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Evaluation of a Model Based on Reference Crop Evapotranspiration (ET_o) for Precision Irrigation Using Overhead Sprinklers during Nursery Production of *Ligustrum japonica*

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Abstract

A model for automated precision irrigation of *Ligustrum japonica* developed from lysimeter data collected in 2001-2002 was used to produce market size plants in 11.4 L black polyethylene containers. The model calculated daily irrigation rates based on the previous day ET_o and a water needs index (WNI – a crop coefficient-like value derived from percent canopy closure). Percent canopy closure was calculated by squaring average canopy width and dividing by allocated plant area then multiplying by 100. Average canopy width was determined manually and input every 3 weeks during production. Plant allocated area was increased once. ET_o was calculated using instrumentation of a standard weather station connected to the irrigation controlling data logger. Plant growth and irrigation applications were compared to those of plants whose irrigation frequency and volume were adjusted manually to approximate 1800 mm of overhead irrigation annually. Each irrigation regime was replicated 4 times. ET_o controlled irrigation produced the same marketable size plants as the manual regime, but 3 weeks faster, with 400 mm less irrigation. The model functioned well without modification during the winter quiescent period and sequential spring growth flush.

time
data

INTRODUCTION

The majority of container-grown woody ornamentals produced in the United States, both in terms of number and economic value, are in 3.5 to 27.0 L containers. Most of these containers have relatively small diameters, usually with a height:width ratio of 1:1. Although small diameters permit a greater density of plants when containers are abutting each other, most woody ornamentals eventually require substantial space between containers to allow for development of shoot quality. Quality has a larger influence on woody ornamental sales than plant size, especially in the landscape trade. As spacing increases linearly, percentage of overhead irrigation reaching a container surface declines exponentially, resulting in substantial irrigation waste at modest distances between containers (Beeson and Knox, 1990). Excessive overhead irrigation compounds this waste, since only 35% of overhead irrigated water falls into a container at a common spacing of half a container diameter.

With small substrate volumes relative to shoot size, container production of woody ornamentals requires frequent and abundant irrigation. In Florida, amounts of up to 2900 mm per year were common in the mid-1970's, in addition to an annual mean rainfall of 1100 mm (Harrison, 1976). In 1992, maximum allowed rates of 2300 mm of supplemental irrigation were imposed by Florida's Water Management Districts. In 2003, this maximum was reduced to 1800 mm for nurseries in areas with high competition for potable water from expanding urban centers. With further restrictions probable, nurseries must become much more precise in their irrigation application to remain in their current profitable locations.

In Florida, overhead irrigation at container nurseries has been restricted during most of the daylight hours since the early 1990's. To cope with this imposition, along with increased nursery size and decreasing labor pools, irrigation almost exclusively occurs at night and is controlled by irrigation time clock systems. Most irrigation managers are only marginally aware of day-to-day changes in reference crop evapotranspiration (ET_o) and corresponding changes in actual evapotranspiration (ET_A), resulting in poor management of irrigation, especially on a day to day basis. Since much nursery irrigation is already centrally controlled using electric valves, implementation of a model relating daily climatic conditions to container irrigation needs could improve plant growth and conserve water.

Attempts to develop such an irrigation model have been limited. In the late 1980's, Knox (1989) reported relatively high correlations between pan evaporation, a growth index and ET_A for 5 woody ornamentals during a year's production cycle. However, a working model was not reported. Fitzpatrick (1983a,b) reported water consumption for several tropical ornamentals along with monthly potential evapotranspiration (ET_P) derived from the Thornthwaite equation. Successful irrigation was based on a previously developed model (Fitzpatrick, 1980), but was dependent on a specific growth rate and monthly estimates of ET_P.

Two groups have used the Penman-Monteith equation to make daily calculations of ET_o and calculated corresponding crop coefficients (k_c). Burger et al. (1987) at UC Davis used container surface area to normalize ET_A for 22 woody ornamental species growing in 3.8 L containers. At marketable size, k_c ranged from 1.1 to 5.1, depending on species and container spacing. The high k_c values, relative to agronomic crops, were justified by large canopy to container surface area ratios (Burger et al., 1987). Differences in k_c values between diverse locations were minimum. Later, Schuch and Burger (1997) reported k_c values, averaged over 20 months, ranged from 1.0 to 2.5 for woody ornamentals grown in 15.6 L containers. In Florida, Beeson (1993) reported moderate correlations of ET_o and ET_A for 'Formosa' azaleas in 11.4 L containers. While no model was presented, a k_c of 0.31 was derived based on projected canopy surface area. Later, Beeson (1996) reported linear models of ET_o and ET_A normalized on fixed container surface area and projected canopy area basis. Correlations ranging from 0.533 to 0.695 were modest for the well-watered treatments when normalized by projected canopy area. Correlations were also significant ($P<0.05$), but much lower when normalized by container surface area ($r^2<0.30$). Crop coefficients for *Ligustrum japonica* ranged from 1.28 to 6.12, when based on container surface area; and 0.5 to 0.63 when based on canopy area. More recently, Beeson (2004) presented a model based on ET_o and a water needs index (WNI) derived from percent canopy closure. WNI was created for use in nursery crops to relate ET_A to ET_o where large swaths of homogeneous canopies are not found. WNI serves the same function as a k_c, being the ratio of ET_A:ET_o, but without the requirement of a large homogenous canopy.

The objectives of the experiment presented here were to evaluate the proposed irrigation model presented by Beeson (2004) for functionality, irrigation water conservation and plant growth. For comparison, a conservative, manually adjusted irrigation regime was included with a goal of limiting annual irrigation to 1800 mm.

MATERIALS AND METHODS

From 10 to 15 March 2005, 800 rooted cuttings of *Ligustrum japonica* were transplanted into 11.4 L black polyethylene containers at the University of Florida's Mid-Florida Research and Education Center, Apopka, Florida, USA (28.7° N 81.5° W), located near the center of the Florida peninsula. Substrate consisted of a blend of 64% composted pine bark (screened to < 25 mm), 27% Florida sedge peat and 9% coarse sand, amended with 2.3 kg m^{-3} dolomite limestone and 0.88 kg m^{-3} micronutrients. Containers were equally and randomly placed on eight independently irrigated and metered pads within a production area. Each pad was square, 7.7 m to a side, with two 1.5 m tall risers with a partial circle impact sprinkler (25BPJ, Rain Bird Corp., Glendora, CA, USA) located in opposite corners. Prior to placement of plants, Christiansen Coefficients of Uniformity (Haman et al., 1997) were determined for a rectangle area 4.6 x 6.2 m in the center of each pad. Sprinklers were adjusted until a minimum uniformity of 0.85 was achieved. Concurrently, percentage of metered irrigation falling within each rectangle area was determined along with application rate. Containers were initially arranged in 2 columns of 10 rows long and 5 containers per row set with containers abutting each other. In March 2006, containers were spaced one-half container diameter apart (15 cm). After initial transplanting, 10 plants were selected for measurement and scattered uniformly within each pad. On 16 March around 62 g of a 9 month controlled released fertilizer (18-6-12 Polyon, Harrell's Fertilizer, Lakeland, FL. USA) was applied to each container and all were treated with pre-emergence herbicide (Ornamental Herbicide II, Scotts. Co. Marysville, OH, USA). On 1and 22 April, each container was given around 150 ml of a 21.4 μmol N solution of liquid fertilizer (Peters 20-20-20, Scotts Co.).

For the first 3 weeks after transplanting, all pad areas were irrigated 6.2 mm daily. Beginning the fourth week, two methods of irrigation control were implemented. Pads were blocked spatially into 4 groups, with each method randomly assigned to a pad within each block. The control method depended on manual input of irrigation rates and frequencies. Decisions were based on general trends in ET_A observed during data collection for *L. japonica* during the 2001-02 production period and a goal to limit irrigation to 1800 mm annually. Manual changes, when considered necessary, were usually made once every 3 weeks.

The second method was based on ET_o and percent canopy closure (Beeson, 2004). ET_o was calculated daily by a CR10X data logger (Campbell Scientific, Logan, UT, USA) using a program supplied in Campbell's Application Note 4D. This program calculates ET_o on an hourly basis using the ASCE Penman-Monteith equation with resistances (Allen et al., 1989). Input for ET_o calculations were measured with a pyranometer (Li-190, Li-Cor Inc., Lincoln, Neb. USA), anemometer (014, Met-One Instruments, Medford, Ore., USA), and temperature/humidity sensor (HMP45C-L, Campbell Scientific). Rainfall was recorded with a tipping bucket rain gauge (TE525, Texas Instruments, Dallas, TX, USA). Each midnight, the data logger calculated daily ET_o. An algorithm, developed from data collected from *L. japonica* in 2001-2002 (Beeson, 2004), was used to calculate a water needs index (WNI) for each pad based on percent canopy closure. Percent canopy closure was calculated by the data logger by squaring the mean canopy width of 10 plants per pad (greatest width plus width perpendicular to the greatest width divided by two; mean projected canopy area, mm^2), then dividing by the square of the distance on center between plants (plant space allocation, mm^2) and multiplying by 100. As plant grew beyond their allocated space, percent canopy closure increased to over 300% as they neared marketable size (Beeson, 2004). Nightly potential irrigation volume (mm^3) per plant per pad was calculated by multiplying the day's ET_o (mm) by the respective WNI and mean projected canopy area (mm^2). This volume was then divided by the upper surface area of a root ball (mm^2) since only irrigation falling within the cylinder of the container diameter would be available to a plant (Beeson, 2004). Rainfall (mm) occurring since the previous midnight was subtracted from the calculated potential irrigation (mm). Rainfall in excess of potential irrigation was discarded. Similar subtraction of rainfall occurred for the manual based irrigation regime. Irrigation calculated at less than 6.2 mm, due to small plants or less than required rainfall, was stored until cumulative total at midnight exceeded 6.2 mm. Potential irrigation was calculated independently for each pad and each pad was irrigated only as needed. For the first 37 weeks after transplanting (WAT), final calculated irrigation applied was multiplied by 1.0. For the remainder of the experiment, this factor was increased to 1.2 when most canopies extended beyond the width of a container to partially offset canopy shedding of overhead irrigation (Beeson and Yeager, 2003).

Canopies of selected plants were measured for widest width and width perpendicular to it and average canopy height about every 3 weeks. Growth indices (GI) were calculated for each plant using these measurements, assuming canopy volume could be estimated as a rectangle box. Mean canopy width was input into the program for each pad area after each canopy measurement.

Treatments were terminated when ~90% of the 40 measured plants per irrigation regime had obtained marketable size based on the Florida fancy grade (highest), as defined by Florida Grades and Standard (DACS, 1995). For this size container, a plant had to achieve an average height of 0.5 m with an average width of at least 2/3 plant height. At termination, final canopy dimensions were recorded and shoots were severed at the crown and dried at 65°C until a constant mass was obtained.

Final growth data (GI, height, canopy width and shoot dry mass) were analyzed as a randomized complete block design using a one-way ANOVA, with two treatments of four blocks each with 10 plant replications per block. Total irrigation volumes were analyzed similarly using a one-way ANOVA with four replications. Growth variables and cumulative irrigation volumes were analyzed over time as repeated measures using a split plot design, with irrigation regime as the main plot and WAT as the sub-plot (Snecdor and Cochran, 1980). Where interaction of treatment and time was significant, treatment means were tested for difference by a t-test at $P < 0.05$. All statistical analysis was conducted using SAS (ver 9.1, SAS Institute, Cary, NC, USA).

RESULTS AND DISCUSSION

Termination and harvest of an irrigation regime was based on 90% of measured plants obtaining commercially marketable size based on established Florida Nursery Grades and Standards (DACS, 1995). Ninety percent was the minimum number of marketable plants expected from a crop. This required both treatments to achieve the same canopy size, and in terms of irrigation quantity penalizes treatments that produce quality plants but with reduced growth rates. The ET_0 controlled regime achieved 90% minimum marketable size plants first, and was harvested three weeks earlier than the manually controlled regime. At harvest, there were no differences ($P > 0.05$) in shoot height. However all other canopy variables measured; average canopy width, canopy spread (width x width), growth index and shoot dry mass were larger ($P < 0.05$) for the manually controlled regime than the ET_0 based regime (data not shown). There was also a substantial difference ($P < 0.001$) in cumulative irrigation applied. Mean cumulative irrigation applied to the ET_0-based regime was 1690 mm. This was below targeted 1800 mm annually even though production required 59 weeks. The manual based regime required a mean of 2100 mm over a 62 week period. Over the first 52 weeks, 1250 mm were applied to the manual based regime plants, well within the 1800 mm annually. Over the last 10 weeks, during March and April, 850 mm were applied as plants neared marketable size. During the latter 4 months of the production period, the region was under drought conditions, with a cumulative monthly rain deficit from January through the April of 190 mm. No rainfall occurred during March, when traditionally spring bud burst occurs with resulting shoot growth that pushes plants to marketable dimensions by the end of the month. Average rainfall for March and April is 134 mm (www.weatherreport.com, accessed 25 June 2006). The dearth of rain in March and April pushed irrigation quantities above what would likely have been required normally and probably accounts for much of the extended production period compared 2001-2002 (Beeson, 2004). Rain is also much more effective at penetrating shrub canopies than overhead irrigation (Beeson, unpublished. data).

Analyzing cumulative irrigation applied over time, differences ($P < 0.05$) occurred between irrigation regimes, but the interaction of WAT and treatment was of greater significance ($P < 0.0001$). Cumulative irrigation was similar between regimes for the first 15 WAT, thereafter the manual based regime received more irrigation than the ET_0 based regime through to final harvest (Fig. 1). Despite higher cumulative irrigation, there were never differences ($P > 0.05$) between irrigation regimes for any of the canopy variables, nor were the interactions of regime with WAT significant ($P > 0.05$) for canopy variables until compared at final harvest, which was separated by 3 weeks (Fig. 1). Even though less cumulative irrigation was applied by the ET_0 based regime, plant growth was not affected until final harvest. The extra 3 weeks required for the manual controlled regime to achieve 90% marketable size accounts for the larger canopies at harvest and 260 mm of the additional 410 mm of supplemental irrigation.

In respect to objectives, the ET_o based model was successful. It conserved water. This was partially due to reduced irrigation frequency when plants are young. Reduced frequency reduces evaporation from a substrate surface (Beeson, 2004) and promotes root growth deeper into a container substrate, where virgin water supplies of increasing quantity are available (Spoomer, 1974). Water conservation was also increased by accounting for effective rainfall. The ET_o based model produced market size plants faster than the conservative manual based system and maintained similar canopy size with lower cumulative irrigation. While it is tricky to compare directly across years, growth rates of the ET_o controlled regime were 9 weeks slower than *L. japonica* plants given more luxurious irrigation in 2001-2002. This 17% slower growth rate was likely due to the drought conditions or related effects, and doubtfully due to sub-optimum substrate moisture. Concurrent with this experiment was a comparable experiment where *L. japonica* were irrigated back to near container capacity nightly. Spring bud burst was also delayed in these plants in 2006 even though they received substantially more supplemental irrigation (Beeson, unpublished data). Irrigation control by the ET_o based model appears fully functional. It requires initial operator input of the distance between plants on center and whenever this changes. Otherwise irrigation managers are only required to input average canopy width on a tri-weekly basis. The model also functions well during periods of quiescence during winter months where irrigation is required and sub-freezing temperatures are infrequent. Unlike the model proposed by Schuch and Burger (1997), elaborate mathematical transformations are not required to account for multi-year production. Ongoing research is evaluating calculation of WNI based on canopy closure for other shrub species. Additionally the model used here and alterations are under evaluation for other shrub species.

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Figures

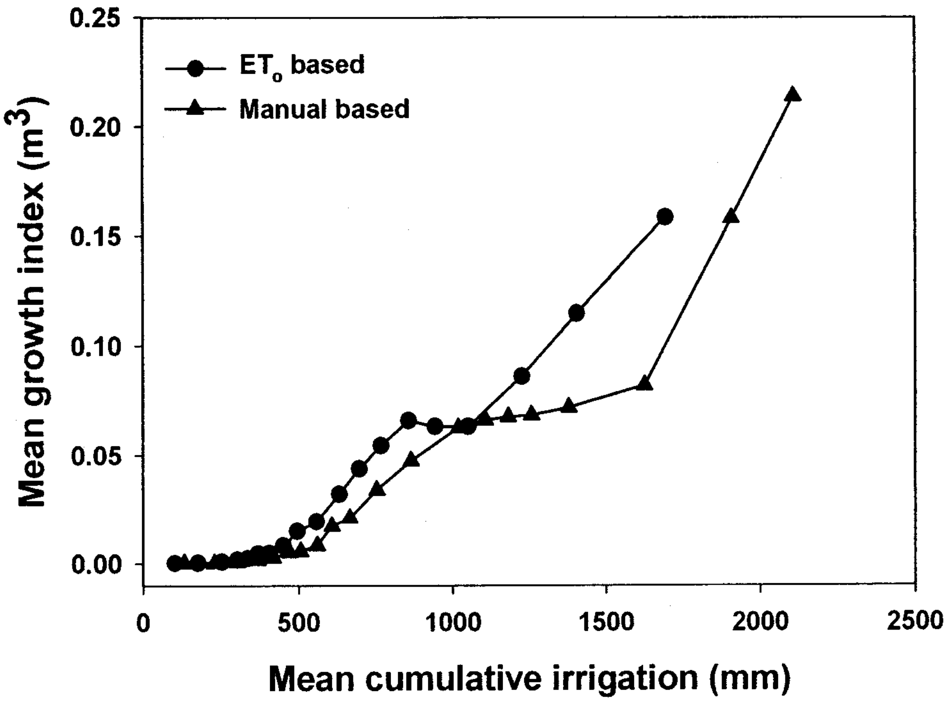

Fig. 1. Relationship of mean cumulative irrigation depth to mean growth index (canopy volume) for *Ligustrum japonica* irrigated by an ET_0 based control system or through manual irrigation control. Each point is the mean of 4 irrigation and 40 plant replicates.

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