Irrigation Time of Day — Does It Really Matter?©

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Pine-bark-based container substrates, common in the southeastern United States, 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 this study was to evaluate the effects of irrigation timing on plant growth and photosynthesis, water-use efficiency, and substrate temperature. The daily total volume of irrigation to maintain 0.2 leaching fraction 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; or 0600, 1200, and 1800 HR. Irrigation applied at 1200, 1500, and 1800 HR produced 69% greater total plant dry weight compared to irrigation applied following current guidelines (early morning). Root:top ratio was unaffected by irrigation timing. Irrigation applied at 1200, 1500, and 1800 HR had higher water-use efficiency compared to irrigation applied at 0300, 0500, and 0700 HR; and 0600, 0900, and 1200 HR. Plants irrigated at 1200, 1500, and 1800 HR maintained higher rates of net CO_2 assimilation and had lower substrate temperatures from 1800 to 2200 HR compared to plants irrigated at 0300, 0500, and 0700 HR; or 0600, 0900, and 1200 HR.

INTRODUCTION

To produce a high quality plant requires proper irrigation management. Pine-bark-based container substrates, common in the southeastern United States, have low moisture retention properties; therefore, daily irrigation during the growing season is required to maximize plant growth. However, concerns with water use have forced many nurseries to search for "best management practices" (BMPs) to improve water-use efficiency. Current BMPs 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 (Yeager et al., 1997). A recent survey of Alabama nurseries reported that more than 60% of the nurseries were following these recommendations (Fain et al., 2000). However, limited previous research indicated that multiple application of water each day resulted in more growth compared to early morning application. Keever and Cobb (1984) reported irrigation during the day (1300 HR or split application at 1000 and 1500 HR) reduced substrate and canopy temperature, which increased top and root growth of *Rhododendron* 'Hershey Red' compared to irrigation at 2000 HR. Beeson (1992) working with four woody ornamentals also reported increased growth when irrigation was applied during the day in contrast to predawn (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. No studies have reported if irrigation timing affects water usage and water-use efficiency. Therefore, our objectives were to evaluate the effects of irrigation timing on plant growth and photosynthesis, water-use efficiency, and substrate temperature.

MATERIALS AND METHODS

The study was a randomized complete block design with four replications. Rooted cuttings of *Cotoneaster ×suecicus* 'Skogholm' (syn. *C. dammeri* 'Skogholm') were potted into 1-gal containers in a pine bark and sand (8 : 1, v:v) substrate amended with 1.2 $kg \cdot m^{-3}$ (2 lb per yd^3) dolomitic limestone. Each plant was fertilized at potting with 5.0 g N (0.18 oz) from 17N-5P_2O_5-10K_2O (5-6 month, Pursell Technology, Sylacauga, Alabama).

The daily total volume of irrigation to maintain a 0.2 ±0.05 leaching fraction (LF) within each treatment was divided into three equal parts and applied at the following times:

A. 0200, 0400, and 0600 HR (predawn)
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. Irrigation was applied via pressure compensated spray stakes {Acu-Spray Stick; Wade Mfg. Co., Fresno, CA [200 ml per min (0.3 inches per min)]}.

Substrate temperatures were measured in two locations in one container in every replication (total of 8 thermocouples/treatment) for the entire study. One copper-constantan thermocouple was positioned in the substrate halfway down the container profile on the southern exposure, 1 inch from the container wall; the other thermocouple was positioned in the substrate halfway down the container profile on the northern exposure, 1 inch from the container wall. The thermocouples were connected to a 23X micrologger via a AM-32 multiplexer (Campbell Scientific, Logan, Utah). Temperature data were recorded every 5 min and averaged over each 60-minute interval. Maximum, minimum, and average temperature along with time of maximum, and time of minimum were recorded every 60 minutes.

At harvest, tops (aerial tissue) from five randomly chosen containers per plot (total of 20 containers per treatment) were removed. Roots were placed over a screen and washed with a high pressure water stream to remove substrate. Shoots and roots were dried at 65.6°C (150°F) for 5 days and weighed. Diurnal measurements of net CO_2 assimilation were made on 20 July and 17 Aug. 2000 on one plant from each replication (4 plants per treatment), using a portable photosynthesis system containing a LI-6200 computer and LI-6250 gas analyzer (LI-COR, Lincoln, Nebraska). A diurnal measurement event consisted of measurements during late morning from 1030 to 1130 HR, at midday from 1300 to 1400 HR and late afternoon from 1600 to 1700 HR.

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

RESULTS AND DISCUSSION

Leaching Fraction and Dry Weight. A total of 18.7, 26.4, 27.5, and 26.4 liters of irrigation water applied at predawn, AM, PM, and all day applications, respectively, resulted in leachate fractions (LFs) of 0.19, 0.15, 0.13, and 0.13, for predawn, AM, PM, and all day, respectively. Plants irrigated at PM had significantly greater top dry weight compared to all other irrigation periods (predawn, AM, and all day) (Table 1). Top dry mass was 71% greater when irrigated at PM (1200, 1300, and 1600 HR) compared to predawn. Root dry mass increased 62% when irrigated with PM compared to predawn. Plants irrigated at midday, PM, and all day irrigation had similar root dry mass. Root : top ratio was unaffected by irrigation timing illustrating that top and root dry mass responded similarly to irrigation timing. These data combined with results from Keever and Cobb (1984) and Beeson (1992) support the hypothesis that plant growth can be increased significantly if irrigation is applied in the PM. In general, plants irrigated during the PM produced the best results which is in contrast to the current recommendation of irrigating in the early morning hours. This study suggests that if presumably sufficient daily irrigation is restricted to early morning hours, growth will be significantly reduced compared to plants grown with irrigation applied during the day.

Water-Use Efficiency. Irrigation applied during the PM had higher water use efficiency requiring 0.3 liters$\cdot g^{-1}$ of plant dry mass compared to 0.4 liters g^{-1} of plant dry mass for predawn irrigation (data not presented). This is an increase of 33%. Even though it required more water to maintain the LF for the PM and midday irrigation compared to predawn — PM and midday produced more plant dry mass with less water.

Photosynthesis and Stomatal Conductance. Results from 20 July and 17 Aug. were similar, so only data from 17 Aug. are presented. At 1100 HR, plants irrigated during the PM and all day had 48% higher rates of photosynthesis compared to

Table 1. Effect of irrigation timing on dry weight and root: top ratio of *Cotoneaster* ×*suecicus* 'Skogholm'.

Irrigation timing	Dry mass (g) Top	Root	Root : top^{z}
Predawn	60.7 d^{y}	12.8 b	0.21 a
AM	80.3 c	18.0 a	0.22 a
PM	103.5 a	20.7 a	0.20 a
All day	91.0 b	19.7 a	0.22 a

^{z}Root : top = root dry mass ÷ top dry mass.

^{y}Means within columns followed by the same letter or letters are not significantly different as determined by LSD, P = 0.05.

predawn and AM cycles (Table 2). Compared to 1100 HR measurements, photosynthesis of all treatments decreased at 1330 HR. This is probably due to increased canopy and substrate temperature. Martin et al. (1991) working with containerized *Magnolia grandiflora* 'Saint Mary' in Florida reported a similar decline in midday photosynthetic levels attributing the decline to increasing container and air temperature. Only plants irrigated all day had significantly greater photosynthesis than predawn 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 for PM irrigation (1200 HR). Thus, plants irrigated PM may have had reduced photosynthesis due to limited water availability. At 1630 HR, photosynthetic levels of plants irrigated predawn, AM, and all day decreased compared to 1330 HR suggesting increasing water and temperature stress. However, plants irrigated with PM had increased photosynthetic measurements compared to 1330 measurements. At 1630 HR, plants irrigated with PM had 86% higher rates of photosynthesis compared to predawn and AM. Both AM and all day cycles had water applied at 1200 HR but this does not appear to be sufficient to maintain photosynthetic levels through 1630 HR. Plants irrigated during the PM received additional water at 1500 HR which appeared to maintain photosynthetic levels. Beeson (1992) reported the greatest differences in shoot water potential between plants irrigated predawn and plants irrigated throughout the day occurred in mid- to late afternoon. Generally by 1300 HR plants irrigated predawn had lower water potential with the difference becoming more pronounced by 1600 HR.

Substrate Temperature. Containers irrigated with predawn and AM treatments had similar temperature profiles (data not presented). The time of daily maximum for containers irrigated predawn occurred at 1630 HR [43.9°C (111°F)]. Time of daily maximum and maximum temperature for containers irrigated PM and all day were similar {1530 HR, [40°C (104°F)}. Martin et al. (1991) working with a pine bark, peat, and sand substrate (3: 1 : 1, by volume) in Florida reported maximum container temperatures of 45°C (113°F) from 1715 to 1745 HR. Containers irrigated predawn had significantly lower temperatures at 0600, 0700, and 0800 HR compared to the PM cycle, however, differences were very small. Containers irrigated during the PM and all day cycles had significantly lower temperatures from 1800 to 2200 HR

Table 2. Effect of irrigation timing on net CO_2 assimilation (umol CO_2 $m^{-2} \cdot s^{-1}$) of *Cotoneaster* ×*suecicus* 'Skogholm'.

Irrigation timing	Time 1100	1330	1630
Predawn	5.9 b[z]	5.4 b	4.0 c
AM	5.5 b	4.6 b	4.2 bc
PM	8.7 a	6.5 ab	7.6 a
All day	8.4 a	7.5 a	6.0 ab

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

compared to predawn for most days. Compared to predawn, daily maximum temperatures for the PM cycle were usually significantly lower by 2 to 3°C (3 to 5°F). This difference in temperature in combination with available water could have a significant impact on photosynthesis (Ruter and Ingram, 1990). Martin et al. (1991) reported a 50% increase in caliper growth of *Magnolia grandiflora* 'Saint. Mary' when maximum temperature was reduced by 3°C (5°F) [47.8 to 45°C (118 to 113°F).

Plants that were irrigated during the PM cycle significantly outperformed plants grown with current irrigation timing guidelines. This strongly suggests that further investigations with irrigation timing with other nursery crops in other environments should be conducted.

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