Influence of Irrigation Regime on Water Relations, Gas Exchange, and Growth of Two Field-grown Redbud Varieties in a Semiarid Climate[1]

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Abstract

For three growing seasons (2003–2005) two newly planted, field-grown redbud (*Cercis canadensis* L.) varieties were subjected to three reference evapotranspiration (ETo)-based irrigation regimes (100, 66, and 33% ETo). Over this time period, water relations (pre-dawn leaf water potential), gas exchange (mid-day stomatal conductance), and growth data (trunk cross sectional area increase, tree leaf area, and shoot elongation) were measured. Pre-dawn leaf water potential (ψ_l) was more negative for trees receiving the least amount of irrigation, and for Mexican redbud [*C. canadensis* var. *mexicana* (Rose) M. Hopkins] trees. However, mid-day stomatal conductance (g_s) was similar for Texas redbud (*C. canadensis* var. *texensis* S. Watson) trees across the three irrigation regimes, and was highest for Mexican redbud trees receiving the greatest amount of irrigation volume. Growth varied by variety and irrigation regime. Trunk cross sectional area increase was greatest for Mexican redbud trees, leaf area was highest for trees receiving the greatest amount of irrigation, and shoot elongation was greatest for trees receiving the 66% ETo irrigation regime. However, despite differing irrigation volumes, greatest gas exchange and growth was not necessarily associated with greatest irrigation volume. When considering conservation of precious water resources, these redbud varieties maintain adequate growth and appearance under reduced irrigation.

Index words: irrigation management, reference evapotranspiration, tree growth.

Species used in this study: Mexican redbud [*Cercis canadensis* var. *mexicana* (Rose) M. Hopkins]; Texas redbud (*C. canadensis* var. *texensis* S. Watson).

Significance to the Nursery Industry

Available water and water quality are concerns in many regions of the United States. Therefore, conserving water in production nurseries and landscapes is essential. In many municipalities and water districts, irrigation limits have been implemented with little regard to actual plant water requirements. However, limited research has been conducted on water requirements of recently planted field-grown trees in nursery, or landscape settings. Following transplanting, water relations, gas exchange, and growth of recently planted, field-grown, Texas and Mexican redbud trees subjected to three reference evapotranspiration (ETo)-based irrigation regimes (100, 66, and 33% ETo) was investigated. Greatest gas exchange and growth was not always associated with trees receiving the greatest irrigation rate. Therefore, irrigation water likely could be conserved while growing these redbud varieties in field nurseries, or home landscapes. If water conservation is to be implemented, water conservation measures must be promoted, and research investigating water requirements of trees must continue.

Introduction

Trees are an important component of urban landscapes, and require a substantial investment to maintaining proper tree health (31). However, rapid population growth (27), depletion of water tables (7), poor water quality (29), and drought (32) have emphasized the need for many communities to implement water conservation programs (32, 33). Despite admirable intentions to conserve water, these programs are often implemented without regard to actual plant water requirements. In numerous communities, urban landscape irrigation is estimated to be a large fraction of total water use. In fact, in southwest communities of North America, landscape irrigation is estimated to consume 60% or more of all residential water used during the growing season (16). Due to these concerns and restrictions, there is a need for woody plant species that are adapted to soils and climatic conditions found in semiarid and arid regions (29, 32). Because trees are commonly grown in landscapes that require frequent irrigation, a challenge confronting irrigation managers is to conserve water while meeting plant irrigation requirements (33). Production nurseries also face water restrictions and increased pressure to improve water management practices (23), and water conservation research in production nurseries is critical to nursery sustainability (23).

An ideal method to schedule irrigation would be to estimate water requirements and replenish the root system with the required volume (23). However, because irrigation requirements of many landscape tree species are not well known and vary with climate (17, 24), nursery and landscape irrigation managers are often unsure of the volume of water landscape trees require (8). In fact, because of the lack of information regarding tree irrigation requirements, landscape and nursery trees are frequently irrigated in excess (which may result in water-logged soil, poor plant growth, increased irrigation runoff, leached nutrients, increased water bills, and misuse of irrigation water), or deficit (which may result in poor plant growth, poor plant aesthetics, and plant death) amounts (16, 23, 24). In either case, performance of orna-

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mental tree species will not meet production or landscape expectations.

A robust approach to estimate water needs of plants is to define plant water loss factors by a constant, standardized measure of reference that is a function of climatic factors (21). The American Society of Civil Engineers Penman-Monteith (ASCE-PM) equation has defined ETo as the rate of evapotranspiration from a hypothetical reference plant (4), and variables needed to calculate ETo are readily available from automated weather stations.

The ASCE-PM approach determines plant water loss by parameterizing empirically measured plant evapotranspiration (EC) as a function of ETo using a water loss coefficient (Kc). The dimensionless Kc is computed as:

$$EC = (Kc) \times (ETo) \qquad \text{[Eq. 1]}$$

where both EC and ETo have units of depth of water evaporated (mm) / (unit time). Water loss of turfgrass is closely related to ETo. Therefore, Kc values have been developed for many turf species (10, 12).

However, due to the difficulty of quantifying values (16), the great diversity of species (34), and the reality that Kc values determined in one climate may not translate to another climate (17), there are a limited number of Kc values reported for woody tree species used in landscapes. Levitt et al. (21) estimated Kc values for mesquite (*Prosopis alba* 'Colorado' Griseb.) and live oak (*Quercus virginiana* 'Heritage'Mill.) trees grown in 15.0 liter (4.0 gal) containers. Estimated Kc values for mesquite and live oak were 0.5 and 1.0, respectively. Montague et al. (24) used lysimetry to estimate total leaf area-based Kc values for five newly transplanted balled and burlaped trees. Corkscrew willow (*Salix matsudana* 'Tortuosa' Koidzumi) and littleleaf linden (*Tilia cordata* 'Greenspire' Mill.) had the greatest Kc values (1.1 and 0.9, respectively) and Norway maple (*Acer platanoides* 'Emerald Queen' L.) had the lowest (0.2). In a semiarid climate, Fox and Montague (13) examined growth of 13 field-grown tree species exposed to three ETo-based irrigation regimes (33, 66, and 100% ETo). Greatest growth for several species was not necessarily associated with species receiving the greatest irrigation volume, and all trees appeared healthy and had adequate growth even when exposed to the lowest irrigation volume. Others (10, 27, 30, 31) have also reported Kc values for several woody and herbaceous landscape species.

Because of its moderate size and early spring flowering (36), Eastern redbud (*Cercis canadensis* L.) is a common landscape tree in much of the southeastern United States. In addition, because varieties of redbud are considered tolerant of high temperatures and adapted to xeric conditions (14, 15, 29), redbud is a common landscape tree in semiarid climates. Despite previous research on adaptability (11, 29, 35) and water relations (2, 15) of redbud, there is a need to determine irrigation requirements for redbud varieties that are adapted to conditions found in semiarid climates. Therefore, this research investigated water relations, gas exchange, and growth of two newly transplanted, field-grown redbud varieties subjected to three ETo-based irrigation regimes while growing in a semiarid climate.

Materials and Methods

Research was conducted in a field nursery located in Lubbock, TX (U.S. Dept. of Agriculture hardiness zone 7a). Prior to year one of the study, nine container-grown [11.4 liter (3 gal)] trees of Mexican and Texas redbud variety were planted 2.5 m (8 ft) apart in east-west rows with 2.5 m between each row. Soil consisted of an Amarillo fine sandy loam (fine-loamy, mixed, superactive thermic Aridic Paleustalfs) with a pH of 8.5, organic matter content of 0.8%, and CEC 13.5 $meq \cdot 100\ g^{-1}$. Research presented here is based upon a portion of a larger project. Fox and Montague (13) outline additional materials and methods information.

Irrigation regimes were based upon estimated tree root area (cm^2) and local ETo (mm). During the first growing season of the study, (April–October) tree root area was estimated using the radius of the plant's container [13.3 cm (5.2 in)] plus an additional 15.2 cm (6 in). Following the first growing season, radius means of each variety were estimated to equal 122 cm (4 ft), and 183 cm (6 ft) for the second and third growing seasons, respectively. Climatic data were collected from an onsite weather station (Campbell Scientific, Inc., model Metdata1, Logan, UT). Collected weather data were used to calculate daily total ETo. Reference evapotranspiration was calculated using ETo calculation software (5). Climatic variables required to calculate ETo were: total daily incoming radiation ($MJ \cdot m^{-2} \cdot day^{-1}$), maximum and minimum daily temperature (C), maximum and minimum daily relative humidity (%), and average daily wind speed ($m \cdot second^{-1}$). Reference evapotranspiration was calculated for a well-watered, non-stressed, cool season grass using the Penman-Monteith equation with an assumed crop height of 0.12 m (4.7 in), an albedo of 0.23, and a fixed surface resistance of 70.0 $seconds \cdot m^{-1}$ (5). Based upon total weekly ETo and root surface area irrigation was applied once each week at one of three Kc values [100, 60, and 30% of ETo (high, intermediate, and low, respectively)]. Weekly irrigation volume was calculated as follows:

$$V = [((ETo) - (P)) \times (A)] / (1000)] \times (Kc) \qquad \text{[Eq. 2]}$$

where V is irrigation (liters) applied each week, P is weekly precipitation (cm), A is mean soil surface area above each tree's roots (cm^2), and Kc is fraction of ETo (1.0, 0.66, or 0.33). Once each week trees were irrigated through a drip irrigation system. To achieve the desired irrigation volume, each tree had one, two, or three emitters [3.8 $liters \cdot hr^{-1}$ (1 $gal \cdot hr^{-1}$)] placed at the base of the tree. Trees were not fertilized or pruned during the experiment, and weed control was done by hand. To aid establishment, during the growing season prior to the study all trees were irrigated at 100% ETo. Irrigation treatments began during the second growing season, and continued for two additional growing seasons.

Throughout summer months (May–September), pre-dawn leaf water potential (ψ_l), and mid-day stomatal conductance (g_s) were measured six days after an irrigation. Water relations and gas exchange data were measured the following dates: year one (June 9, June 23), year two (May 20, June 3, June 10, June 24, July 15, July 30, and August 12), year three (June 23, July 14, August 4, and September 9). Pre-dawn ψ_l was measured at 600 am (Central Daylight Savings Time) on two randomly selected, mature leaves from each tree. Leaves were excised before dawn, immediately sealed in a plastic bag, and placed in a portable cooler. Pre-dawn ψ_l was measured within a half-hour of excision with a pressure chamber (model 3005; Soilmoisture Corp., Santa Barbara, CA). Each day pre-dawn ψ_l was measured, mid-day (1200 to 1400 pm)

g_s was measured with a steady-state porometer (model LI-1600; LI-COR, Lincoln, NE). For g_s data collection purposes, single trees of each treatment combination (irrigation regime × variety) were grouped, and one measurement cycle (time required to measure g_s on each tree in group) included a tree from each treatment by variety combination. Measurement cycles were repeated throughout the day until g_s on all trees were measured. Stomatal conductance data were measured on five, mature full-sun leaves from each tree.

Each year (prior to budbreak and in November), trunk diameter 15 cm (6.0 in) above soil level was measured on each tree using a digital caliper (Mitutoyo Corp., model 500-196, Japan). For each tree, trunk cross sectional area increase was determined as the difference between spring and fall measurements. Also in the spring of each year, 10 randomly selected shoots on each tree were selected and shoot elongation (based on growth from the bud scale scar to the terminal bud) was measured on selected shoots in late fall. At the termination of each growing season, each tree was defoliated and tree leaf area was measured using a portable leaf area meter (model LI-3000 with LI-3050A conveyor attachment; LI-COR, Lincoln, NE).

Because statistical trends in yearly data were similar (irrigation regime effects did not differ between years), water relations and gas exchange data for each variety, irrigation treatment, and year were pooled (pre-dawn ψ_l and g_s for each variety by irrigation regime were taken as the mean of 72 and 180 measurements, respectively). In addition, trends in yearly growth data were also similar. Therefore, growth data from each growing season were also pooled (shoot elongation, trunk cross sectional area increase, and total tree leaf area for each variety by irrigation regime were taken as the mean of 90, 9, and 9 measurements, respectively). Data were exposed to ANOVA appropriate for a randomized block design (three randomized irrigation regime blocks with three trees of each variety planted randomly within each irrigation block). If differences were found, means were separated by Fisher's least significance difference procedure (LSD, $P \leq 0.10$) (SAS Institute Inc., Version 9.2 for Windows). For pre-dawn ψ_l, trunk cross sectional area increase, and total tree leaf area there were no variety by irrigation treatment interactions. Therefore, only main effects (irrigation regime or variety) data are presented. However, an irrigation by variety interaction occurred for g_s and shoot elongation. Therefore, g_s and shoot elongation irrigation by variety means are presented.

Results and Discussion

From 1997 to 2007 annual precipitation in Lubbock, TX averaged 48.2 cm (19.0 in) (6). During the experiment period, total yearly precipitation was greater than average during the second year of the study, but lower than average during the first and third years of the study. During the experiment period, yearly low temperature ranged from –15.3 to –11.6C (4.5 to 11.1F) and maximum yearly high temperatures ranged from 37.8 to 39.2C (100.0 to 102.4F). Mean growing season daily high temperature for each year was near 30.0C (86.0F), and growing season mean daily ETo each year was approximately 6.0 mm (0.25 in). Volume of water applied to trees in the low irrigation regime ranged from 483 liters (127 gal) during the first growing season to 2,072 liters (547 gal) during the third growing season. Irrigation to trees which received intermediate irrigation ranged from 967 liters (255 gal) during the first growing season to 4,145 liters (1,095 gal) during the third growing season. During the first growing season, high irrigation regime trees were irrigated with 1,466 liters (387 gal). While during the third growing season, high irrigation trees received 6,443 liters (1,702 gal). Throughout the experiment period, all trees of each variety survived and appeared healthy.

Trees that received the greatest amount of irrigation had less negative pre-dawn ψ_l when compared to trees receiving the low and intermediate irrigation treatments (Table 1). In addition, Mexican redbud trees had less negative pre-dawn ψ_l when compared to Texas redbud trees. Unlike data from this research, Abrams (2) reports pre-dawn ψ_l of 4 month old, container-grown *C. canadensis* seedlings from three different provenances (Kansas prairie, Kansas understory, and Indiana understory) did not differ between provenance, but pre-dawn ψ_l of trees from each provenance became more negative as days from irrigation increased. Leaf water potential data of native, field grown *C. canadensis* saplings (Kansas forest understory and prairie) also show more negative ψ_l as soil moisture levels decrease (1, 3). More negative ψ_l in response to water stress has also been reported for numerous woody landscape plants (26, 28, 33). Mexican and Texas redbud are considered to be heat- and drought-tolerant varieties (14, 15, 29). However, Texas redbud's native range (eastcentral Texas and Oklahoma) is considered more mesic when compared to Mexican redbud's native range (southwestern Texas to northeastern Mexico) (14, 15). Because pre-dawn ψ_l of Texas redbud was more negative when compared to pre-dawn of ψ_l of Mexican redbud (Table 1), data demonstrate Mexican redbud's clinal adaptation to native moisture regimes (14),

Table 1. Effects of irrigation treatment (low = 33%, intermediate = 66%, and high = 100% of reference evapotranspiration) on physiology of field grown Mexican (*Cercis canadensis mexicana*) and Texas redbud (*C. canadensis texensis*) trees during three growing seasons[z,y].

	Predawn water potential (Mpa)	Stomatal conductance ($mmol \cdot m^{-2} \cdot s^{-1}$)
Irrigation treatment		
Low	–0.64b	—
Intermediate	–0.62b	—
High	–0.54a	—
Species		
Mexican redbud	–0.57a	—
Texas redbud	–0.63b	—
Irrigation by species		
Texas redbud, low irrigation	—	156.4a
Texas redbud, intermediate irrigation	—	157.1a
Texas redbud, high irrigation	—	163.5a
Mexican redbud, low irrigation	—	148.1b
Mexican redbud, intermediate irrigation	—	168.8a
Mexican redbud, high irrigation	—	145.4b
Significance	$P > F$	
Irrigation	<0.0001	0.0381
Species	0.0005	0.1755
Irrigation by species	0.6641	0.0021

[z]Each mean represents physiology measurements from three growing seasons.

[y]Mean separation within irrigation treatment and species column by LSD ($P \leq 0.10$).

and each varieties variety's tolerance of low soil moisture (18, 20).

Decreased irrigation volume did not influence g_s for Texas redbud trees. In addition, Mexican redbud trees with intermediate irrigation had greater g_s when compared to trees receiving higher and lower irrigation volume (Table 1). Abrams (1, 2, 3) reported decreased g_s of native Kansas and Indiana redbud trees as trees were exposed to reduced soil moisture. Reduced g_s in response to water deficit stress is also common for many woody plant species (25, 28, 33). However, few reports are found in the literature that demonstrate g_s of woody landscape species not responding to reduced irrigation. Stabler and Martin (33) studied two species adapted to arid landscapes: red bird of paradise [*Caesalpina pulcherrima* (L.) Sw.] and blue palo verde (*Cercidium floridum* Benth.). Container-grown plants were exposed to three irrigation regimes: frequent (every 2 days), moderate (every 5 days), and infrequent (every 10 days). Mid-day g_s was measured prior to irrigation on day after initiation of treatments (DAT) 50–58, and DAT 138–147. For each measurement period, blue palo verde g_s was highest for frequently-irrigated plants. Despite variable irrigation, g_s for bird of paradise was not different between irrigation treatments during the first measurement period. However, during the second measurement period (DAT 138–147), g_s of bird of paradise plants exposed to frequent irrigation was greater when compared to other irrigation regimes. As previously stated, Mexican redbud's native range is considered more xeric when compared to the native range of Texas redbud (14, 15). Greater g_s for Texas redbud trees likely demonstrates Texas redbud's adaptation to native regions with less limiting moisture, and may be an adaptation to maximize gas exchange (transpiration, photosynthesis) in environments where soil moisture is less limiting (22). Although Mexican redbud generally had lower g_s when compared to Texas redbud, Mexican and Texas redbud g_s measurements over each irrigation regime are comparable to previous redbud studies (1, 2). In addition, because drought-tolerant species tend to have greater g_s at times of low soil moisture availability (20), each redbud variety appears to have tolerance of low soil moisture (18, 20, 35).

Trunk cross sectional area increase did not differ among irrigation treatments (Table 2). However, trunk cross sectional area increase for Mexican redbud trees was 38% greater when compared to trunk cross sectional area increase of Texas redbud trees. Total tree leaf area was 51 and 37% greater for trees receiving the high irrigation treatment when compared to trees receiving the low and intermediate irrigation treatments (Table 2). Total tree leaf area did not differ between varieties. However, Texas redbud trees receiving intermediate irrigation, and Mexican redbud trees receiving low and intermediate irrigation treatments had greater shoot elongation when compared to trees of other irrigation levels (Table 2). As was found with the previous study (13), these data illustrate that measured growth parameters for these redbud varieties is not always correlated with greater irrigation. Redbud species are known to have a great range of shade and cold tolerance (3). In addition, redbud varieties appear to be tolerant of several soil types, and demonstrate drought tolerance (11). Maintaining plant growth and reducing nursery irrigation is critical to the production nursery industry (23). For Mexican and Texas redbud varieties, trunk cross sectional area increase and shoot elongation can be sustained despite reduced irrigation volume. Reduced shoot growth and leaf area is a common response for plants exposed to mild water stress (19), and has been documented in redbud (1, 2, 3). As was likely the case in this research, redbud varieties exposed to moderate water stress develop

Table 2. Effects of irrigation treatment (low = 33%, intermediate = 66%, and high = 100% of reference evapotranspiration) on growth of field grown Mexican (*Cercis canadensis mexicana*) and Texas redbud (*C. canadensis texensis*) trees during three growing seasons[z,y].

	Trunk cross sectional area increase (cm^2)	Tree leaf area (cm^2)	Shoot elongation (cm)
Irrigation treatment			
Low	3.16	1585c	—
Intermediate	4.33	2056b	—
High	3.51	3266a	—
Species			
Mexican redbud	4.54a	2479	—
Texas redbud	2.79b	2125	—
Irrigation by species			
Texas redbud, low irrigation	—	—	11.7b
Texas redbud, intermediate irrigation	—	—	12.7a
Texas redbud, high irrigation	—	—	10.4c
Mexican redbud, low irrigation	—	—	12.3ab
Mexican redbud, intermediate irrigation	—	—	13.7a
Mexican redbud, high irrigation	—	—	11.6b
Significance		*P* > F	
Irrigation	0.5611	<0.0001	0.4451
Species	0.0598	0.2383	0.0001
Irrigation by species	0.2308	0.6316	0.0037

[z]Each mean represents growth measurements from three growing seasons.

[y]Mean separation between irrigation treatment and species column by LSD ($P \leq 0.10$).

soil water deficits which may reduce shoot and leaf growth, and allocate surplus carbohydrates to roots (19).

Interestingly, this research demonstrates greatest gas exchange and growth of field-grown Texas and Mexican redbud trees was not necessarily associated with trees receiving the greatest volume of irrigation. Therefore, growers and landscape managers irrigating these varieties may likely reduce irrigation volume and produce trees with appropriate growth. In addition, it appears the influence of irrigation volume on gas exchange and growth of these redbud varieties is variety and plant structure specific. Data also suggest irrigation of these field-grown redbud varieties based upon soil surface root area and local ETo measurements may be a means to conserve irrigation water and produce trees with acceptable growth. However, for most growers, estimating root area may not be practical. Therefore, other means to estimate required irrigation volume (such as trunk cross sectional area, projected crown area, etc.) should be examined.

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