scapes that do not require use of pesticides. They expressed interest in disease- and insect-resistant plants.

Smaller areas to landscape was listed as a trend by relatively few firms but was listed as their number 1 concern by all firms listing this trend. In conjunction with smaller areas they expect taller buildings which creates a need for plants with columnar habit.

The ''environmental movement" trend was identified by approximately 56% of the respondents as a third choice in importance. The most frequently listed comment for this trend was increased use of native plants. Other comments included wildlife habitat landscaping and more wetland plants.

Several landscape architects identified a trend toward the use of more trees in the landscape and in city planning, citing city ordinances requiring replanting of trees or use of more trees in parking lots. They also predicted use of larger caliper trees. All firms that listed this trend identified it as a prime concern.

This study demonstrates that trees are approximately 50% of the value of all plants specified by landscape architects. The predicted trends provide guidelines for advertising and marketing communications directed to landscape architects. Plant catalogs and plant availability listings could include plants organized by these trends. This format would simplify plant selection by landscape architects. Marketing communications could highlight how specific plants accommodate one or more landscape trends.

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A Model for Irrigation Scheduling in Container-Grown Nursery Crops Utilizing Management Allowed Deficit (MAD)[1]

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Abstract

Plant growth and water use of container-grown *Photinia ×fraseri* (Dress) were studied under varying irrigation regimes. Treatments were based on management allowed deficit (MAD) irrigation (including 0, 5, 10, 25, 50, 75 and 95% MAD), which links evapotranspiration (ET) and plant available moisture in determining irrigation schedules. Plant growth was maximized under 25% MAD irrigation. Plant performance and water use were significantly reduced as moisture deficit levels in the growing medium exceeded 50% under MAD irrigation of 50%, 75% and 95%. Plant performance also tended to decrease, but plant water use increased with lower MAD treatments (i.e., 0%, 5%, 10%). The research reported provides a model for nursery managers and researchers to use MAD irrigation in determining optimum irrigation regimes to meet plant water needs and maintain maximum plant performance.

Index words: Irrigation scheduling, nursery production, *Photinia ×fraseri*, plant water use, media air-filled porosity.

Significance to the Nursery Industry

The research reported here provides a model for nursery managers and researchers to use management allowed deficit (MAD) irrigation in determining optimum plant water needs and maintaining maximum plant performance based on the dynamics of evapotranspiration (ET) and growing medium characteristics. The experiment required only 28 days for significant differences to appear. Plant growth was maximized under 25% MAD irrigation. Plant performance tended to decrease when growing medium exceeded MAD treatments of 50% and when MAD treatments decreased below 10%. The model represents a quick, low-technology, but highly valuable method of irrigation scheduling. By scheduling irrigation with the MAD concept, the nursery

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manager can optimize irrigation water use for increased plant quality and reduced costs, plus decrease risk of contaminating effluent runoff.

Introduction

Water is a limiting factor in agriculture (9) and the challenge for irrigated agriculture is to achieve maximum crop yield with a minimum of irrigation water (10). The commercial nursery industry represents an increasing segment of irrigated agriculture.

Irrigation in commercial nurseries is commonly applied at fixed frequencies and amounts. Changes in irrigation schedules are made predominantly by intuitive management decisions with regard to plant water needs. Few nurseries monitor evapotranspiration (ET) or moisture levels of the growing medium in order to more closely meet plant water requirements and increase irrigation efficiency. As a result, excess irrigation is applied and nurseries have experienced four problems: 1) higher irrigation costs, 2) increased capital investments for developing larger water supplies, 3) chemical contamination of streams and groundwater from irrigation run-off containing fertilizer and pesticides, and 4) reduced plant quality and/or plant growth. To optimize water use, irrigation management decisions should be based on actual crop water requirements, which are directly affected by ET demands and moisture-holding characteristics of the growing medium.

To date, irrigation research for container nursery crops has centered around identification of maximum water-use rates of species and determination of ET crop coefficients using actual and potential ET rates (1, 3, 5, 6). No research has been conducted on the optimization of water use by container-grown ornamentals using the concept of management allowed deficit (MAD) irrigation. This approach links ET and plant available moisture (PAM) in determining irrigation schedules and is a common practice in agronomic crop production (8).

MAD is the soil moisture deficit at the time of irrigation, expressed as a percentage of PAM in the root zone. Ideally, each crop would have a prescribed MAD that produces the best economic balance between crop returns and cost of irrigation (8). Irrigation scheduling based on the MAD concept allows the moisture level of the medium to be depleted until a predetermined percentage of PAM is obtained. The accumulating amount of ET is subtracted from the known PAM reservoir in the growing medium. Upon reaching the percent deficit desired, irrigation occurs at an amount adequate to return the PAM content of the growing medium back to full capacity (i.e., field capacity, container capacity). For example, crops grown at 10% MAD would receive irrigation when the PAM deficit level reaches 10% (or 90% of the PAM is remaining) and the irrigation amount would be equal to the deficit.

The optimum MAD level employed depends on the specific soil, crop, depth of root zone, climate and irrigation system. Soil type and root-zone size determine the volume of PAM; climate determines the evaporative demands on the crop; and the irrigation system utilized may limit the MAD levels through restricted application rates. Crop species also dictate MAD levels since some species tolerate less moisture deficit than others.

The research reported here investigated the effect of various levels of MAD irrigation on plant growth of *Photinia* × *fraseri*, thus determining the optimum level of MAD irrigation for this crop. The test crop, *Photinia* × *fraseri*, was chosen because it is a standard crop grown by many southern nurseries. This research can serve as a model for determining optimum MAD levels for other container-grown nursery crops.

Materials and Methods

Cultural Conditions. Rooted cuttings of *Photinia* × *fraseri* (4), averaging approximately 20 cm in length, were planted (one per container) into 3.8 l plastic containers containing 2294 cm^3 of a soilless medium consisting of 1:1:2 (by volume) vermiculite:peat:bark mix (Metro-mix 500, W.R. Grace Co., Cambridge, MA). Plants were grown for 30 days before treatment initiation so that the root system would permeate the entire growing medium. The experiment was conducted in a greenhouse on the campus of Texas A&M University in College Station, Texas, with average greenhouse temperatures of 30°C (86°F) day and 21°C (70°F) night.

Irrigation treatments included MAD levels of 0, 5, 10, 25, 50, 75 or 95%. The 0% MAD level was maintained by providing an unlimited, constant moisture supply to the container through subirrigation, therefore maintaining container capacity in the growing medium. Corresponding irrigation amounts for each MAD treatment are shown in Table 1. The experiment was terminated after 28 days (May 15 to June 9, 1989) when significant differences in plant performance were observed.

A 2294 cm^3 (140 in^3) volume of medium was placed in each container using a standardized procedure which resulted in a uniform bulk density of 0.21 g cm^{-3} (0.12 oz in^{-3}) throughout all containers. Container capacity, as described by White (11), was determined for this volume, and bulk density of the medium was determined using techniques established by Fonteno *et al.* (7). Five containers filled with 2294 cm^3 (140 in^3) of medium were wetted from the bottom for 24 hours to allow maximum water absorption. The top of the water reservoir was maintained at the same level as the medium in each container. The containers were removed from the water reservoir and allowed to drain freely for 12

Table 1. Treatments of management allowed deficit (MAD) irrigation, and corresponding growing medium characteristics of moisture deficit before irrigation, air-filled porosity, water-filled porosity and approximate water potential for a 3.8 liter container filled with a soilless growing medium.[z]

MAD irrigation treatment (%)	Moisture deficit before irrigation (ml)[y]	Air-filled porosity (% by vol)	Water-filled porosity (% by vol)	Approximate water potential (kPa)[x]
0	0	11.3	61.2	–11
5	47	13.3	59.2	> – 33
10	133	17.1	55.4	> – 33
25	285	23.7	48.8	> – 33
50	534	34.6	37.9	> – 33
75	800	46.2	26.3	– 33
95	1006	55.2	17.3	– 1200

[z]Metro-mix 500 is a mix with a 1:1:2 (by vol) of vermiculite, peat and bark.

[y]Moisture deficit before irrigation is equivalent to the amount of irrigation for each MAD treatment.

[x]Values represent the approximate water potential of the medium for the entire root zone at the time of irrigation.

hours into a beaker for measurement (note: evaporation from the medium surface was prevented). The drained growing medium was weighed in grams, then oven-dried and weighed. The difference in weight between the drained medium and the oven-dried is the amount of water (in grams) held by the medium at container capacity. Since one gram of water is equal to one milliliter or one cubic centimeter, the average container capacity was 1403 ml (42 oz) (61.2% by volume water-filled porosity) of water. The volume of water that drained freely from the wetted medium was divided by the total growing medium volume (2294 cm^3, 140 in^3), thus yielding an air-filled porosity of the medium at container capacity of 11.3% by volume. The total porosity (air-filled porosity plus water-filled porosity) was 72.5% by volume. Water content at permanent wilting point (−1500 kPa) for Metro-Mix 500 was 326 ml (14.2% by volume) per container, as determined using pressure plate techniques described by Fonteno *et al.* (7). Therefore, plant available moisture (moisture at container capacity minus that at wilting point) was estimated at 1047 ml (31 oz) (47% by volume) per container.

During the experiment, irrigation schedules and actual water use (ET) for each plant was determined gravimetrically, twice daily (2). With one gram of water equal to one milliliter of water, weight loss is equivalent to water use (note: the changes in dry weight of the plants was considered negligible). When the water loss (ET) from a plant equalled the moisture deficit in the medium as prescribed by the MAD treatment, then the plant was irrigated. Upon each irrigation, medium moisture levels were returned to container capacity. Water used was replaced by hand irrigation using reverse osmosis-treated water.

Saucers placed at the bottom of containers were used to collect and return any drainage back to the container. Slow-release fertilizer including minor nutrients (17-6-12, Sierra Chemical Co., Milpitas, CA) was incorporated in the medium at the beginning of the experiment at the rate of 0.75 kg m^{-3} (2 lb yd^{-3}).

Plant Growth Measurements. Shoot extension and number of new leaves were determined weekly. These two growth parameters are significant indicators for nursery production systems and are easily obtainable by nursery managers and researchers.

Statistics. A completely randomized block design was utilized, with five replications of each treatment. Regression analysis was used to relate plant growth to MAD irrigation levels.

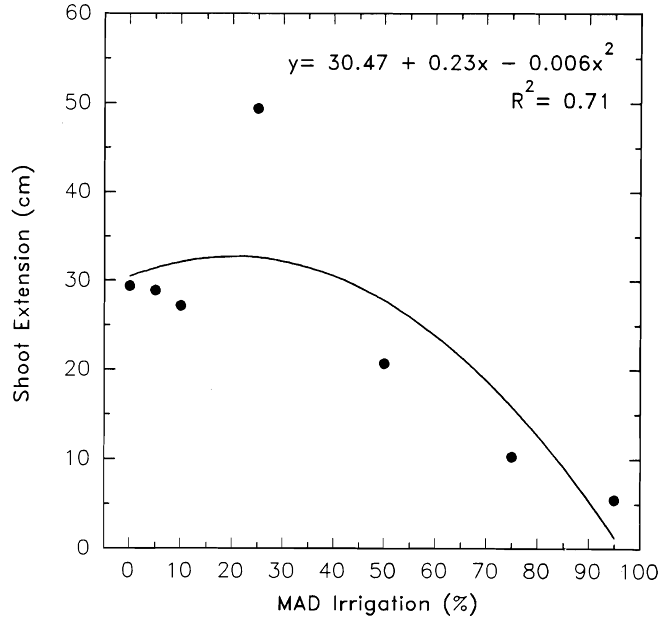

Fig. 1. **Shoot extension in *Photinia* × *fraseri* at various levels of management allowed deficit (MAD) irrigation. Each data point is the mean of shoot extension for 5 plants.**

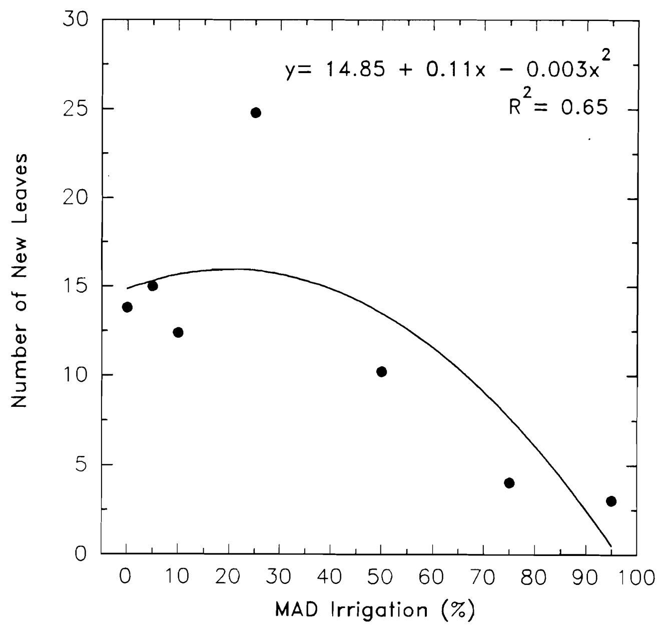

Fig. 2. **Number of new leaves in *Photinia* × *fraseri* at various levels of management allowed deficit (MAD) irrigation. Each data point represents the mean number of new leaves for 5 plants.**

Results and Discussion

Plant Growth. Significant relationships between MAD irrigation levels and growth measurements were evident. Shoot extension and number of new leaves were regressed against MAD irrigation levels and resulted in quadratic functions and R^2's of 0.71 and 0.65, respectively (Figures 1 and 2). The maximum growth measurements correlated with a 25% MAD irrigation level.

Plant Water Use. Cumulative water-use data indicated a significant difference between MAD treatments (Table 2). No differences were seen between plants of the 5%, 10% and 25% MAD treatments; however, the higher MAD treatments were significantly different from other treatments. The interval between irrigations showed significant differences, ranging in interval from nearly twice daily to every 18 days.

This research determined the optimum MAD irrigation level to be 25% for *Photinia* × *fraseri* grown under these conditions. Plant performance deteriorated significantly at MAD levels of 50% and higher.

The data also indicated that using 25% MAD irrigation levels, the plants were irrigated on average every 2.87 days (Table 2). This contrasts to the daily irrigations at the 10%

Table 2. **Effect of management allowed deficit (MAD) irrigation on cumulative water use (evapotranspiration) and interval between irrigations in *Photinia × fraseri*.**[z]

MAD irrigation treatment(%)	Cumulative water use(ml)	Interval between irrigations (day)
5	3141 a[y]	0.60 a
10	3256 a	1.06 a
25	3105 a	2.87 b
50	2635 b	6.72 c
75	2112 c	14.00 d
95	1622 d	18.00 e

[z]Values could not be obtained from 0% MAD treatment.

[y]Means within columns followed by the same letter are not significantly different as determined by Duncan's multiple range test, $P = 0.05$.

MAD level and nearly twice daily for the 5% MAD level. The superior plants under the 25% MAD level were therefore irrigated as much as 5 times less often during the study. For the nursery manager and researcher who manually irrigate a crop, these results have significant implications for labor savings. For the automated irrigation system user, perhaps the major benefits for reducing the number of irrigation events may be reducing disease, prolonging the life or irrigation equipment, reducing the chances of stream and groundwater contamination by runoff, and/or reducing the length of crop production time.

Water-use data for plants under 5%, 10% and 25% MAD irrigation was not significantly different. Relative to 25% MAD, high water use of 5% and 10% MAD plants may not be due to increased growth and transpiration, but perhaps to increased evaporation of moisture from the surface of the growing medium. Higher irrigation frequencies at 5% MAD may have maintained higher moisture levels at the medium surface which enhanced evaporation. Less frequent irrigation of higher MAD treatments may have allowed the surface to dry and form a barrier against evaporation.

It is suspected that the 25% MAD irrigation level resulted in maximum plant growth in this experiment (Table 2) due to the optimization of both air-filled porosity and water potential of the medium at the 25% MAD level. At the lower MAD levels (i.e., 0%, 5%, 10%), low air-filled porosity and poor aeration could have adversely affected plant growth. And at higher MAD levels, low water potentials in the medium perhaps limited plant growth.

Although this study does not address which MAD level produces the optimum economic balance between crop returns and irrigation costs, Table 2 signals a trend for future research, suggesting that 25% MAD may increase irrigation efficiency and economic returns.

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