Irrigation Regimens Differentially Affect Growth and Water Use Efficiency of Two Southwest Landscape Plants[1]

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Abstract

Growth and water use efficiency (WUE) of two, common Southwest landscape plants, red bird of paradise (*Caesalpinia pulcherrima* L.) and blue palo verde (*Cercidium floridum* Benth. Ex A. Gray), were studied in response to three irrigation regimens (frequent, moderate, and infrequent) that mimicked a range of residential landscape watering practices in Phoenix, AZ. During 50 to 58 and 138 to 147 days after the start of irrigation treatments (DAT), mid-day measurements of shoot water potential (Ψ), osmotic potential (Ψ_o), and gas exchange were made. Concurrently, diurnal measurements of whole plant transpiration (T) and estimates of dry weight accrual were made to calculate WUE. More frequent irrigations increased shoot length of both species and dry weight of *Cercidium.* For both species, Ψ and Ψ_o showed patterns of osmotic regulation as the substrate dried between watering events for moderately and infrequently irrigated plants. Infrequently irrigated *Caesalpinia* and *Cercidium* had the lowest WUE, except for 138 to 147 DAT during which time infrequently irrigated *Cercidium* had the highest WUE. Instantaneous transpiration efficiency (ITE) was negatively correlated to the ratio of intracellular to ambient CO_2 (Ci/Ca) in all treatments, suggesting that under more frequently irrigated conditions, WUE of *Caesalpinia* and *Cercidium* might be reduced by negative feedback effects of high Ci/Ca ratios on stomatal conductance.

Index words: gas exchange, landscape maintenance, water relations, xeriphytic.

Species used in this study: blue palo verde (*Cercidium floridum* Benth. ex A. Gray), red bird of paradise (*Caesalpinia pulcherrima* L.).

Significance to the Nursery Industry

Many municipalities in the Southwest United States now impose restrictions on the types and numbers of plants for landscaping purposes because of concerns about the distribution, abundance, and quality of fresh water resources. Installation of drought tolerant plants in Southwest city landscapes as a water conservation strategy might not result in water savings because of ensuing inconsistent watering practices by an uninformed public (17). We found that growth and WUE of two common Southwest landscape plants were related to the length of time between watering events, but the effects were dependent on species and plant maturity. Our study suggests that water availability may not be the factor limiting WUE, but that efficient use of the available water by plants might be. Based on our data, WUE for *Caesalpinia* might be optimized by an irrigation regimen that avoids excessively wet or dry soils. For *Cercidium*, high WUE might be attained by shorter, more frequent irrigations when trees are being established in the landscape with longer, less infrequent irrigations after establishment. Ultimately, factors that emphasize the aesthetic value and reduce maintenance requirements rather than maximizing growth should be considered when defining optimum WUE for plants in urban landscapes.

Introduction

In the southern and western United States, irrigation of plants in cities is a common landscape practice. Because of increased public awareness of water conservation and the finite availability of high quality water, many municipalities have adopted ordinances and codes that promote water conservation through installation of xeriphytic landscape plantings (2, 4). A recent survey of homeowners in the Phoenix, AZ, metropolitan area showed that residents recognized the importance of water conservation and were willing to practice Xeriscape™ concepts (3), but that they were not aware of how much irrigation water they were applying to their landscapes or how often they should irrigate (17).

Although xeriphytic plant species possess morphological and physiological mechanisms to both tolerate drought and compete for sporadic water supplies in arid systems (5), there is probably no advantage for these plants to conserve water when it is readily available such as in irrigated urban landscapes. Often plants initially selected for their xeriphytic habit are over-watered to stimulate growth and an appearance of vigor. Paradoxically, these plants must then be frequently pruned to limit plant size. Under this scenario, we hypothesized that frequent irrigation might lower WUE and lead to an 'inefficient' use of water.

Data collected during 1998 and 1999 in the Phoenix metropolitan area revealed that residential xeric plantings and plantings with mesic or more 'high water use' species were irrigated by homeowners with similar amounts of water per landscaped area, even though the foliar canopy area of the mesic landscapes was 2.6 times greater than the so-called xeriscapes (17). A concomitant study also showed that there were no differences in landscape carbon assimilation (A), transpiration (E), or ITE (A/E) between landscape plants in xeric or mesic designed residential yards (14).

Given the need for information on landscape irrigation scheduling as it relates to plant fitness, we conducted research on the effects of irrigation frequency on growth and WUE of two common southwestern landscape plants. In this paper, we define WUE as the ratio of dry weight accrual to the amount of water transpired (13). We also address ITE as a comparative measure of water use efficiency (5).

Materials and Methods

Plant species. Red bird of paradise (*Caesalpinia pulcherrima* L.) and blue palo verde (*Cercidium floridum*

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Benth. Ex A. Gray) were used in this study. Both species are in the Family *Fabaceae* and are commonly seen in Southwest urban landscapes. *Cercidium floridum* is native to riparian washes in the lower Sonoran Desert, grows into a medium-sized, multiple trunk tree [10.5 m (32 ft) mature height] in urban landscapes, and has photosynthetically active green stems and lemon yellow spring flowers. *Caesalpinia pulcherrima* is a sub-tropical shrub, 2–4 m (6–12 ft) in height, with an accent of striking red, orange, and yellow flowers occurring in terminal clusters during summer. *Caesalpinia* is native to the West Indies, but is well adapted to hot, low desert conditions and in isolated cases has naturalized in parts of the Sonoran Desert in Arizona.

Growth conditions. Single source, uniform seedlings [15 cm (6 in) height] of both species were potted into 12-liter (#3) containers filled with a mixture of washed masonry sand, #12 silica sand, and Gilman clay loam (8:1:1 v/v). The container soil mixture was formulated to simulate the average particle size distribution and drainage properties of soil collected in the upper 25 cm (10 in) soil profile of residential research plots located in the Phoenix metropolitan area, and was amended with Best® controlled-release fertilizer (15N–7.2P–12.5K–4.5S–1.1Fe–0.5Zn) at a rate of 5 kg/m^3. At potting, container soil total porosity was 26.6%, air-filled porosity 3.8%, and water holding capacity 22.9%.

After potting, all plants were grown for 5 months in an environmentally-controlled glasshouse (55% light exclusion) with a 16 hr photoperiod [natural light extended with 60-watt incandescent lamps positioned 2 m (6 ft) above plant canopies]. Glasshouse microclimate conditions were monitored continuously for the first 45 days after initiation of treatments (DAT) using a Campbell Scientific® 21X micrologger (Campbell Scientific Inc, Logan, UT) programmed to record data every 30 minutes. The mean daily range of air temperature at canopy height was 18–31C (64–88F), container soil temperature in the middle of the soil profile was 18–27C (64–81F), % relative humidity was 8–24, and vapor pressure deficit was 1.6–3.9 MPa.

Irrigation treatments. Beginning on the DAT until 150 DAT, all plants were watered in excess of container capacity (1986 ml) with a drip irrigation system according to one of three irrigation regimens: 1) frequent, every 2 days for one min, 2) moderate, every 5 days two min, or 3) infrequent, every 10 days for three min. Irrigation water was supplied in the morning (0800HR) with a single drip emitter at the average rate of 652 ml/min. Selection of the irrigation treatments were based on a prior survey of homeowner irrigation practices in Phoenix, AZ (Stabler and Martin, unpublished data), and were designed to apply similar volumes of water to each plant. Soil moisture tensions were recorded with tensiometers that were inserted into the container root-zone half way between the plant and container wall to a depth of approximately 15 cm (6 in), about half of the total pot depth. Soils tensions were near zero immediately after a watering event and declined to –0.1, –0.5, or –0.7 MPa for the frequent, moderate or infrequent irrigation regimens, respectively, just prior to a watering event. Monthly measurements of container leachate pH and electrical conductivity were made. Leachate pH ranged from 5.9 to 7.2 and electrical conductivity ranged from 0.7 to 2.1 dS/m. Leachate pH and EC values were unrelated to irrigation treatments.

Growth data and dry weight calculations. Total shoot length was measured on all plants every 10 days for the duration of the experiment. On 55, 80,108, 142, and 150 DAT, stem caliper at 2 cm (0.8 in) above the container soil surface was measured. At 150 DAT, the study was terminated and shoots and roots were separated and dried in a drying oven at 60C (140F) for 72 hr and dry weights recorded.

Regression models were constructed to determine allometric relationships between total shoot length (SL), caliper (C) and total dry weight (DW) (1, 7). For each species, we found that the allometric relationship with the highest R^2 value was:

Cercidium:

$$DW = 0.0542 * SL \qquad R^2 = 0.84 \quad \text{(Eq. 1)}$$

Caesalpinia:

$$ln DW = (0.017 * SL) + (0.327 * C) \quad R^2 = 0.98 \quad \text{(Eq. 2)}$$

We then used these allometric relationships to predict DW at various time intervals during the experiment for use in calculation of WUE.

Plant water status, gas exchange, whole plant transpiration, and water use efficiency. For all plants, total shoot water potential (Ψ), osmotic water potential (Ψ_o), and shoot gas exchange were measured the day before (dry soil) and four hours after (wet soil) a watering event during two intensive study intervals, 50–58 and 138–147 DAT. Mid-day shoot Ψ was measured using a Scholander type pressure bomb. Sap osmotic concentration was measured by first removing a 10 cm (4 in) segment of herbaceous shoot for *Cercidium* and one recently expanded leaf for *Caesalpinia.* These tissues were then immediately frozen for a minimum of 2 hr to disrupt cellular membranes. Plant tissues were then thawed to room temperature and placed in a pressure bomb to collect sap osmoticum from the severed end with a 1 cc-tuberculin syringe through a 27-gauge needle. Sap osmotic concentration was measured using a Precision Instruments Osmette® freezing point depression osmometer (Precision Instruments, Natick, MA). Shoot Ψ_o was then calculated as $\Psi_o = -RCT$ where Ψ_o is osmotic potential (–MPa), R is the gas constant (MPa/m^3/K), T the absolute temperature (K) and C the osmotic concentration (mol/m^3) (18).

Mid-day measurements of carbon assimilation (A), instantaneous transpiration (E), stomatal conductance (gs), and the ratio of intercellular to ambient CO_2 (Ci/Ca) were using a LI-6200 portable photosynthesis system (Li-Cor, Lincoln, NE). Gas exchange measurements were made on 10 cm (4 in) herbaceous shoot segments of *Cercidium* and the most recently expanded leaves of *Caesalpinia* one-day before watering events and again fours hours after plants in each treatment had been watered. Instantaneous transpiration efficiency (ITE) was expressed as the ratio of A/E (11).

Whole plant transpiration (T) was measured gravimetrically 50–58 and 138–147 DAT. Pots were bagged and sealed about the basal stem and weight loss over a 24-hr period at the beginning and end of an irrigation cycle was measured using a top loading balance. WUE was then calculated as T (g H_2O/day) per predicted DW accumulation (mg/day) during the irrigation cycle using regression equations 1 and 2.

Experimental design and data analyses. Plants were arranged in a randomized complete block design of three irri-

Table 1. **Repeated measures analysis of variance of significant polynomial time trends and treatment contrasts for increases in shoot length of *Caesalpinia pulcherrima* and *Cercidium floridum* in response to three irrigation treatments[z].**

Source of variation	MS	F	P value[y]
Caesalpinia			
Frequent vs. Moderate	140.9	1.55	0.2281
Frequent vs. Infrequent	1308.7	14.41	0.0012L
Moderate vs. Infrequent	2649.9	7.15	0.0150L
Cercidium			
Frequent vs. Moderate	236,002.3	8.11	0.0004L
Frequent vs. Infrequent	376,317.9	28.88	0.0001L
Moderate vs. Infrequent	16,293.7	1.25	0.2761

[z]All plants were irrigated to container capacity every 2 days (frequent), every 5 days (moderate) or every 10 days (infrequent).

[y]Linear (L) fitted line responses across time.

gation frequency treatments and eight single plant replications of each species for a total of 48 plants. For all treatment comparisons, an analysis of variance was calculated using a general linear models procedure [SAS version 6.03 (19), SAS Inst., Cary, NC]. Tukey/Kramer's method was used to compare mean variable responses to irrigation treatments at $\alpha < 0.05$. Shoot length data were subjected to repeated measures analysis (12). Pearson's correlation coefficients (r) were calculated to determine the measure of the degree of association between response variables using Statview®5 (SAS Inst., Cary, NC).

Results and Discussion

Shoot lengths of frequently or moderately irrigated *Caesalpinia* increased linearly over time compared with those irrigated at the infrequent interval (Table 1 and Fig. 1A). By the end of the study, shoot length of *Caesalpinia* irrigated at either frequent or moderate intervals was 1.7 or 1.5 times longer, respectively, than those irrigated infrequently (Fig. 1A). In contrast, shoot length of frequently irrigated *Cercidium* increased linearly over time compared with those irrigated at moderate or infrequent intervals (Table 1 and Fig. 1B). By the end of the study, shoot length of frequently irrigated *Cercidium* was 1.7 or 2.4 times longer, respectively, than those irrigated at the moderate or infrequent intervals (Fig. 1B). *Caesalpinia* final shoot and root DW were not affected by irrigation frequency treatments (Table 2). In contrast, final shoot and root DW of frequently irrigated *Cercidium* were 2.4 and 3.3 times greater, respectively, than for those irrigated at the moderate or infrequent intervals. *Caesalpinia* or *Cercidium* shoot to root ratio (S/R) were the same regardless of irrigation treatment.

Trends in mid-day shoot gas exchange measurements differed between *Caesalpinia* and *Cercidium* (Table 3). For *Caesalpinia*, leaf A was lowest for frequently irrigated plants 138–147 DAT immediately after watering events when soils were moist, while E was highest for frequently irrigated plants throughout the study. Frequently irrigated *Caesalpinia* had the lowest ITE before watering events on both dates and after watering events 138–147 DAT. Frequently irrigated *Caesalpinia* had the highest gs and Ci/Ca before watering events 138–147 DAT and the highest Ci/Ca values before watering events 50–58 DAT and after watering events 137–148 DAT.

For *Cercidium*, the moderate irrigation frequency suppressed shoot A after watering events during 50–58 DAT and before watering events during 138–147 DAT (Table 3). Otherwise, *Cercidium* A was not affected by irrigation treatments.

Table 2. **Effect of irrigation treatments on harvest shoot and root dry weights (DW) and shoot to root ratio (S/R) of *Caesalpinia pulcherrima* and *Cercidium floridum***

Genus Irrigation[z]	Shoot DW (g/plant)	Root DW (g/plant)	S/R
Caesalpinia			
Frequent	12.2[y]a	8.8a	1.90a
Moderate	14.1a	14.7a	1.14a
Infrequent	7.8a	8.7a	0.97a
Cercidium			
Frequent	31.2a	14.0a	2.33a
Moderate	13.0b	5.9b	2.22a
Infrequent	9.1b	4.4b	2.04a

[z]All plants were irrigated to container capacity every 2 days (frequent), every 5 days (moderate) or every 10 days (infrequent).

[y]Values are treatment means, n = 8. Treatment means within columns by species with the same letter are not significantly different at $\alpha = 0.05$ by the Tukey/Kramer method.

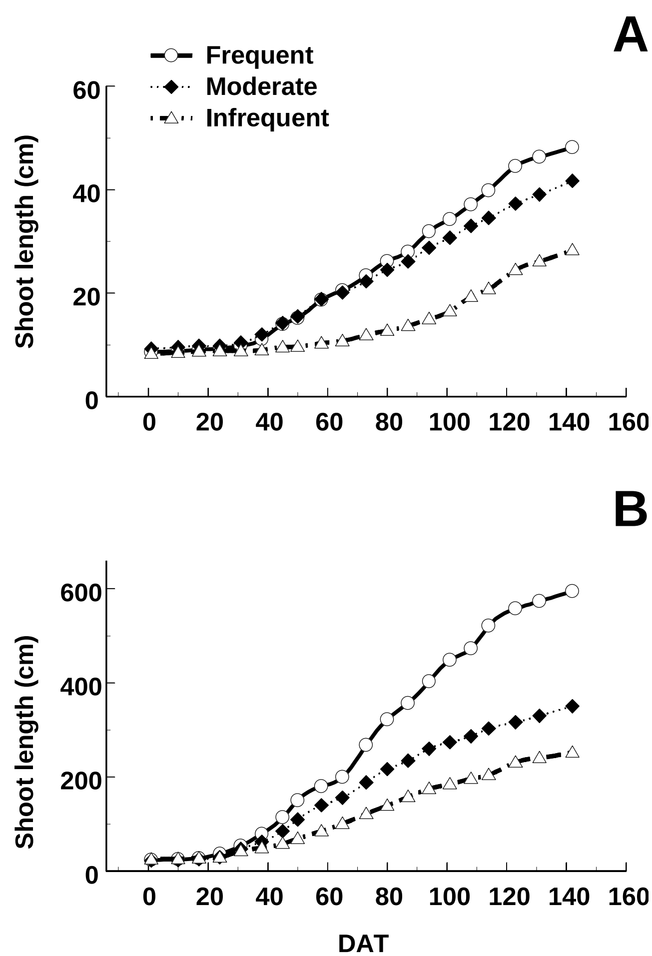

Fig. 1. **Effect of frequent, moderate and infrequent irrigation frequency treatments on shoot length of (A) *Caesalpinia pulcherrima* and (B) *Cercidium floridum* during 150 days after the initiation of treatments (DAT). Values are treatment means, n = 8.**

Table 3. **Carbon assimilation (A), instantaneous transpiration (E) instantaneous transpiration efficiency (ITE), stomatal conductance (gs), and the ratio of intercellular to ambient CO_2 (Ci/Ca) of *Caesalpinia pulcherrima* and *Cercidium floridum* in response to three irrigation treatments at 50 to 58 and 138 to 147 days after transplanting (DAT). Gas exchange data were measured on dry days (one day before an irrigation) with wet days (four hours after an irrigation) in parenthesis.**

Genus Irrigation[z]	A (µmol/m²/s)	E (mmol/m²/s)	ITE[y]	gs (mmol/m²/s)	Ci/Ca
Caesalpinia					
DAT 50–58					
Frequent	7.7[x]a (10.1a)	4.9a (4.3ab)	1.6b (2.3ab)	131a (116a)	0.67a (0.52)a
Moderate	10.7a (9.2a)	3.1b (5.7a)	3.5a (1.6b)	120a (144a)	0.58ab (0.66)a
Infrequent	11.0a (11.7a)	4.1ab (3.7b)	2.7a (3.0a)	122a (148a)	0.53b (0.63)a
DAT 138–147					
Frequent	5.8a (4.1b)	5.4a (3.8a)	1.1b (1.1b)	160a (97a)	0.72a (0.66a)
Moderate	4.2a (5.4ab)	2.3b (2.0b)	1.8a (2.7a)	48b (52a)	0.48b (0.50b)
Infrequent	5.9a (7.4a)	3.1b (2.6ab)	1.9ab (2.8a)	76b (88a)	0.54b (0.53ab)
Cercidium					
DAT 50–58					
Frequent	9.4a (14.8a)	7.5a (9.5a)	1.3b (1.6b)	224a (302a)	0.74a (0.71a)
Moderate	10.0a (9.2b)	3.3b (7.7b)	3.0a (1.2b)	130b (227b)	0.60b (0.75a)
Infrequent	11.3a (16.6a)	4.0b (5.2c)	2.8a (3.2a)	120b (202b)	0.46c (0.60b)
DAT 138–147					
Frequent	13.1a (10.2a)	12.6a (8.2a)	1.0b (1.2a)	600a (236b)	0.81a (0.70b)
Moderate	7.7b (11.4a)	5.7b (7.7a)	1.4a (1.5a)	169b (255b)	0.72b (0.71b)
Infrequent	11.1a (10.9a)	10.4c (8.1a)	1.1b (1.2a)	351c (406a)	0.76b (0.80a)

[z]All plants were irrigated to container capacity every 2 days (frequent), every 5 days (moderate) or every 10 days (infrequent).

[y]ITE is the ratio of A/E where E is transpiration in mmol/m²/s.

[x]Values are treatment means, n = 8. Treatment means within columns by species and DAT with the same letter are not significantly different at $\alpha = 0.05$ by the Tukey/Kramer method.

Before and after watering events, E was always highest for frequently irrigated plants except 138–147 DAT when there was no irrigation treatment effect. During 50–58 DAT, frequently irrigated *Cercidium* had the lowest ITE values before watering events. After watering events, the ITE of infrequently irrigated *Cercidium* was 2.7 or 2.0 times higher, respectively, than those plants irrigated at the moderate or frequent intervals. During 138–147 DAT, *Cercidium* ITE was only affected by irrigation frequency before watering events, and was highest for moderately irrigated plants.

On DAT 50–58, frequently irrigated *Cercidium* shoots had the highest gs and CICA ratios both before and after watering events (Table 3). On DAT 137–148, this pattern changed so that before watering events, gs and Ci/Ca ratios were highest for frequently irrigated plants, but were highest for infrequently irrigated plants after watering events.

Overall trends in mid-day Ψ and Ψ_o measurements in response to treatment were somewhat similar for *Caesalpinia* and *Cercidium* (Table 4). For *Caesalpinia,* shoot Ψ during 50–58 DAT was not affected by irrigation frequency before watering events, but after waterings was most negative for those plants irrigated at moderate intervals. Shoot Ψ_o of moderately irrigated *Caesalpinia* during 50–58 DAT was most negative before and after watering events. During 138–147 DAT before watering events, both shoot Ψ and Ψ_o of *Caesalpinia* were most negative for moderately and infrequently watered plants. After watering events, irrigation frequency had no effect on *Caesalpinia* shoot Ψ, while those irrigated at moderate intervals had the lowest shoot Ψ_o.

For *Cercidium,* shoot Ψ during 50–58 DAT was not affected by irrigation frequency before watering events, but like *Caesalpinia,* was most negative for those plants irrigated at moderate intervals after watering events. Also similar to *Caesalpinia*, shoot Ψ_o of moderately irrigated *Cercidium* during 50–58 DAT was most negative before and after watering events. During 147–158 DAT before watering events, both *Cercidium* shoot Ψ and Ψ_o were most negative for moderately and infrequently irrigated plants. After watering events, *Cercidium* shoot Ψ and Ψ_o were most negative for moderately irrigated plants only.

For *Caesalpinia*, WUE was lowest for infrequently irrigated plants throughout the study and was positively correlated to growth (SL, r = 0.66; DW, r = 0.51) (Table 4). In contrast, C*ercidium* WUE was negatively correlated to growth (SL, r = –0.53; DW, r = –0.50) and infrequently irrigated *Cercidium* had the lowest WUE during 50–58 DAT, but had the highest WUE during 138–147 DAT (Table 4). For all irrigation treatments, *Cercidium* WUE was as much as ten times higher than was *Caesalpinia* WUE.

Patterns of gas exchange and WUE in response to irrigation treatments differed between the two plant species. For example, *Caesalpinia* ITE (A/E) was generally lowest for the frequently irrigated plants, while WUE was lowest for infrequently irrigated plants. In contrast, the trend for *Cercidium* was high ITE for frequently irrigated plants throughout the study, with a shift in WUE from lowest to highest values in infrequently irrigated plants as the study progressed. Values for *Caesalpinia* and *Cercidium* ITE were most closely (and negatively) correlated to Ci/Ca with Pearson's correlation coefficients ranging from r = –0.77 to –0.91. Although we found that neither Ci/Ca or ITE were significantly positively correlated to plant growth or WUE, some studies indicate that Ci/Ca may act as the so called 'set point' for gas exchange metabolism, particularly in drought stressed plants (6). There was also a positive correlation between Ci/Ca and gs (*Caesalpinia*, r = 0.60; *Cercidium*, r = 0.70), suggesting that regulation of A and E may be related to stomatal control of internal CO_2 concentrations (15).

Table 4. **Effect of irrigation treatments on total shoot water potential (Ψ), osmotic potential (Ψ_o) and water use efficiency (WUE) of *Caesalpinia pulcherrima* and *Cercidium floridum* during DAT 50–58 and DAT 138–147. Water and osmotic potential data were measured on dry days (one day before an irrigation) with wet days (four hours after an irrigation) in parenthesis.**

Genus **Irrigation**[z]	**Ψ (MPa)**	**Ψ_o (MPa)**	**WUE**[y]
Caesalpinia			
DAT 50–58			
Frequent	–1.11[x]a (–0.95ab)	–1.24a (–1.14a)	0.40a
Moderate	–1.38a (–1.29b)	–1.55b (–1.47b)	0.53a
Infrequent	–1.10a (–0.75a)	–1.33ab (–1.18a)	0.10b
DAT 138–147			
Frequent	–1.15a (–1.03a)	–1.45a (–1.55a)	0.18a
Moderate	–1.78b (–1.18a)	–1.91b (–1.81b)	0.28a
Infrequent	–1.91b (–1.10a)	–1.96b (–1.40a)	0.06b
Cercidium			
DAT 50–58			
Frequent	–1.31a (–1.24ab)	–1.47a (–1.44a)	2.83a
Moderate	–1.58a (–1.49b)	–1.79b (–1.72b)	3.25a
Infrequent	–1.70a (–0.99a)	–1.79b (–1.58ab)	1.24b
DAT 138–147			
Frequent	–1.07a (–1.02a)	–1.51a (–1.75ab)	3.13b
Moderate	–1.74b (–1.63b)	–2.12b (–1.89a)	4.07b
Infrequent	–2.19b (–1.33ab)	–2.16b (–1.56b)	7.57a

[z]All plants were irrigated to container capacity every 2 days (frequent), every 5 days (moderate) or every 10 days (infrequent).

[y]WUE is grams H_2O transpired per estimated mg of plant DW accumulation.

[x]Values are treatment means, n = 8. Treatment means within columns by species and DAT with the same letter are not significantly different at a = 0.05 by the Tukey/Kramer method.

Although growth was generally reduced by the infrequent irrigation regimens, all plants maintained good water status and accumulated biomass throughout the course of the study. Treatment-mediated patterns of shoot Ψ_o were most evident before watering events when substrate tensions as a function of treatment were most negative and distinct. Infrequently and moderately irrigated plants of both species had more negative shoot Ψ_o than frequently irrigated plants, indicating that the moderately and infrequently irrigated plants were osmotically adjusting to water stress imposed by the drying soil between watering events (8, 9).

The impetus of past research on plant WUE has been on agricultural crops in hopes of improving drought tolerance while maximizing crop yield (10, 16, 20). In urban landscapes, overall plant yield may not be of paramount interest, but rather the most efficient use of available soil water as applicable to plant fitness and appearance. Results from the present study suggest that WUE was species specific and was temporally dynamic for *Cercidium*. Though increased irrigation frequency stimulated growth of *Cercidium*, WUE was ultimately highest for infrequently irrigated plants. Frequently irrigated *Caesalpinia* had the highest Ci/Ca, E, and gs, and the lowest ITE, possibly an indication of the inefficient use of water by plants subjected to chronically moist soil. Since growth patterns of frequently and moderately irrigated *Caesalpinia* were similar, these data suggest that water availability might not be the factor most enhancing WUE, but that the efficient use of the available water might be.

In conclusion, moderation of irrigation frequency to avoid excessively wet or dry soils might improve WUE in *Caesalpinia*. For *Cercidium*, an efficient irrigation strategy for optimizing WUE may consist of shorter, more frequent irrigation when trees are being established in the landscape, with longer, less frequent irrigation after establishment. Based on this study, we recommend irrigation practices that optimize landscape WUE by considering specific plant needs based on species and developmental stage.

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