Cyclic Microirrigation in Container-grown Landscape Plants Improves Plant Growth and Water Conservation[1]

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Abstract

Four tree (*Acer rubrum* L., *Ulmus alata* Michx., *Quercus virginiana* Mill. and *Lagerstroemia indica* L.) and two landscape shrub species (*Rhododendron indicum* L. 'Formosa' and *Elaeagnus pungens* Thunb.) were grown in 10-liter (#3) polyethylene containers. Plants were irrigated with overhead impact sprinklers (control) or with individual low volume spray stakes. Microirrigated treatments consisted of same or double volume per day per container as controls applied as one to three cyclic subvolumes. Shrub growth was seldom influenced by irrigation treatment. Xeric tree species (*U. alata* and *Q. virginiana*) grew as well with single volumes applied in 2 cycles as double volumes applied in 3 cycles; both produced significantly larger trees than the control. Mesic species (*A. rubrum* and *L. indica*) irrigated with double volumes in 3 cycles produced the largest trees that were significantly larger than single volume microirrigated or control trees. Growth of single cycle, single volume trees (overhead and microirrigation) was equivalent; thus, growth effects were due to cycling, not microirrigation. With commercially representative container spacings used, superior trees were produced with cycled microirrigation using 25% (xeric) or 50% (mesic) of the water volume per area applied through the overhead sprinkler. Further aspects of irrigation requirements and water efficiency are discussed.

Index words: cyclic microirrigation, overhead irrigation, irrigation requirements, container production.

Species used in this study: Live oak (*Quercus virginiana* Mill.); Red maple (*Acer rubrum* L.); Winged elm (*Ulmus alata*. Michx.); Crape myrtle (*Lagerstroemia indica* L. 'Tuscarora'); 'Formosa' azalea (*Rhododendron indicum* L. 'Formosa'); Silverthorn elaeagnus (*Elaeagnus pungens* Thunb.).

Significance to the Nursery Industry

Microirrigation can reduce irrigation volumes to one-fourth that used by overhead sprinkler systems while producing same size plants in 10-liter (#3) containers. Microirrigation applied in daily subvolumes (cyclic microirrigation) significantly increased tree growth and irrigation efficiency compared to the total volume applied once daily. Neither microirrigation nor cycled microirrigation improved plant growth compared to overhead irrigation for the two shrub species tested; though similar growth required only one-fourth the water per unit area. Similar benefits of cyclic irrigation are anticipated for trees grown in larger containers.

Introduction

Cyclic irrigation is defined as applying a daily quantity of water in several subvolumes throughout the day. Water retention characteristics of plant canopies (3) and evaporation rates during sunny days (12) necessitate under-the-canopy microirrigation techniques if daily cyclic irrigation quantities are to be minimized.

When irrigated in early morning, container-grown landscape plants in the southern United States often develop mild water stress by afternoon; preventing achievement of optimum growth (4). Yet, when irrigated frequently during the day with microirrigation, water stress was minimized and growth optimized (4). Greater shoot growth also occurred with cyclic overhead irrigation (7, 10). In Florida, overhead irrigation has been prohibited during midday since 1991. In certain regions, restrictions on annual irrigation volumes have been enacted and will likely expand. Thus, techniques that optimize growth and water conservation are crucial to the Florida nursery industry. This study's objectives were: 1) to determine the minimum number of microirrigation cycles required to achieve the greatest growth in a season and compare this to growth with overhead irrigation; 2) to relate differences in growth to microirrigation frequencies and their effect on shoot water stress; and 3) to compare water conservation between overhead and cyclic microirrigation.

Material and Methods

Ninety-one liners per species were transplanted into 10-liter (#3) polyethylene containers and grown in full sun on polyethylene ground cloth. Experiments were initiated in 1992 and 1993 in mid-March and terminated the following December. Potting medium consisted of pine bark fines:Florida sledge peat:coarse sand (6:2:2, by vol) amended with 0.89 kg/m^3 (1.5 lb/yd^3) micronutrients (Peter's Fritted Trace Mineral, Grace-Serra Chemical Co., Milpitas, CA). Medium bulk density at transplanting in 1992 was 0.53 ± 0.04 g/cm^3 (0.31 ± 0.02 oz/in^3) with a percent porosity at 100% container moisture of 22.4 ± 3.3 (v/v), percent water holding capacity of 36.5 ± 0.9 (v/v) and percent total porosity of 61 ± 14 (v/v) as determined by Australian Standard methods (13) based on 3 random samples. Physical properties varied little between years, though new media was purchased each year.

Thirteen plants of each species were randomly distributed into each of 6 microirrigated treatments and an overhead irrigated control. All irrigation was initiated at 0500 hr daily, independent of rainfall. Overhead irrigation was supplied with impact sprinklers (Model 1345, Nelson's Corp., Peoria, IL) at a rate of 31.9 mm (1.25 in) per hour. Microirrigation was applied with an individual spray stake

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(terracotta Spot Spitter; Roberts Irrigation Products, San Marcos, CA) per container at a rate of 11.1 liter (2.9 gal) per hour. Treatments 1–1, 1–2, and 1–3 (volume–number of cycles) received equivalent volumes of water per day as overhead irrigated control plants; based on application rate and container surface area, assuming 100% penetration through the canopy. Treatments 2–1, 2–2, and 2–3 received twice the overhead volume per day. Treatments 1–1 and 2–1 were irrigated once. Treatments 1–2 and 2–2 were irrigated with volumes split into equal applications at 0500 hr and 1300 hr. Treatments 1–3 and 2–3 were irrigated at 0500, 1100, and 1500 hr with one-third volumes at each cycle. Both years all species were topdressed with 70 g (2.5 oz) of Osmocote 18-6-12 in mid-March and again in mid-July. Plants were pruned and staked for commercially acceptable quality.

1992. Seedlings of *Ulmus alata* Michx. (winged elm) and *Acer rubrum* L. (red maple), and rooted cuttings of *Rhododendron indicum* L. 'Formosa' (azalea) and *Elaeagnus pungens* Thunb. (silverthorn elaeagnus) were used. Due to limitations of spray stake flow rates and time clock minimum units (1 min), initial single volumes were 1.1 liter (0.29 gal) per day and the equivalent (18.1 mm; 0.71 in) applied overhead. Volumes were increased 50% in late May and to double initial volumes in mid-July to counter canopy shedding. From mid-July until December overhead irrigated plants received 36.2 mm (1.42 in) of supplemental water daily and microirrigated treatments consisted of 2.2 liters (0.58 gal) and 4.4 liter (1.17 gal) per day for single and double volumes, respectively. Overhead and microirrigation were calibrated thrice.

In July, elm trees were large enough for monthly sampling of diurnal water potential measurements to begin. Elm trees' highly branched growth permitted multiple sampling with minimum canopy disruption. Twigs were sampled about every 2 hr predawn until after sunset (dusk) on 3 trees per treatment. Water potential was measured using a pressure chamber (Model 3001, SoilMoisture Equip. Co., Santa Barbara, CA) as described previously (4). The area over a diurnal water potential curve was integrated and cumulative daily water stress (S_Ψ) calculated (4).

1993. Seedlings of *Quercus virginiana* Mill. (live oak) and rooted cuttings of *Lagerstroemia indica* L. 'Tuscarora' (crape myrtle) and silverthorn elaeagnus were employed using the same system and initial irrigation rates as in 1992. However, irrigation volumes remained constant through December.

During production, 3 containers each of live oak and crape myrtle in each treatment were nested inside thick polyethylene bags in concurrence with growth measurements. Water draining from each container over 24 hr was measured. Percentage of water applied and retained within a container (% retention) was calculated as:

$$\text{percent retention} = \frac{(\text{vol applied} - \text{drainage vol})}{\text{vol applied}} \times 100$$

Area under the seasonal curve developed for each plant was integrated, then analyzed as a random design with each plant serving as a replicate.

Both years, percentage of overhead irrigation penetrating a canopy and reaching container medium (% capture) was measured in concurrence with growth measurements on 3 randomly chosen plants per species. Disposable diapers (medium boys, Dri Bottoms, Paragon Trade Brands, Federal Way, WA) were trimmed and cut into 4 pieces such that > 98% of the medium surface area was covered. Preliminary tests indicated diapers saturated at about 2 liters (about 1 hr of overhead irrigation) and negligible to no water penetrated cut diapers before saturation. Weighed diapers were placed in a container and plants overhead irrigated for 20 min (10.6 mm, 0.47 in). Collected diapers were re-weighed and water contained calculated. Prior to irrigation, 8 collection vessels were placed among plants with openings extending 10 to 30 cm (4 to 12 in) above the canopies. Water falling within the cylinder of a container was calculated based on the nearest collection vessel. Percent capture was calculated by dividing the volume of water contained in a diaper by the estimated volume falling within the cylinder above a container multiplied by 100. Percent capture was measured in early morning when wind was undetectable.

Growth was measured about every 6 weeks. For elaeagnus and azalea, a growth index was calculated as the widest width × width perpendicular to the widest width × shoot height. For trees, height and trunk diameter at 15 cm (6 in) above the soil were recorded. Final measurements occurred in mid-December shortly after shoot elongation had stopped. In 1992, a subset of 7 random plants from each treatment and species were harvested for shoot dry weight. Of harvested maples, root dry weights of 3 was determined. In 1993, shoot dry weights of all plants were measured with root dry weights of 4 oaks also measured.

Analysis of variance calculated for final growth measurements for each species used a randomized design with each plant a replicate. Growth rates for height, trunk diameter and growth index were analyzed by calculating linear regression equations for each species and treatment, then comparing slopes using single-degree-of-contrast (11). Predawn and dusk water potential data and S_Ψ values were analyzed as repeated measurements using a split plot design with treatment as the main plot and weeks as the subplot (11).

Results and Discussion

Shrubs. Azaleas were 0.45 to 0.53 m (17.5 to 21.5 in) in height and 0.7 m (27 in) average width with no significant differences among treatments. Elaeagnus shoot dry weights were also similar among treatments in 1992. However, microirrigated plants had larger growth indices (0.27 to 0.30 m^3; 9.5 to 10.4 ft^3) than those of overhead irrigated plants (0.22 m^3; 7.7 ft^3), with growth indices comparable among microirrigated treatments. In 1993, elaeagnus shoots were similar among all irrigation regimes.

Overhead irrigation penetrating the canopies of azaleas started around 65% and gradually increased to over 100%; whereas, % capture of elaeagnus tended to decline with growth to mid-season, then rebound in late fall (Fig. 1A). Similar trends were measured in 1993 (Fig. 1B).

Most nurseries in Florida strive to apply 12.4 mm (0.5 in) overhead irrigation daily during the growing season. Though first documented in the mid-1970s and justified based on estimated container water capacities and evapotranspiration, the origin of this rate appears to be based on grower preference (5, 6). Hardware limitations prevented applying equal volumes in the combinations of cycles tested with less than 18.1 mm (0.71 in) applied overhead. Shoot growth was not

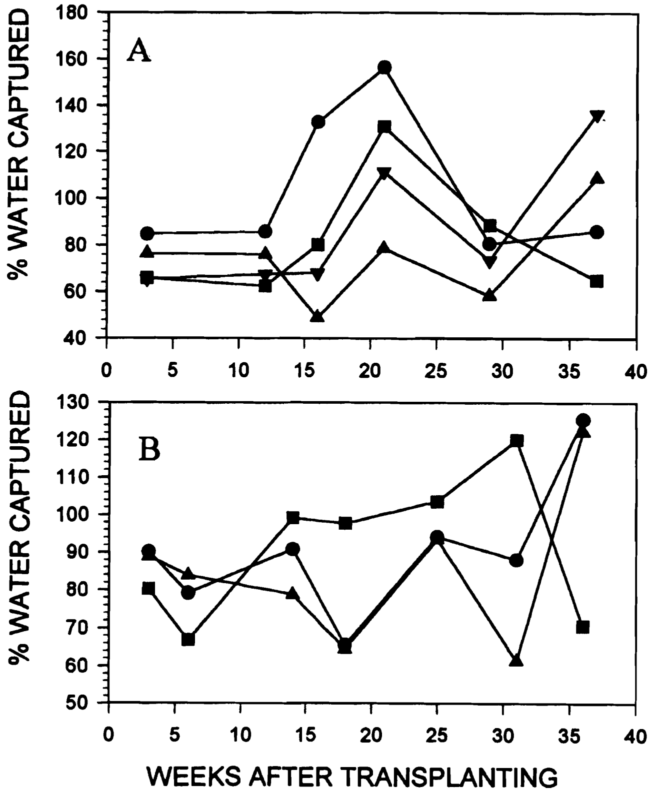

Fig. 1. Seasonal percentage of the overhead sprinkler irrigation that penetrated the canopies (% captured). Species consisted of winged elm (●), red maple (■), elaeagnus (▲) and azalea (▼) in 1992 (A). In 1993, the species live oak (■), crape myrtle (●) and elaeagnus (▲) were used (B). Means are representative of 3 replications.

increased by cycling to promote near 100% container moisture, using microirrigation to compensate for canopy shedding, or doubling the volume of water applied. The unresponsiveness to cycling contrast that found previously (4). However, roots in the earlier study nearly filled the containers before the experiment began (4); whereas here small liners were transplanted into large containers. Thus, cyclic irrigation provides no growth benefit for shrubs until roots fill a container and moisture becomes limiting. Since elaeagnus growth was comparable within the irrigation range of 18.1 mm to 72.4 mm (0.71 to 2.8 in) per day, irrigating more than 18.1 mm (0.71 in) or 1.1 liters (0.292 gal) per day provides no growth benefit. Microirrigation substantially reduced water consumption compared to overhead irrigation. At spacings used (18 mm; 7 in between containers), microirrigation (Trmt 1–1) required only 25% per unit bed area of water applied overhead. Greater reductions from microirrigation would be calculated if irrigated walkways and driveways were included.

Trees. Cyclic irrigation had the greatest effect on tree growth. Elms grown with multiple cycles had larger trunk diameters, were taller and had more shoot dry weight in December than control trees or trees cycled just once per day (Table 1). Doubling the water volume did not significantly increase growth (Table 1). Minimum irrigation volume and cycles required to obtain growth superior to that of overhead or single cycled trees was the single volume applied in 2 cycles (Trmt 1–2).

Interaction of treatment with time after potting was significant for predawn and dusk Ψ_T and S_Ψ. Differences among treatments over the production period were also significant for S_Ψ (Table 1). For predawn and dusk Ψ_T, significant ($\alpha = 0.05$) differences among treatments did not occurred until the final diurnal measurement of Ψ_T, when Trmt 1–2 and 2–1 had more negative predawn Ψ_T than the other treatments and dusk Ψ_T of overhead irrigated elms were more negative then microirrigated trees (data not shown).

Elms irrigated with multiple cycles averaged significantly lower S_Ψ values than trees irrigated only once (Table 1). S_Ψ is a quantitative measure of diurnal fluxuations in stem water potential (4). Lower S_Ψ values indicate less water stress and thus higher plant water status over time. No differences in S_Ψ values among multiple cycle irrigated trees indicates similar water status and agrees well with growth data. Similarly, elm root sucker elongation rates were proportional to soil water, with highest rates occurring at highest soil water contents (16). In the initial shrub study, each 1% increase in S_Ψ was generally associated with a 2% decrease in growth (4). This was true of shoot dry weights of elm, where Trmt 2–2 averaged 16% lower S_Ψ than Trmt 2–1 while shoot dry mass of Trmt 2–2 was 38.6% higher.

Maple growth increased with cycle number and increasing irrigation volume (Table 2). Double water volumes applied in 3 cycles (Trmt 2–3) produced taller trees with significantly more shoot and root dry weight than most other treatment or control trees. Trunk diameters and root:shoot ratios were not significantly different among treatments.

Crape myrtles grown with either volume applied as 3 cycles were significantly ($\alpha = 0.05$) taller than overhead irrigated and most microirrigated plants at season's end (Table 3). Trunk diameter and shoot dry weights were significant greater than other treatments when the double water volume was applied in 3 cycles (Table 3). Only the microirrigation equivalent to overhead irrigation (Trmt 1–1) produced similar shoot dry weight to the control. Double volume or multiple cycle irrigation significantly increased shoot dry weight compared to control plants.

Applying the double volume in 3 cycles (Trmt 2–3) produced the largest live oaks which were significantly greater in height, trunk diameter and shoot dry weight by Decem-

Table 1. Comparison of treatment means of final growth measurements for winged elms produced in 1992. Height and trunk diameter and shoot dry weight are based on 13 replications, while cumulative daily water stress (S_Ψ) is the seasonal mean of 3 replications.

Treatment	Height (m)	Trunk diam (mm)	Shoot dry wt (g)	S_Ψ (MPa-h)
1–1[z]	1.56b[y]	20.8b	309.2bc	86.64a
2–1	1.50b	24.2a	369.1b	84.62a
1–2	1.94a	24.7a	526.4a	74.55b
2–2	1.90a	24.5a	601.7a	72.91b
1–3	1.96a	24.0a	526.5a	76.64b
2–3	1.82a	24.1a	517.2a	74.50b
Control	1.40b	19.1b	233.3c	83.58a

[z]Cycle treatments where the first number signifies a single (1) or double (2) daily irrigation volume and the second number signifies number of cycle subvolumes through which a volume was applied. Control trees were overhead irrigated with a single volume at 0500 hr.

[y]Means with same letters are not significantly different within columns at $\alpha = 0.05$ as separated by Fisher's Protected LSD.

Table 2. **Comparison of treatment means of final growth measurements for red maple produced in 1992. Means of height, trunk diameter, and shoot dry weight are based on 13 replications. Root dry weight and root:shoot ratios are based on 3 replications.**

Treatment	Height (m)	Dry weight (g)	
		shoot	root
1–1[z]	1.47c[y]	147.2c	75.9d
2–1	1.72b	314.4ab	166.6ab
1–2	1.78ab	209.2bc	97.2d
2–2	1.91ab	248.6bc	129.8bcd
1–3	1.87ab	232.1bc	158.7abc
2–3	2.01a	381.6a	210.0a
Control	1.34c	148.0c	104.5cd

[z]Cycle treatments where the first number signifies a single (1) or double (2) daily irrigation volume and the second number signifies number of cycle subvolumes through which a volume was applied. Control trees were overhead irrigated with a single volume at 0500 hr.

[y]Means with same letters are not significantly different within columns at $\alpha = 0.05$ as separated by Fisher's Protected LSD.

ber than overhead irrigated trees (Table 4). Differences in root dry weight and root:shoot ratios among treatments were not significant nor were trunk diameter growth rates. Minimum irrigation volume and cycles required to produce superior trees were a single volume applied in 2 cycles (Trmt 1–2).

For all tree species, larger shoots in December compared to control and Trmt 1–1 trees were due to greater growth rates throughout the production period. This was determined by single-degree-of-freedom contrast of growth measurements recorded every 6 weeks (data not shown).

Patterns of % capture of overhead irrigation were identical for elms and maples, though elms generally captured about 20% more than maples; perhaps due to more vase-like growth habits of elm (Fig. 1A). With growth, % capture increased over 100% during mid-season to declined in late fall with leaf scenscence. The % capture of oaks tended to increase as the season progressed to high of 120%, then declined sharply the last measurement, though there was no leaf scenscence (Fig. 1B). Reasons for this decline are not evident. Crape myrtle % capture was variable, perhaps due to multiple flowering and pruning cycles, but demonstrated an upward trend as plants grew (Fig 1B).

The % retention of overhead irrigated crape myrtle peaked early (week 14) then linearly declined after mid-season (18 Aug; Fig. 2A). In contrast, % retention was lower than the overhead for the microirrigated equivalent (Trmt 1–1) throughout the first two-thirds of the season. Percent retention for Trmt 1–1 gradually increased, peaking over 90% by mid-fall. Percent retentions for Trmts 1–2 and 1–3 peaked early and remained high until early winter. Percent retention was lowest when double water volumes were applied. All double volume treatments exhibited gradual increases in retention throughout the production period until the final measurement. Comparisons of integrated areas under % retention curves found Trmts 1–3, 1–2 and the overhead control to retain the most, with the least efficient retained by Trmt 2–2 (Table 3).

Changes in % retention with time for live oak were similar to those observed with crape myrtle (Fig. 2B). The % retention of overhead irrigated trees peaked early then declined, while % retentions of Trmts 1–2 and 1–3 became high early and remained so until winter. Double volumes retained the least. There were no significant difference in seasonal % retentions among Trmts 1–3, 1–2, 1–1, 2–1 or the overhead control (Table 4).

High % retentions calculated for overhead irrigated trees do not include fluctuations in water volumes reaching container surfaces (% captured). Percent captured increased above 100% when canopies expanded sufficiently to intercept water droplets over an area greater than that of the container, channelling water into the pot; while overcoming deflection of droplets falling above the pot surface. Peak % retentions correspond to lows in % captured as do decreased % retentions correspond with % captured above 100%. If % captured is included in calculations of % retention, then single volumes applied in 3 cycles (Trmt 1–3) were the most efficient application of water.

Table 3. **Comparison of treatment means of final growth measurements for crape myrtle produced in 1993. Means for height, trunk diameter, and shoot dry weight are representative of 13 replications.**

Treatment	Height (m)	Trunk diam (mm)	Shoot dry wt (g)	Integrated retention[z]
1–1[y]	1.13c[x]	15.5bc	142.0bc	2762bc
2–1	1.25abc	15.9bc	156.2b	2634bc
1–2	1.19bc	16.4b	168.8b	3172ab
2–2	1.19bc	16.1bc	158.3b	1490d
1–3	1.26ab	15.7bc	159.5b	3419a
2–3	1.35a	18.5a	232.3a	2300c
Control	1.11c	14.3c	116.9c	3530a

[z]Means of the integrated areas under the seasonal % retention curves. Each mean is representative of 3 replications.

[y]Cycle treatments where the first number signifies a single (1) or double (2) daily irrigation volume and the second number signifies number of cycle subvolumes through which a volume was applied. Control trees were overhead irrigated with a single volume at 0500 hr.

[x]Means with same letters are not significantly different within columns at $\alpha = 0.05$ as separated by Fisher's Protected LSD.

Table 4. **Comparison of treatment means of final growth measurements for live oaks produced during 1993. Means for height, trunk diameter, and shoot dry weight are representative of 13 replications.**

Treatment	Height (m)	Trunk diam (mm)	Shoot dry wt (g)	Integrated retention[z]
1–1[y]	1.44b[x]	15.6bc	167.4d	2935a
2–1	1.71a	16.9ab	234.5abc	2821ab
1–2	1.70a	17.4a	254.1ab	3309a
2–2	1.60ab	15.5bc	213.0bcd	1626c
1–3	1.59ab	16.4abc	213.9bc	3359a
2–3	1.72a	17.7a	260.6a	2072bc
Control	1.48b	15.2c	198.3cd	3371a

[z]Means of the integrated areas under the seasonal % retention curves. Each mean is representative of 3 replications.

[y]Cycle treatments where the first number signifies a single (1) or double (2) daily irrigation volume and the second number signifies number of cycle subvolumes through which a volume was applied. Control trees were overhead irrigated with a single volume at 0500 hr.

[x]Means with same letters are not significantly different within columns at $\alpha = 0.05$ as separated by Fisher's Protected LSD.

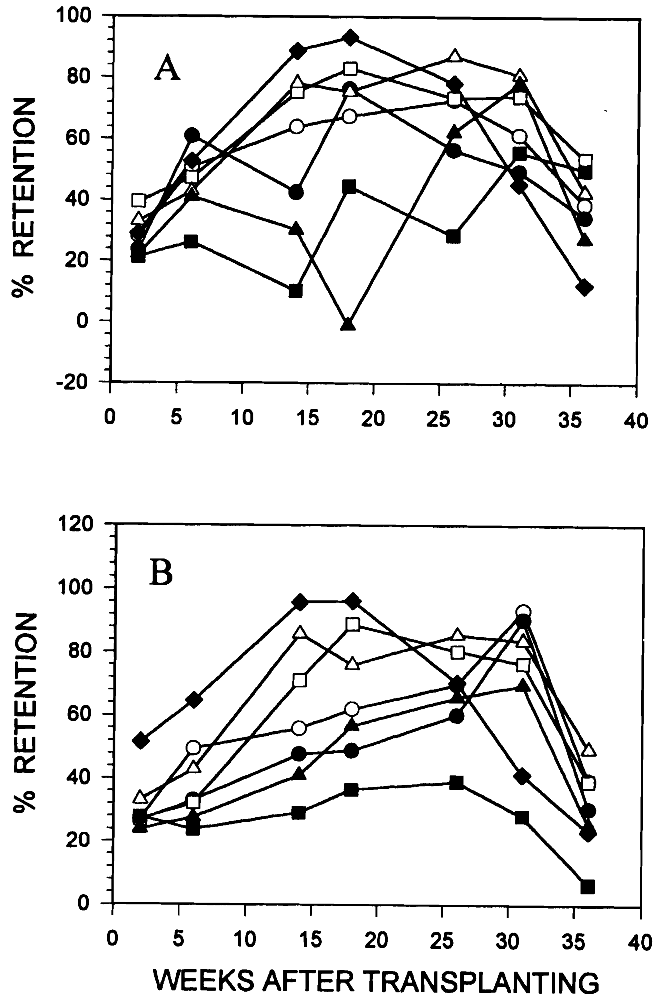

Fig. 2. **Seasonal percentage of irrigation water applied in each treatment retained by the medium within the container (% retention) for crape myrtle (A) and live oak (B) in 1993. Percent retention was calculated as the volume applied minus drainage, divided by the volume applied and multiplied by 100. Treatments consisted of a single (Trmt 1–1; ○) or double (Trmt 2–1, ●) volume applied once daily, a single (Trmt 1–2; □) or double (Trmt 2–2; ■) volume applied in 2 subvolumes daily and single (Trmt 1–3; △) or double (Trmt 2–3; ▲) volumes applied in 3 subvolumes daily. Control (◆) plants were irrigated with overhead sprinklers at 0500 hr daily using the single volume of water (18.1 mm; 0.71 in). Means are representative of 3 replications.**

Higher % retentions occurring with multiple cycles were due applying less volume in excess of that required to resaturate the medium each irrigation. Applying subvolumes is more efficient than applying a single volume because water absorption rates by media become limiting at high water volumes (8). Since irrigation was daily, media moistures were moderate to high. If allowed to dry, % retention would likely have been lower due to hydrophilic conditions that develop in pine bark based-media at low moisture (2).

Similar growth between control and single cycle microirrigated trees (Trmt 1–1) indicate growth increases obtained were due to cycling rather than microirrigation alone. Cyclic irrigation promoted maintanence of high container moisture levels. Increased shoot growth from cyclic irrigation did not change root:shoot ratios, root mass remained proportional to shoot size. Similar effects of optimum root and shoot growth have been report for *Pinus resinosa* (14) and *Photinia* x *fraseri* (15) grown with high soil moisture contents.

Minimum cycle frequency and volume appear associated with drought tolerance. Mesic trees, red maple and crape myrtle, grew largest when irrigated at maximum volumes and frequencies tested (Trmt 2–3). Red maples have been shown to increase growth with increased irrigation up to 400% evapotranspiration (9). Percent retention of crape myrtle (Trmt 2–3) was >50% by week 14, indicating a requirement for more than the equivalent of 18.1 mm (0.71 in) for maximum growth. Xeric species of live oak and winged elm, produced similar growth whether over-irrigated with double volumes or more efficient single volume applied in 2 cycles. This contrast to mesic species may be because photosynthetic rates of oaks remain high over a wide range of soil water contents (1). Winged elm may also be less responsive to soil water since it thrives in droughty soils. Thus, the best regimes tested for balancing rapid growth with water conservation were 1.1 liters (0.29 gal) daily for xeric species and 2.2 liters (0.58 gal) daily for mesic species applied in 2 or 3 subvolumes, respectively, with microirrigation.

The standard practice of 12.7 mm (0.5 in) applied daily is 70% of that applied here. Once % retentions were >70%, this standard would have been insufficient for maximum growth. By week 14, % retentions were >70% when 1.1 liters (0.29 gal) was applied in multiple cycles, with 60% of the growing season remaining. Reducing the 2.2 liter (0.58 gal) rate by 25% to 1.7 liters (0.33 gal) applied in 3 cycles, % retention is extrapolated to be >70% half way through the season. Thus, data suggest the irrigation standard would have limited growth of the trees tested.

Best volumes and frequencies reduced irrigation volumes per area to 25% and 50% of that applied overhead for xeric and mesic species, respectively. Compared to standard overhead practice, best cyclic microirrigation regimes would require only 36% and 72% of the volume per production area, while preventing development of container moisture limitations by mid-season. Similarly, if 1.7 liters (0.33 gal) were applied to mesic species, almost 50% the water applied with the standard overhead practice would be saved with probably no growth reductions.

Most rainfall occurred as afternoon thunderstorms, principally from late May to mid-July (weeks 14 to 20) and late August to mid-October (weeks 20 to 32). Rainfall during the experiment in 1992 was 152 cm (59.8 in) with 65.8 cm (25.9 in) in 1993. Differences among treatments, in spite of afternoon thunderstorms, suggest even greater benefits of cyclic microirrigation during drought or in less humid regions. Growth was maintained longer into the winter with cyclic microirrigation than overhead irrigation. Thus, cyclic microirrigation may need to be stopped before the first freeze to promote cold hardiness.

In summary, cyclic microirrigation increased growth rates in red maple, winged elm, live oak and crape myrtle; but not in azaleas or elaeagnus. Increased growth rate is proposed due to prevention or reduction of container moisture stress which limits growth. For trees, this limitation occurs much faster than for shrubs, due to more rapid increases in shoot size and root system development. For shrubs, container moisture limitations were not evident after 9 months. Container media with less water holding capacities then used here may develop growth-limiting container moisture levels earlier than found here, and should benefit more from cyclic microirrigation than reported.

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Effect of Drought and Phenological Stage at Transplanting on Root Hydraulic Conductivity, Growth Indices, and Photosynthesis of Turkish Hazelnut[1]

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Abstract

A single drought episode was applied to two groups of container-grown *Corylus colurna* L. (Turkish hazelnut) seedlings which had concomitantly reached distinct phenological stages; 1) buds opening and no new root growth visible and 2) shoot extension well underway and new root growth just beginning. Two days after rewetting, root hydraulic conductivity was lower for plants exposed to drought, but there was no phenological stage effect. No differences in root hydraulic conductivity were apparent among well-watered plants of stage 1, 2 and a third stage, 3) shoot extension complete (buds set) and root growth well underway. Twenty five days after return to daily irrigation, those plants subjected to the drying treatment had smaller diameter trunks, but total plant height and dry weight of root-balls were similar. No differences in photosynthetic rate or stomatal conductance were evident 25 days after transplanting.

Index words: *Corylus colurna* L., transplant shock, plant establishment.

Significance to the Nursery Industry

Since container-grown plants are by necessity grown in well-drained media, root-balls are susceptible to rapid drying unless frequent, often daily, irrigation is applied. Perhaps the most drought vulnerable stage in the transplanting process is after plants are delivered to the landscape job, but before the actual planting occurs. Unless these plants are quickly planted, exposure to increased heat loads and wind can create high evaporative conditions, and root-balls can quickly desiccate. In addition, plants are often delivered to the site dry, and irrigation is usually unavailable until after they are planted.

The results of this experiment indicate that a single severe drying episode at transplanting will result in plants with a decreased conductance of water through root systems and smaller stem diameters. It is therefore important that pro-

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