Influence of Irrigation Regime on Water Stress and Growth of *Ligustrum japonicum* and *Myrica cerifera* During Establishment[1]

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Abstract

Native plants are often promoted for water conservation in urban landscapes. However, direct comparisons between native and introduced species utilizing physiological measures of plant water stress are unavailable to support or refute such recommendations. *Ligustrum japonicum* and *Myrica cerifera*, representing evergreen introduced and native species, respectively, were selected based on similar landscape function, non-stressed photosynthetic rates, and water use efficiencies. Both species were transplanted into a fine sand soil to evaluate establishment rates and growth characteristics under two irrigation regimes, irrigated either daily or every 3 d at 1.3 cm (0.5 in) of irrigation per event for the first 8 months after transplanting (MAT). Water potentials were recorded on two consecutive days each month, with cumulative stress intervals calculated. Water potential was significantly influenced by day of water stress level. On days without irrigation, water stress was generally greater and affected growth. Of the two species, *Myrica* irrigated daily had the greatest shoot growth, yet plants receiving irrigation every 3 d had the lowest root mass and biomass 8 MAT. In contrast, *Ligustrum* exhibited no differences in most parameters measured between irrigation regimes except for growth index. These contrasting differences stem from different strategies for coping with water stress.

Index words: landscape irrigation, landscape water management, plant establishment.

Species used in this study: southern waxmyrtle, *Myrica cerifera* L., syn. Morella cerifera (L.) small; Japanese privet, *Ligustrum japonicum* Thunb.

Significance to the Nursery Industry

Native landscape plant materials are often promoted to reduce landscape water consumption based upon perceived drought tolerance and water use efficiency. Comparisons between native and nonnative plant species are largely unavailable to support such recommendations. Results from our study suggest that landscape performance may be due to a plant's physiology and natural range rather than its status as a native or non-native. Plant species should be selected based upon physiological evidence and observed landscape performance rather than assumed drought tolerance.

Introduction

Irrigation accounted for approximately one-third of residential water use in the United States in the 1990s (13), and up to 64% in Central Florida from 2001 to 2003 (10). Water is one of the most limiting factors in establishing container-grown trees and shrubs in the landscape (3). Water Management Districts throughout Florida rely on regulations governing irrigation frequency to reduce landscape water consumption. Regulations vary, however, among municipalities. Generally 30 to 60 days of daily irrigation is permitted for establishment with twice weekly applications thereafter for maintenance. Container-grown shrubs require 6 to 12 months in Florida to establish normal root to shoot ratios (6). Irrigation frequency effects on growth during both establishment and post-establishment phases have been demonstrated for a number of tree and shrub species. Gilman (7) found less frequent irrigation during establishment promoted deeper rooting but decreased shoot growth for *Ilex cornuta* Lindl. & Paxton 'Burford Nana'. Scheiber (15) found establishment of the common landscape shrubs *Ilex cornuta* 'Nana Burfordii', *Pittosporum tobira* (Thunb.) W.T.Aiton 'Variegata' and *Viburnum odoratissimum* Ker.-Gawl required 3–4 months if irrigated every 2 or 4 d in the absence of rainfall; however, greater growth occurred if irrigation was applied every 2 d.

Native plants are recommended with the assumption of drought tolerance (9, 12) despite limited research utilizing physiological measures of plant water stress to support or refute such claims. Water Use Efficiency (WUE) is the ratio of carbon gain to the volume of water transpired. In theory, the higher the WUE, the more likely a species is drought tolerant. Blicker (2) found two native grasses had greater WUE than an introduced grass species. In contrast, Glenn (8) found no differences in WUE among two exotic and two native riparian plant species. Given limited available research, the objective of this study was to quantify effects of irrigation frequency on growth, cumulative water stress, and time until establishment of an introduced and native evergreen shrub species.

Materials and Methods

Myrica cerifera L. and *Ligustrum japonicum* Thunb. were selected for this study as being comparable in terms of landscape function and leaf gas exchange. Both are large evergreen shrubs planted as screening hedges, and had the same mean WUE of 0.00358 ±0.00059 mol^{-1} CO_2·H_2O mol^{-1} (0.21 oz CO_2·oz H_2O) under well-irrigated conditions (Beeson, unpbl. data). *Myrica cerifera* is native to the East Coast from New Jersey to southern Florida and through the Gulf states

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to Texas. It inhabits sandy coastal sites, swamps, and upland forests. In the landscape, *Myrica* is either a large shrub or small, multi-trunked tree [7.6 m (24.9 ft) mature height] that is semi-evergreen to evergreen. *Ligustrum japonicum* is an evergreen large shrub or multi-trunked small tree [6.1 m (20 ft) mature height] in landscapes. Native to Japan and Korea, it is well adapted to a wide variety of soil types and moisture conditions (16).

Both species were obtained from a commercial nursery in 11.4 liter (3 gal) containers and transplanted on February 10, 2004 into an excessively-drained fine sand soil (Apopka fine sand series, pH = 5.3, organic matter content = 0.6%). Forty-eight plants of each species were randomly planted into each of 6 beds on 1.8 m (6 ft) centers in 1.5 m (5 ft) wide strips previously treated with Roundup Pro (glyphosate) (Monsanto Corp., St. Louis, MO). Areas between strips were maintained as 1.5 m (5 ft) wide sodded bahiagrass (*Paspalum notatum* Flugge) strips. Three beds were randomly assigned to be irrigated daily while the other three beds were irrigated every 3 d. Each irrigation event applied 1.3 cm (0.5 in) of water. After 8 months after transplanting (MAT), irrigation frequencies were altered such that all plants were irrigated every 3 d as previously described. Irrigation was applied within each bed area with microirrigation spray stakes equipped with a strip spreader (Model Stake 31, Spreader Blue Series 7000, Maxijet, Dundee, FL). Spray stakes were situated in a linear pattern with each emitter 1.2 m (4 ft) apart and mounted 22.9 cm (9 in) above ground level such that the entire bed area was irrigated. The Christiansen Coefficient of Uniformity was a minimum of 0.71 prior to planting (11). Irrigation of each bed was controlled as a separate zone using an automated irrigation time clock (Raindial, Hardee Irrigation, Laguna Niquel, CA). Irrigations began at 0500 HR and were completed by 0700 HR each day, independent of rain events. Flow meters (Model C700TP, ABS, Ocala, FL) were installed for each zone to record irrigation volumes Monday through Friday.

Growth indices and biomass. Measurements of average canopy height, widest canopy width, and width perpendicular to the widest width were recorded to calculate growth indices (growth index = height × width1 × width2). All plants were measured immediately after transplant, monthly, and at final harvest. The experiment was terminated on February 24, 2005. At 2, 4, 8, and 12 MAT, three replicates of each treatment combination were removed to determine shoot dry mass, new root dry mass, biomass and total shoot-to-new-root ratios. Shoots were severed at the soil line and dried at 65C until constant dry weight was obtained. Prior to drying, all leaves were removed and leaf area determined using a LI-COR 1500 leaf area meter (LI-COR Biosciences, Inc., Lincoln, NE). Stem and leaf dry mass were summed to attain total shoot dry mass. To obtain new root dry mass, segments of the soil volume outside of the rootball and extending beyond the longest root were excavated from the north and south sides of each plant. At 2 MAT, 1/4 segments from the north and south sides were removed from each plant for each species. Dry mass from each segment were summed and multiplied by 2 to obtain total new root dry mass. As time increased from transplant and root density and volume increased, sampled segments decreased in size. For both species, 1/4, 1/8, and 1/16 segments were harvested from the north and south sides of a plant 4, 8, and 12 MAT, respectively. Soil was removed from roots by hand washing, and roots were dried as described for shoots. Dry masses of north and south segments were summed and multiplied by an appropriate coefficient to obtain total new root dry mass. Shoot-to-root ratios were obtained by dividing total shoot mass by total new root mass. Biomass was calculated as the sum of total shoot dry mass and new root dry mass. Root lengths were determined by measuring the longest root extending from the center of the root ball in each harvested segment.

Stem water potential measurements. Shoot water potential (Ψ_w) was measured monthly on three replicates of each species (one plant per bed) for each treatment beginning at transplant. Measurements were taken at predawn, mid-day, and dusk on the day prior to irrigation (maximum stress day) and the day of irrigation (minimum stress) to represent plants at maximum and minimum stress levels for the 3-day treatment. Shoot water potential was determined with a pressure chamber (Model 3000; Soil Moisture Equipment Corp., Santa Barbara, CA) using compressed nitrogen, with pressure increasing at a rate of 2.5 kPa·s^{-2} (0.36 psi·s^{-2}). Measurements were made on individual twigs [≈ 5 cm (2.0 in) long]. Cumulative daily water stress integrals (S_Y) were calculated as described by Schulze (17) and Beeson (1). Area over the water potential curve was integrated and the absolute value taken for each species on each sampling date.

Data analysis. The experiment was conducted as a randomized complete block design with three blocks of single plant replicates. Each block contained both species (*Ligustrum* and *Myrica*) and irrigation frequency (1- and 3-d) combinations. Growth data from harvests at 2, 4, 8 and 12 MAT, consisting of leaf area, shoot dry mass, new root dry mass, biomass, and shoot-to-root ratio were analyzed as a three-way factorial with two irrigation frequencies and two species over time with three replications. All growth data were analyzed separately by harvest date. Monthly growth indices and plant height data were analyzed by regression, with two irrigation frequencies, two species and three replications. Slopes of resulting regression equations were compared by single-degree-of-freedom contrast (18). Cumulative water stress integrals values were analyzed as repeated measures using a split plot design with irrigation frequency as the main plot, species as a subplot and day as a sub-subplot (18). Where significant differences were indicated, mean separation was by Fisher's Protected least significance differences (F-Protected LSD). All analysis was conducted using SAS (Version 9.2, SAS Institute, Cary, NC).

Results and Discussion

Growth and biomass. Canopy size of *Ligustrum* and *Myrica* increased linearly over time for both irrigation frequencies (Fig. 1). *Myrica* irrigated daily increased canopy size 3 times faster than either species irrigated every 3 d, and twice as fast as daily irrigated *Ligustrum* (Fig. 1). Final canopy size of daily irrigated *Myrica* was 86% greater than *Ligustrum* irrigated daily, and 175% greater than either species irrigated every 3 d. Canopy sizes were 1.6- and 1.4-fold larger ($P < 0.05$) for *Ligustrum* irrigated daily compared to those plants irrigated every 3 d. Irrigation every 3 d increased canopy size of *Myrica* slightly faster ($P < 0.05$) than similarly irrigated *Ligustrum*.

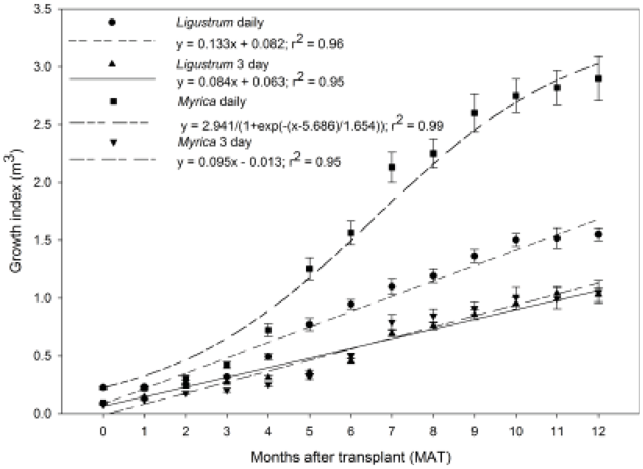

Fig. 1. Mean growth indices of *Ligustrum japonicum* and *Myrica cerifera* irrigated with two frequencies (1- or 3-d) over a 12-month period beginning in early February in central Florida. Error bars represent the standard error of the mean of 6 plants.

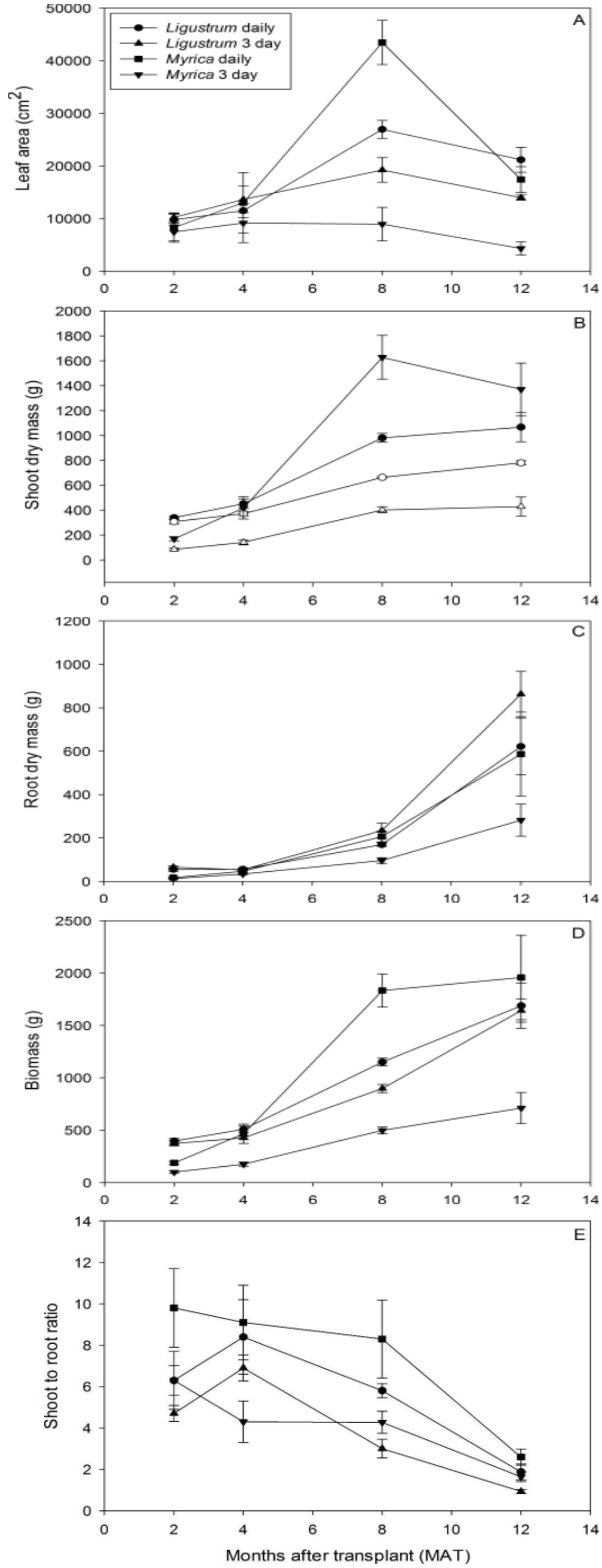

Fig. 2. Leaf area (A), shoot dry mass (B), root dry mass (C), biomass (D), and shoot-to-root ratio (E) measurements for *Ligustrum japonicum* and *Myrica cerifera* irrigated with two frequencies (1- or 3-d) over a 12-month period beginning in early February in central Florida. Error bars represent the standard error of the mean of 3 plants.

A three way interaction of species by irrigation frequency over time ($P < 0.01$) occurred for leaf area, shoot, root and total dry mass, and shoot-to-root ratios. For leaf area there were no differences ($P \geq 0.05$) among species or irrigation frequency at 2 or 4 MAT ($P \geq 0.05$; Fig. 2A). However, there was a tendency for greater leaf area for *Myrica* irrigated daily compared to all other treatments. By 8 MAT, greater leaf area was observed among plants receiving daily irrigation for both species. *Myrica* plants producing nearly 80% more leaf area than *Ligustrum* (Fig. 2A) when irrigated daily. In contrast, *Ligustrum* irrigated every 3 d had double the leaf area of similarly irrigated *Myrica* plants. Declines in leaf area after 8 MAT occurred for both species and irrigation regimes, but was much greater for daily irrigated *Myrica*, reducing leaf area by more than half. The overall trend is attributed to decreased water availability. Rainfall declined from a monthly average of 22.7 cm (5.4 in) from February through October 2004, to 4.3 cm (1.7 in) from November 2004 to February 2005 (5). This decline in rainfall was also concurrent with the one third reduction in irrigation when frequency was reduced for previously daily irrigated plants. Leaf loss was most likely an adjustment to seasonal evaporative demand and reduced water availability.

No differences among species or irrigation frequency occurred for shoot dry mass at 2 and 4 MAT (Fig. 2B). Four months later at 8 MAT, separation by species and irrigation regime were identical to that found for leaf area (Fig. 2B). Daily irrigation increased shoot dry mass ($P < 0.05$) compared to every 3 d, and shoot dry mass of 3 d irrigated *Myrica* was again half that of similarly irrigated *Ligustrum*. Reductions in irrigation frequency from daily to every 3 d after 8 MAT also reduced shoot dry mass, mainly due to leaf senescence, especially for *Myrica*.

New root dry mass of *Ligustrum* was 3.8 fold greater ($P < 0.05$) than *Myrica* at 2 MAT, though like shoot mass, there were no differences at 4 MAT (Fig 2C). However by 8 MAT, *Ligustrum* irrigated every 3 d had more root dry mass than daily irrigated *Ligustrum*, and similar mass to daily irrigated *Myrica*. This trend had modified by the last excavation at 12 MAT. While greatest root mass was still found for *Ligustrum* irrigated every 3 d, similar, but more variable root growth occurred for both daily irrigated *Ligustrum* and *Myrica*. *Myrica* irrigated every 3 d generated less new root growth than any other combination beginning 8 MAT and continued until the final excavation.

Despite losing half the leaf area measured at 8 MAT, *Myrica* irrigated daily still had the greatest total biomass at 12 MAT, although it started at 2 MAT with less biomass than *Ligustrum* (Fig. 2D). Much of this was due to greater new branch growth between 4 and 8 MAT compared to *Ligustrum*. Overall, the reduction in available water after 8 MAT had no effect on total biomass accumulation for either *Ligustrum* irrigation regimes, or for *Myrica* irrigated every 3 d (Fig. 2D). Biomass increased linearly for all three, with massive increases in root dry mass after irrigation that made up for decreases in leaf mass during the last 4 MAT. In contrast, daily irrigated *Myrica* produced less root dry mass once daily irrigation was reduced both in actual dry mass and relative to shoot growth.

Shoot-to-root ratios were similar ($P \geq 0.05$) among species and irrigation treatments 2 MAT (Fig. 2E). Between 4 and 8 MAT, shoot-to-root ratios were 2-fold greater for daily irrigated plants. Greater shoot-to-root ratios resulted from greater availability of water. Shoot-to-root ratios were similar for *Myrica* between 4 and 8 MAT, but decreased linearly for *Ligustrum* after 2 MAT. Shoot-to-root ratios decreased for all treatments after 8 MAT, especially for *Myrica* once daily irrigation was reduced. Large reductions in shoot-to-root ratios for *Myrica* are attributed to leaf senescence and decreased shoot dry mass after 8 MAT (Fig. 2B).

Water potential. Cumulative water stress (Sψ) is a quantitative measure of the amount of water stress experienced by plants (14). Values are dependent on the evaporative demand of the time period, the length of day and most importantly relative ratio of transpiring leaf area to accessible plant available water. Accessible plant available water, under well-irrigated condition, is dependent on root mass and elongation into the substrate.

Ligustrum irrigated daily for the first 8 MAT exhibited overall little variation between the two back-to-back diurnal (Sψ) measurements (Fig. 3). This variation was probably due to differences in evaporative demand from day to day. Two months after all irrigation was converted to every 3 d (10 MAT), Sψ was higher ($P < 0.05$) pre- irrigation than the day of irrigation for all plants, and similar to that of plants irrigated every 3 d.

For *Ligustrum* irrigated every 3 d, differences in Sψ between before and after irrigation were significant ($P < 0.05$) between 4 and 10 MAT. By 12 MAT, in mid-February, there were no differences in Sψ between initial 3 d and daily irrigation regimes. For the initial 3 d irrigation regime, pre-irrigation Sψ was higher ($P < 0.05$) between 2 and 10 MAT compared to the day these plants were irrigated. However 10 MAT, there were no differences in Sψ between the initial 3 d and daily irrigated *Ligustrum* when compared stressed or the day irrigated. On days of irrigation (unstressed), there were no differences in Sψ ($P < 0.01$) between daily and 3 d irrigated plants throughout the experiment.

Differences in Sψ between the day before and day of irrigation were small for both species, suggesting both were established by 12 MAT. This occurred during the period of massive root growth (Fig. 2C).

Cumulative water stress of *Myrica* was affected by stress day ($P < 0.05$) and ranged from 2.8 to 11.5 MPa·h^{-1} (28 to 115 bar·h^{-1}), substantially lower values than *Ligustrum* (Fig. 3). Irrigation frequency had no affect ($P < 0.05$) on Sψ (Figure 2B) on the day before irrigation (stressed). After irrigation (unstressed), *Myrica* irrigated every 3 d had lower ($P < 0.05$) Sψ at 4 and 6 MAT than *Myrica* irrigated daily (Fig. 3). Greatest Sψ differences between stressed (nonirrigated) and unstressed (irrigated) *Myrica* occurred for plants irrigated every 3 d at 2, 4 and 8 MAT.

Among plants irrigated daily, cumulative water stress of *Ligustrum* was 1.4- to 1.6-fold greater than *Myrica* between 6 and 12 MAT. Cumulative water stress for plants irrigated every 3 d was affected by a species by stress day interaction ($P < 0.05$). On the day before irrigation (stressed) *Ligustrum* had greater Sψ than *Myrica* ($P < 0.05$) between 4 and 10 MAT, yet on the day after irrigation (unstressed) *Ligustrum* had greater Sψ ($P < 0.05$) at 4 MAT.

Shrubs are considered established when Sψ between stressed (nonirrigated) and unstressed (irrigated) plants are comparable (15). Cumulative water stress between stressed and unstressed *Ligustrum* and *Myrica* irrigated every 3 d were comparable within 10 and 6 MAT, respectively and

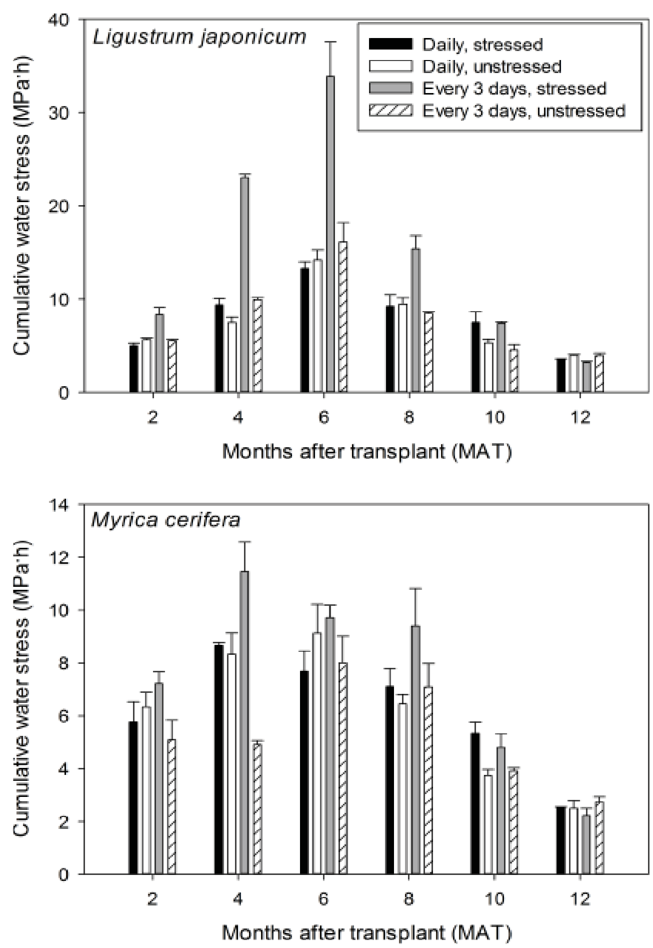

Fig. 3. Cumulative daily water stress integrals (Sψ) calculated monthly on the day before irrigation (stressed) and irrigation day (unstressed) for *Ligustrum japonicum* and *Myrica cerifera* irrigated with two irrigation frequencies (1- and 3-day) over a 12-month period beginning in early February in central Florida. Error bars represent the standard error of the mean of 3 plants.

thus established (Fig. 3). Establishment period of *Myrica* irrigated every 3 d was similar to *Illex cornuta* 'Burford Nana', but longer than *Pittosporum tobira* 'Variegata' and *Viburnum odortissimum* under similar irrigation regimes (15). Despite more rapid establishment, *Myrica* had lower ($P < 0.05$) root dry mass and biomass than *Ligustrum* at 8 MAT but similar ($P \geq 0.05$) leaf area, shoot dry mass, root dry mass, and biomass at 12 MAT. Irrigating *Ligustrum* every 3 d resulted in 200% reduction in irrigation volume applied with equivalent growth.

In this study, the native species (*Myrica*) established sooner than the introduced species (*Ligustrum*); yet, had similar final leaf area, shoot dry mass, root dry mass, and biomass. Reduction of daily irrigation 8 MAT resulted in water stress. *Myrica* responded through leaf senescence as a drought avoidance mechanism, whereas *Ligustrum* tolerated drought conditions and lost little shoot dry mass. Differences in growth response as a result of water stress suggest drought resistance and water use efficiency may be due to a plant's physiology rather than its status as a native or non-native (4). Selection of plant material should be based upon physiological evidence and observed WUE as an approach for water conservation in urban landscapes rather than assumed drought tolerance. Since WUE is rarely known, varies with the level of water stress, and doesn't account for drought tolerant strategies, such isohydric behavior at low water potentials, and/or shifts root to shoot ratios as *Myrica* exhibited here; its use as a predictor of plant water stress tolerance is limited. The most accurate way to evaluate drought tolerance of landscape plants is also the least desirable, establish them in the ground in rainout shelters, and iteratively apply levels of irrigation while evaluating growth and aesthetic quality.

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