Influence of Irrigation Regime on Growth of Select Field-grown Tree Species in a Semi-arid Climate[1]

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Abstract

Over three growing seasons (2003 through 2005) we investigated stem area increase and shoot growth of field-grown (FG) trident maple (*Acer buergeranum*), hedge maple (*A. campestre*), autumn blaze maple (*A.* × *freemanii* 'Autumn Blaze'), shantung maple (*A. truncatum*), Mexican redbud (*Cercis canadensis mexicana*), Texas redbud (*C. canadensis texensis*), white Texas redbud (*C. canadensis texensis* 'Alba'), Oklahoma redbud (*C. canadensis texensis* 'Oklahoma'), Washington hawthorn (*Crataegus phaenopyrum*), Arizona ash (*Fraxinus velutina coriacea* 'Bonita'), Mexican plum (*Prunus mexicana*), chinquapin oak (*Quercus muehlenbergii*), English oak (*Q. robur*) trees subjected to three reference evapotranspiration (ETo) based irrigation regimes (100, 60, and 30% ETo). For maple trees, stem area increase did not differ between irrigation treatments. However, except for trident maple shoot elongation varied with irrigation level and species. Stem area did not differ between irrigation regimes for redbud trees, and shoot elongation was generally greatest for trees that received lower irrigation treatments. Depending upon species, oak stem area increase did not differ, or was greatest for trees that received greater irrigation. For each oak species, shoot elongation was influenced by irrigation level. For two of the three remaining species, stem area increase and shoot elongation differed according to irrigation volume. Despite three differing irrigation volumes, greatest growth was not always associated with increased irrigation volume. In addition, each species appears to be suited for regions with low precipitation and high pH soils.

Index words: irrigation management, field-grown tree water requirements, reference evapotranspiration.

Species used in this study: Trident maple (*Acer buergeranum*); hedge maple (*A. campestre*); autumn blaze maple (*A.* × *freemanii* 'Autumn Blaze'); shantung maple (*A. truncatum*); Mexican redbud (*Cercis canadensis mexicana*); Texas redbud (*C. canadensis texensis*); white Texas redbud (*C. canadensis texensis* 'Alba'); Oklahoma redbud (*C. canadensis texensis* 'Oklahoma'); Washington hawthorn (*Crataegus phaenopyrum*); Arizona ash (*Fraxinus velutina coriacea* 'Bonita'); Mexican plum (*Prunus mexicana*); chinquapin oak (*Quercus muehlenbergii*); English oak (*Q. robur*).

Significance to the Nursery Industry

Available water and water quality are concerns in many regions of the United States. Therefore, conserving water in 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 into investigating water requirements of FG trees in nursery or landscape settings. Over three growing seasons we investigated growth of 13 FG tree species (trident maple, hedge maple, autumn blaze maple, shantung maple, Mexican redbud, Texas redbud, white Texas redbud, Oklahoma redbud, Washington hawthorn, Arizona ash, Mexican plum, chinquapin oak, and English oak) subjected to three ETo based irrigation regimes (100, 66, and 33% ETo). Our results indicate greatest growth was not always associated with high irrigation rates, and irrigation water could likely be conserved while growing landscape trees in field nurseries or home landscapes. If water conservation is to be implemented in nurseries and home landscapes, water conservation measures must be promoted, and research investigating water requirements of trees must continue.

Introduction

Isolated trees are an important component of urban landscapes and represent a substantial investment sustained by maintaining proper tree health (27, 39). However, recent droughts have elevated the necessity to irrigate landscape and FG nursery trees. At the same time, because of depleted water tables and high water usage (39), municipalities in arid and semi-arid regions have implemented water conserving ordinances that restrict the amount of irrigation applied to landscape and nursery plants. However, conservation ordinances often restrict irrigation water inputs with little or no regard to plant water requirements. Due to these restrictions and concerns, there is a need for plant material that is adapted to soils and climatic conditions found in semi-arid and arid regions (11, 39). Because landscape trees are frequently grown in landscapes that require irrigation, a challenge confronting irrigation managers is to conserve water while meeting plant irrigation requirements (40). Production nurseries also face water restrictions and increased pressure to improve water management practices (28), and water conservation research for production nurseries is critical to nursery sustainability (9, 26, 28, 41).

An ideal method to schedule irrigation would be to estimate water requirements and replenish the root system with the required volume (28). However, because irrigation requirements of many landscape tree species are not well-known and vary with climate (31), nursery and landscape irrigation managers are often unsure of the amount of water required by landscape trees (10, 35). In fact, because of the lack of information regarding tree irrigation requirements,

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landscape and nursery trees are frequently irrigated in excess (which may result in water-logged soil, poor plant growth, increased 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 (21, 28, 31). In either case, performance of ornamental trees species will not meet grower 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 water loss, which is a function of climatic factors (21). The United Nations Food and Agricultural Organization (UNFAO) 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 UNFAO approach determines plant water loss by parametizing 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) (2). Water loss of turfgrass is closely related to ETo. Therefore, Kc values have been developed for many turf species (15).

Due to the great diversity of species and the difficulty of quantifying values, there are a limited number of Kc values reported for woody landscape species (21). Garbesi (17) reported isolated trees had acceptable growth and appearance with a leaf-area based Kc value of 0.4. Levitt et al. (24) estimated Kc values for mesquite (*Prosopis alba*) and live oak (*Quercus virginiana*) 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. More recently, Montague et al. (31) used lysimeters to estimate total leaf area based Kc values for five newly transplanted balled and burlaped trees. Their results indicate corkscrew willow (*Salix matsudana* 'Tortuosa') and littleleaf linden (*Tilia cordata* 'Greenspire') had the greatest Kc values (1.1 and 0.9, respectively) and Norway maple (*Acer platanoides* 'Emerald Queen') had the lowest (0.2). However, it is unknown if Kc values estimated for young trees (with limited rooting area) are applicable to mature trees.

Although landscape tree evaluation trials have been, and are currently being conducted in the United States, the overwhelming majority of reports on FG tree evaluation trials have been carried out in mesic regions (5, 16, 18, 25, 43, 44). Even though there is a great need to determine which landscape tree species might be adapted to conditions found in semi-arid climates (11), literature is lacking for data that report on FG tree evaluations in arid and semi-arid climates. Therefore, to investigate landscape tree water requirements and observe species adaption to a semi-arid climate, this research investigated growth response of 13 newly transplanted, FG tree species subjected to three ETo based irrigation regimes while growing in a semi-arid climate.

Materials and Methods

Research was conducted in a field nursery located in Lubbock, TX (U.S. Dept. of Agriculture hardiness zone 7a). During April 2002, nine containerized [11.4 liter (3 gal)] trees of selected species 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 $100 \cdot g^{-1}$. Selected species consisted of trident maple (*Acer buergeranum*), hedge maple (*A. campestre*), autumn blaze maple (*A.* × *freemanii* 'Autumn Blaze'), shantung maple (*A. truncatum*), Mexican redbud (*Cercis canadensis mexicana*), Texas redbud (*C. canadensis texensis*), white Texas redbud (*C. canadensis texensis* 'Alba'), Oklahoma redbud (*C. canadensis texensis* 'Oklahoma'), Washington hawthorn (*Crataegus phaenopyrum*), Arizona ash (*Fraxinus velutina coriaceae* 'Bonita'), Mexican plum (*Prunus mexicana*), chinquapin oak (*Quercus muehlenbergii*), and English oak (*Q. robur*).

Irrigation regimes were based upon estimated soil surface area above the tree's root system (cm^2) and local ETo (mm). During the first growing season (April–October, 2002) soil surface area above each tree's root system was estimated using the container's radius [13.3 cm (5.2 in)] plus an additional 15.2 cm (6 in.). During the dormant period following each growing season (January), tree root area was estimated by removing soil from several trees of each species and each irrigation regime. Root surface area estimates were taken as the mean of all measurements [radius mean equaled 122 and 183 cm (4 and 6 ft) for 2004 and 2005, respectively]. Climatic data were collected from an on site weather station (Campbell Scientific, Inc., model Metdata1, Logan, UT). Collected weather data was used to calculate daily total ETo. Climatic variables required to calculate ETo were: maximum and minimum daily temperature (C), total daily incoming radiation ($MJ \cdot m^{-2} \cdot day^{-1}$), 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 ETo calculation software (3) and the ASCE 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 $seconds \cdot m^{-1}$ (4). Based upon total weekly ETo (cm) and root surface area (cm^2) irrigation was applied once each week at one of three Kc values (100, 60, and 30% of ETo (high, medium, 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 applied each week (liters), P is weekly precipitation (cm), A is mean soil surface area above each tree's roots (cm^2), and Kc is percent ETo (1.0, 0.66, or 0.33). Weekly precipitation accumulation was subtracted from ETo.

Trees were irrigated through a drip irrigation system. Each tree had three, two, or one 3.8 $liters \cdot hr^{-1}$ (1 $gal \cdot hr^{-1}$) emitter 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 2002 growing season all trees were irrigated at 100% ETo. Irrigation treatments began spring 2003 and continued through the 2005 growing season. Each year before budbreak, and again 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, stem cross sectional area increase was determined as the difference between spring and fall measurements. Also in the spring of each year,

Table 1. **Climate and irrigation data for field-grown trees species grown in Lubbock, TX using three irrigation regimes (low = 33%, medium = 66%, and high = 100% of reference evapotranspiration (ETo)). Data is for three growing seasons (2003 through 2005).**

Climate and irrigation data	2003			2004			2005		
Total yearly precipitaion (cm)		22.4			84.4			38.2	
Yearly low temperature (C)		–11.6			–15.3			–15.2	
Yearly high temperature (C)		39.2			37.8			39.1	
Growing season daily mean high temperature (C)		30.1			30.0			30.5	
Growing season mean daily ETo (mm)		6.4			6.1			5.9	
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Total irrigation volume (liter/tree)	483	967	1,466	941	1,882	2,851	2,072	4,145	6,443

10 randomly selected shoots on each tree were selected and shoot elongation (based on growth from bud scales to terminal bud) was measured in late fall. Although a longer evaluation period would be desirable, space availability and growth rates of trees limited experiment duration to the 2003 through 2005 growing seasons.

Because of similar yearly data and a limited sample size, growth data from each growing season were pooled (shoot elongation and stem cross sectional area for each species × irrigation regime were taken as the mean of 90 and 9 measurements, respectively) and exposed to ANOVA appropriate for a randomized block design (three randomized irrigation blocks with three trees of each species randomly placed within each irrigation block) using the GLM procedure in SAS (SAS Institute Inc., Version 9.1). When significant differences were observed among treatments, means were separated by Fisher's least significance difference procedure ($P \leq 0.10$).

Results and Discussion

Climatic data from each growing season were collected and seasonal means and totals are presented (Table 1). From 1997 to 2007 annual precipitation in Lubbock, TX, averaged 48.2 cm (19.0 in) (19). During the experiment period, total yearly precipitation was greater than average during 2004, but lower than average during 2003 and 2005 (Table 1). Yearly low temperature ranged from –15.3C (4.5F) to –11.6C (11.1F) and yearly high temperature was near 38.0C (100.4F). Mean growing season daily high temperature for each year was near 30.0C (86.0F) and mean daily ETo each year was approximately 6.0 mm (0.25 in). Volume of water applied to trees in low irrigation regimes ranged from 483 liters (127 gal) during the 2003 growing season to 2,072 liters (547 gal) during the 2005 growing season. Irrigation to trees that received medium irrigation ranged from 967 liters (255 gal) in 2003 to 4,145 liters (1,095 gal) in 2005. High irrigation regime trees were irrigated with 1,466 liters (387 gal) in 2003 and 6,443 liters (1,702 gal) in 2005. Throughout the experiment period all trees of each species survived and appeared healthy.

Maples. For each maple species, stem area increase did not differ between irrigation regimes (Table 2). For trident maple, shoot elongation was similar for each irrigation regime (Table 2). When compared to medium irrigation, hedge maple trees that received low or high irrigation treatments had greater shoot elongation. 'Autumn Blaze' and shantung maple shoot elongation was greatest for trees that received medium irrigation. Of maples tested, trident maple was the only maple in which shoot elongation did not respond to irrigation regime. Dirr (12) and Arnold (6) recommend trident maple as a maple that demonstrates good drought resistance. In fact, trident maple was recommended as a tree suitable for West Texas landscapes in 1932 (20). Hedge maple is also considered drought and air pollution tolerant

Table 2. **Effects of irrigation regime (low = 33%, medium = 66%, and high = 100% of reference evapotranspiration (ETo)) on mean, yearly stem area increase and shoot elongation for 13 field-grown tree species in Lubbock, TX. Each mean represents annual growth over three growings seasons (2003 through 2005).**

	Stem area increase (mm^2)				Shoot elongation (cm)			
	Irrigation treatment				Irrigation treatment			
Species	**P > F**	**Low**	**Medium**	**High**	**P > F**	**Low**	**Medium**	**High**
Acer buergeranum	0.571	227[z]	167	249	0.384	12.7	11.7	13.1
A. campestre	0.457	460	277	181	0.054	11.6a	9.7b	11.1a
A. × *freemanii* 'Autumn Blaze'	0.436	117	120	191	0.002	10.4b	14.8a	12.8a
A. truncatum	0.864	360	271	296	0.008	11.9b	12.9a	11.1b
Cercis canadensis mexicana	0.148	249	564	387	0.055	12.3ab	13.7a	11.6b
C. canadensis texensis	0.935	216	206	243	0.006	11.7ab	12.7a	10.4b
C. canadensis texensis 'Alba'	0.898	302	243	243	0.073	11.8a	9.5b	11.4a
C. canadensis texensis 'Oklahoma'	0.581	437	415	320	0.009	11.7ab	12.7a	10.4b
Crataegus phaenopyrum	0.632	296	206	232	0.001	10.8b	8.9c	13.6a
Fraxinus velutina coriaceae 'Bonita'	0.065	855ab	660b	1029a	0.277	17.1	14.7	16.1
Prunus mexicana	0.091	423b	539ab	784a	0.098	14.3a	14.1a	11.9b
Quercus muehlenbergii	0.227	186	266	333	0.001	7.5b	7.4b	9.7a
Q. robur	0.009	167b	581a	589a	0.001	12.9a	7.9b	12.6a

[z]Mean separation within species and stem area increase or shoot elongation row by LSD ($P \leq 0.10$).

and adapted to compacted and high pH soils (32). 'Autumn Blaze' maple is one of the Freeman maple cultivars (*Acer × freemanii*) developed from a cross between silver maple (*A. saccharinum*) and red maple (*A. rubrum*) (37). Bachtell (7) suggested Freeman maples could be more resistant to stress when compared to red maples. While Zwack et al. (45) advocates Freeman maples to be more ornamental when compared to silver maples. Data from our research indicate 'Autumn Blaze' is adapted to the high soil pH and semi-arid conditions found in regions of West Texas. Shantung maple also performed well in our trials (Table 2) and is thought to be a drought and heat tolerant species (12, 42).

Redbuds. For each redbud species, stem area increase did not differ among irrigation treatments, and shoot elongation tended to be greatest for trees that received less irrigation (Table 2). These data indicate increased irrigation on redbud trees did not promote increased growth. Redbud species are known to have a great range of shade and cold tolerance (38). In addition, several redbud species appear to be tolerant of diverse soil types and demonstrate some drought tolerance (13). Although information is available that describes characteristics of various redbud species (36, 38), our study is likely the first to investigate the relationship between water requirements and growth of redbud species in a semi-arid climate. Each redbud species in this research had outstanding spring flowering and performed well each year data were taken.

Oaks. Stem area increase for English oak was greatest for trees that received the high or medium irrigation treatment. However, stem area increase of chinquapin oak did not respond to irrigation regimes (Table 2). Shoot elongation for chinquapin oak was greatest for trees that received the greatest amount of irrigation. For English oak, there was no shoot elongation difference between trees that received low and high irrigation (Table 2). Many North American oaks are adapted to drought-prone sites and display ability to avoid or tolerate water stress (deep root systems, thick leaves, leaf curling or dropping during drought, and osmotic adjustment) (1). Native to mesic and dry-mesic sites throughout mid-west North America (23), chinquapin oak is thought to be adapted to xeric sites (8). In addition, Arnold (6) recommends chinquapin oak as a tree suitable for West Texas, and better adapted to alkaline when compared to acidic soils. Little research has been published on English oak's tolerance of drought or alkaline soils. However, Dirr (12) describes English oak as adapted to low or high pH soils. Epron and Dreyer (14) examined 30-year-old, native English oak stands over a period of two growing seasons. During this time they imposed severe drought on trees and measured stomatal conductance and photosynthetic rates. Due to its ability to maintain conductance and photosynthetic rates during drought, they describe English oak as a species with a high degree of drought tolerance. Chinquapin and English oaks in our study appear to be very tolerant of the well drained, alkaline soils found in West Texas.

Other species. Stem area increase for Washington hawthorn trees did not differ between irrigation treatments. However, shoot elongation was greatest for hawthorn trees that received the greatest irrigation volume (Table 2). Although Murakami (33) determined seedling Washington hawthorns have some ability to withstand drought, and Dirr (12) and Arnold (6) describe Washington hawthorn as an exceptional small tree, little information is known on the ability of Washington hawthorn to grow in alkaline soils and semi-arid conditions. We found Washington hawthorn to be very adapted to the soil and climate of West Texas. Although thorns can be a liability, spring flowering and reddish orange fruit from fall through winter give Washington hawthorn aesthetic qualities not found on many small trees.

Growth data for Arizona ash indicate greatest stem area increase was found on trees receiving low or high irrigation treatments. For shoot elongation, there was no growth difference between low, medium, or high irrigation levels (Table 2). Balok and Hilaire (8) found Arizona ash to be adapted to moderate drought. They suggest leaf pubescence, thickness, and wax make Arizona ash trees suitable for managed landscapes that are subjected to moderate drought. Arizona ash is known to have a moderate growth rate (8). In our study, regardless of irrigation treatment, Arizona ash generally had the greatest yearly shoot growth of all species (Table 2). Our data indicate Arizona ash to be well adapted to alkaline soils and semi-arid conditions found in much of the Southwest United States.

Stem area increase for Mexican plum was greatest for trees that received high or medium irrigation treatments. However, shoot elongation was greatest for trees that received low or medium irrigation treatments (Table 2). Mexican plum is native from the lower Midwestern United States into Mexico (34), and for a number of years has been recommended for planting in the southern United States (29). Although Mexican plum has been thought to be very drought and heat tolerant (38), our research is the first to compare growth associated with various irrigation treatments on Mexican plum trees in a semi-arid climate.

This research indicates irrigation volume may have an influence on stem and shoot growth of FG tree species. However, it is interesting to note greatest growth was not necessarily associated with trees receiving the greatest amount of irrigation. Therefore, it appears for some tree species irrigation volume may be reduced and produce similar growth when compared to trees receiving greater irrigation volume. In addition, it appears the influence of irrigation volume on growth of these FG tree species is plant structure and species specific. Despite irrigation differences, stem area increase for all but three species was similar. Therefore, for a majority of species in this study, stem area increase appears to be insensitive to irrigation volumes applied in this research. When compared to other growth variables, stem increase generally begins late in the growing season and is dependent upon current photosynthetic products (22, 30). Late in the growing season climatic conditions (light levels, air temperature, etc.) were lower when compared to climatic conditions during the majority of the growing season (data not shown). A mild climate late in the growing season could reduce the influence of water stress on gas exchange (stomatal conductance and photosynthesis) (30) between irrigation treatments such that gas exchange levels may be similar between irrigation treatments for many tree species tested. Within each species, if late season carbon assimilation levels were similar between treatments, it is likely stem area increase differences would not be found between irrigation regimes. Additional research is likely required to confirm how irrigation volume, climate, time of year, and growth patterns of tree species are related. Our data also suggest irrigation of FG trees based upon soil surface root area and local ETo measurements may be a means to conserve irrigation water and produce FG trees with acceptable growth. However, for most growers measuring root area each year on numerous trees would not be practical. Therefore, other means to calculate irrigation volume (stem area, projected crown area, etc.) could be examined.

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