and mineral nutrient content in containerized plant production. J. Environ. Hort. 16:176–181.

7. Karam, N.S., 1993. Overhead sprinkle strategies to reduce water and nitrogen loss from container-grown plants. Ph.D. Dissertation. Virginia Polytechnic Inst. and State Univ. Blacksburg.

8. Keever, G.J. and G.S. Cobb. 1985. Irrigation scheduling effects on container media and canopy temperature and growth of 'Hershey's Red' azalea. HortScience 20:921–923.

9. Kramer, P.J. 1983. Water Relations of Plants. Academic Press, Orlando, FL.

10. Lamack, W.F. and A.X. Niemiera. 1993. Application method affects water application efficiency of spray stake-irrigated containers. HortScience 28:625–627.

11. Martin, C.A., D.L. Ingram, and T.A. Nell. 1991. Growth and photosynthesis of *Magnolia grandiflora* 'St. Mary' in response to constant and increased container volume. J. Amer. Soc. Hort. Sci. 116:439–445.

12. Mostaghimi, S. and J.K. Mitchell. 1983. Pulsed irrigation effects on soil moisture distributions. Water Resources Bul. 19–650–612.

13. Myers, B.J. and J.J. Landsberg. 1989. Water stress and seedling growth of two eucalyptus species from contrasting habitats. Tree Physiol. 5:207–218.

14. Ruter, J.M. and D.L. Ingram. 1990. ^{14}Carbon-labelled photosynthesis partitioning in *Ilex crenata* 'Rotundifolia' as supraoptimal root-zone temperatures J. Amer. Soc. Hort. Sci. 115:1008–1013.

15. SAS Institute, Inc.. 1985. SAS User's Guide: Statistics. Version 6.09. SAS Institute, Inc. Cary, NC.

16. Tyler, H.H., S.L. Warren, and T.E. Bilderback. 1996a. Cyclic irrigation increases irrigation application efficiency and decreases ammonium losses. J. Environ. Hort. 14:194–198.

17. Tyler, H.H., S.L. Warren, and T.E. Bilderback. 1996b. Reduced leaching fractions improve irrigation use efficiency and nutrient efficacy. J. Environ. Hort. 14:199–204.

18. Yeager, T.H., C.H. Gilliam, T.E. Bilderback, D.C. Fare, A.X. Niemiera, and K.M. Tilt. 1997. Best Management Practices Guide for Producing Container-Grown Plants. Southern Nurs. Assoc., Marietta, GA.