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A Study of Irrigation Requirements of Southwestern Landscape Trees

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Introduction

Trees are an important component of our landscapes, providing many benefits from shade to cleaning the air. Large, mature trees provide the greatest benefits in urban landscapes compared to smaller, younger trees and it is therefore important to ensure that trees in our urban forests receive the amount of water they need to develop into healthy, mature specimens.

Trees planted in urban landscapes need regular watering during establishment to develop a healthy root and shoot system. After establishment, tree species differ in how much supplemental irrigation they need to grow to their mature size and to remain healthy. Increasing the amount of irrigation water does not always result in more tree growth. Responses vary by how often and how much water a tree receives, the degree to which the soil dries between irrigations, and the amount of water a plant needs based on weather conditions, primarily solar radiation, temperature and wind. Recommendations for irrigation amounts and frequencies can be found in several publications (AMWUA, 2005; Costello and Jones, 2014) however, these values are generally based on expert agreements or anecdotal evidence and not on scientific experiments.

Following are the results of a study conducted at the University of Arizona Maricopa Agricultural Center in Maricopa, Arizona to determine the irrigation needs of nine species of commonly planted landscape trees. After planting, trees were well watered for 1.5 years for establishment, allowing approximately 25% soil moisture depletion between irrigations during summer (June to August) and 35% depletion during the remainder of the year. In summer, this required weekly irrigation with 20 gallons of water per tree. After this establishment period, three irrigation frequency treatments were applied to trees. This study describes the subsequent four seasons of irrigation regimes after establishment and the irrigation frequency study. During the last year of the study, trees were grown without supplemental irrigation to simulate what happens when irrigation is suddenly turned off. Recommendations are given for irrigating the nine species of trees that were studied.

Experimental Methods

Trees used in this study and their characteristics are listed in Table 1. Trees were transplanted from #15 containers in

Table 1. List of species used and their characteristics.

Latin Name	Common Name	Native / Desert adapted	Type
Cupressus arizonica	Arizona cypress	SW native	evergreen conifer
Chilopsis linearis 'Art's Seedless'	Desert willow	SW native	deciduous
Ebenopsis ebano	Texas ebony	SW native	semi-deciduous
Fraxinus velutina 'Rio Grande'	Rio Grande ash	SW native	deciduous
Parkinsonia thornless hybrid	Palo verde hybrid	desert adapted	semi-deciduous
Pinus eldarica	Afghan pine	desert adapted	evergreen conifer
Pistacia x 'Red Push'	Red Push pistache	desert adapted	deciduous
Prosopis velutina	Velvet mesquite	SW native	deciduous
Quercus virginiana	Southern live oak	desert adapted	evergreen broadleaf

January 2007 at a spacing of 20 feet within a row and 45 feet between rows. Eighteen trees of each species were planted, providing six replicate plants for three irrigation treatments.

Irrigation Treatments and Data Collection

In September 2008 after establishment of the trees, an irrigation frequency study was initiated and applied for 18 months. The three treatments applied were to allow the soil moisture in the root zone (6 foot diameter and depth of 2 feet) to deplete to 70%, 50% or 30% of available soil water and then irrigated to fill the profile. Water depletion was calculated based on the local reference evapotranspiration from the nearby local weather station. Once the root zone was depleted to the appropriate amount, all trees in a treatment were irrigated using a bubbler system with one bubbler placed in a circular trench 3 feet from the trunk. The amount of water applied to each treatment on a yearly basis was the same, but irrigation frequencies varied between treatments. Growth and plant quality of each species did not differ between the treatments and trees for each species were of similar size when the study was concluded in April 2010 (data not shown). For the following study, all trees irrigated most often (30% depletion) were moved to the medium treatment, those watered with medium frequency were moved to the wet treatment, and the ones watered least (70% depletion) remained in the dry treatment. Each treatment is described in detail below.

From May 2010 until March 2014, three different irrigation treatments were applied to determine how tree growth and quality are affected by different irrigation regimes. Irrigation treatments were applied as a percentage of the reference evapotranspiration (ET_o) at the site. Evapotranspiration is the amount of water lost due to the evaporation of water from the soil surface and the loss of water through plant transpiration. All weather data, including reference ET_o was obtained from the Arizona Meteorological Network (AZMET) weather station located about 600 feet from the experimental site. Irrigation was applied when the available soil moisture in the root zone was depleted by 50%. The bubbler irrigation system then delivered the wet, medium, and dry treatment consisting of 80%, 60%, or 40% of ET_o from May until October and 40%, 30%, or 20% of ET_o from November to April. Irrigation was cut in half during the cool season to test whether plants can tolerate less supplemental water during the winter months when evapotranspiration demand is low. Rainfall of more than 0.2 inches was subtracted from the accumulated ET_o since the most recent irrigation and delayed the next irrigation. Each irrigation event in this study applied between 48 to 58 gallons per tree. This was based on wetting an area of a circle about 6 feet in diameter to a depth of 2 feet. The amount of water applied was calculated based on the soil texture and soil water holding capacity at the study site. Table 2 shows some of the irrigation events and weather conditions at the site.

In April 2014 the irrigation system was removed to determine how trees respond when they are suddenly left to rely only on natural rainfall. In January 2015 trees were cut about 5-10 inches above the ground. Sections of the trunk were prepared for tree ring analysis. Root systems of trees were excavated in March 2015 with a backhoe and soil in the root system was removed with an air spade.

In spring and fall of each year, plant height, trunk diameter (4 inches above the soil), and two canopy diameters (at a height of 4 to 5 feet) which were used to calculate canopy area, were measured. Monthly quality ratings evaluated foliage appearance and density, health problems, and overall appearance. The rating system for overall quality was 0 = dead, 1 = barely alive or very poor quality, 2 = poor quality and unacceptable appearance, 3 = medium quality, minimum acceptable appearance, 4 = high quality, good appearance, 5 = outstanding quality and appearance. Tree ring growth of the most recent six years was measured on the trunk sections. The diameter of the ten largest roots was measured at a constant distance (16 inches for all species except 39 inches for palo verde) from the center of the root ball. Qualitative evaluation of root systems included a rating on the degree of girdling or root bound condition, the percentage of fibrous roots, and vertical and radial root distribution emerging from the original root ball. Irrigation application times and quantities were recorded continuously.

Irrigation Regimes and Weather

The experimental site was located in the arid climate of the Sonoran Desert at an elevation of 1180 feet in Arizona where summer temperatures exceed often 100°F up to several weeks and freezing temperatures occur in December and January (Table 2). ET_o at the experimental site ranged from 2 inches per month in December to 11 inches per month in June, the month with the highest ET_o demand. Rainfall is almost equally divided between the summer rains from July to September and during the winter months.

The frequency of irrigation differed substantially between treatments resulting in about 10 irrigation events for the dry and 21 events for the wet treatments per year (Table 2). Irrigation during the summer was applied more than once per week for the wet and only every other week for the dry treatment. In winter, trees in the wet treatment were irrigated about every three weeks, whereas trees under the dry treatment went without irrigation for over four months. This was primarily the case when ET_o was low and rainfall more than 0.5 inches partially filled the soil profile and delayed the next irrigation.

Plant Responses to Irrigation Treatments

Plant Growth

The three irrigation treatments did not cause differences in height, canopy area, and trunk diameter for each species

Table 2. Irrigation events and weather conditions during irrigation treatments at the experimental site from May 2010 to March 2014.

Events	Wet	Medium	Dry
Irrigation events per year (No.)	19-23	14-17	9-11
Average annual irrigation per tree (Gal.)	940	644	518
Longest interval (days) between irrigations	76-124	132-155	135-189
Shortest interval (days) between irrigations	4-6	6-10	10-15
Annual reference evapotranspiration (ET_o)	73.1 - 74.5 inches		
Annual rainfall	3.1 - 7.4 inches		
Annual highest average monthly maximum temperatures	105 - 107°F		
Annual lowest average monthly minimum temperatures	32 - 35°F		

Table 3. Plant height, canopy area, and trunk diameter at the beginning of the irrigation experiment in March 2010 and at the conclusion of irrigation treatments in March 2014. Means are the average of 18 trees grown under three irrigation treatments.

Species	Height (ft.)		Height increase	Canopy area (ft^2)		Canopy increase	Trunk diameter (in.)		Trunk increase
	2010	2014	%	2010	2014	%	2010	2014	%
Palo verde hybrid	13.2	20.0	52	167	524	214	5.5	9.6	76
Velvet mesquite	9.6	12.3	28	100	269	170	3.5	5.9	67
Red Push pistache	11.4	13.6	19	27	119	340	4.1	7.0	70
Desert willow	9.2	12.6	36	38	103	171	3.1	5.7	80
Texas ebony	6.6	7.8	18	30	53	76	2.6	3.6	40
Arizona cypress	9.0	10.3	14	21	48	127	3.2	4.1	27
Live oak	8.7	9.5	10	14	31	118	2.6	3.6	35
Afghan pine	9.2	11.8	29	11	31	177	3.9	5.1	32
Rio Grande ash	9.9	10.3	4	20	30	49	2.7	3.7	35

over a period of four growing seasons. Average means of the three irrigation treatments are presented in Table 3. The one exception was the Southern live oak where the dry treatment had a smaller canopy area than the wet treatment. Representative trees of each species at the beginning of the irrigation treatments are shown in Figure 1. By March 2014, all plants had significantly increased in size, particularly in canopy area (Table 3, Fig. 3). Palo verde grew fastest, followed by mesquite, pistache, and desert willow, while the other trees grew at a slower rate.

Analysis of tree ring growth after four seasons of irrigation treatments and one season without supplemental irrigation showed no difference between irrigation treatments for each species. Figure 2 shows the trunk section samples and tree ring growth demonstrating that irrigation regime had little effect on trunk circumference. The small diameter of one pine tree growing under the medium treatment may have been related to some factor other than irrigation.

Plant Quality

All plants were in good condition in 2010 when the irrigation treatments started (Fig. 1). Their ratings were between 4 and 5 (5 being the highest) for overall plant quality, indicating that they had foliage, flowers, and fruit as would be expected of a healthy tree, and there was no

Fig. 1. Plants in May 2010 at the beginning of the irrigation experiment. Upper row left to right: live oak, Rio Grande ash, Texas ebony; middle row left to right: Red Push pistache, desert willow, Arizona cypress, Afghan pine; lower row left to right velvet mesquite and palo verde hybrid.

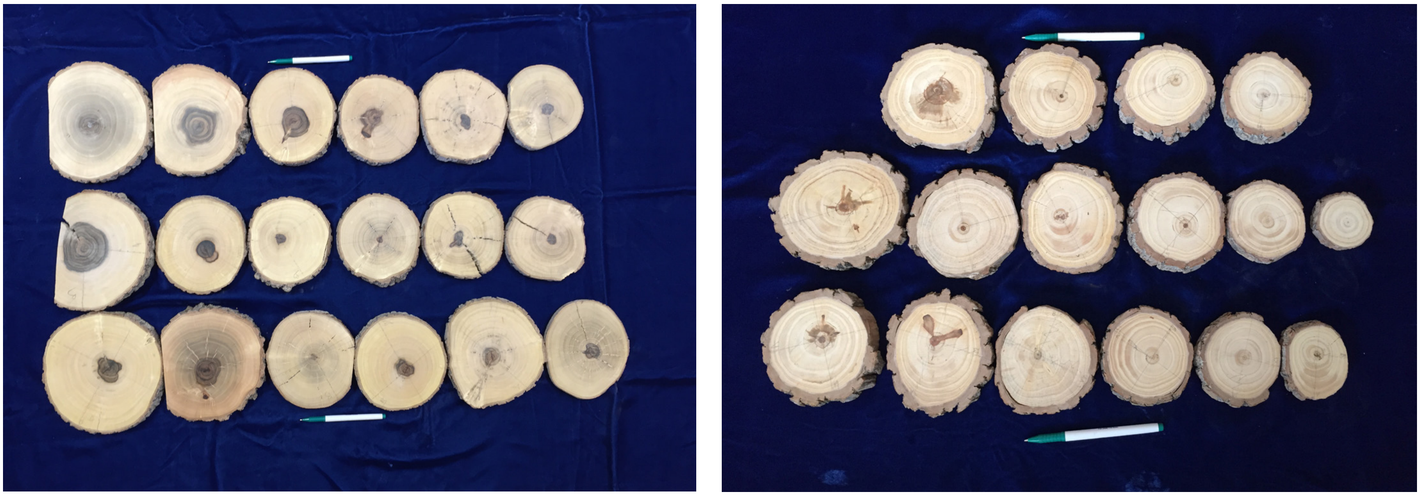

Figure 2. Trunk samples collected in January 2015 of Red Push pistache (left) and Afghan pine (right) prepared for measuring annual growth rings. Trees under wet, medium, and dry treatment are in the top, middle, and bottom row, respectively. (For scale, the pencils are 5.5 inches long.)

Figure 3. Trees that maintained good quality when irrigated with the wet treatment for four seasons. (March 2014).

Figure 4. Arizona cypress (left two images) under wet and dry irrigation, and Afghan pines (right two images) under wet and dry irrigation treatments.

evidence of insect, disease, or abiotic stress. Quality ratings of palo verde, mesquite, pistache, desert willow, Texas ebony, and live oak (except for dry treatment) never dropped below 4.0 (high quality, good appearance) for any treatment from May 2010 until February 2014.

Although all plants continued to increase in size, overall quality of Afghan pine, Arizona cypress, Rio Grande ash, and live oak under the dry or medium irrigation treatment started to decline in quality (Fig. 4, Table 4). Afghan pines under the dry treatment slipped to 2.8 in July 2013, below the minimum acceptable rating of 3.0, and remained there until February 2014. The pines under the wet treatment maintained good quality ratings around 4.4, and those under the medium treatment maintained the minimum acceptable rating. Arizona cypress ratings for the dry treatment were 3.3 from July 2013 until February 2014. The lower quality was due to loss of foliage or foliage with marginal leaf burn or dead leaves. Ash trees under the dry treatment dropped to a 3.0 quality rating in May 2013, down to 2.4 for a couple of months, and recovered to a 3.0 rating by February 2014 (Table 4). From November 2013 until February 2014, Rio Grande ash under the medium and wet treatments had quality ratings barely above the minimum acceptable rating. Live oak overall quality under the dry treatment (3.8) was consistently lower than the excellent rating of the wet treatment, however their appearance and functionality was still good. Many of the stressed trees showed some recovery during early spring, but then continued to decline again as temperatures increased and irrigation was suspended.

Plant Responses under Simulated Drought when Irrigation was Discontinued

Mesquite, pistache, desert willow, live oak and palo verde were not detrimentally affected by lack of irrigation during the 2014 growing season with overall quality rating between 3.4 and 4.8 by January 2015 at the conclusion of the experiment (Fig, 5, 6, Table 4). Palo verde produced fewer leaves although the plant quality was still good. Tree quality of several species deteriorated by June, which is not surprising considering that the total reference evapotranspiration (ET_o) was 28.4 inches during the three months with no precipitation at the site. Average monthly high temperatures were 97°F, 106°F, and 109°F for the months of April, May, and June, respectively.

During the simulated drought in June 2014, the average overall quality of Arizona cypress was 2.9, Afghan pine 2.6, Texas ebony 2.7 and Rio Grande ash 3.1. One Arizona cypress previously irrigated with the wet treatment had started to decline in spring and died by June. Plants from the previous wet treatment which received an overall quality rating indicating unacceptable appearance and poor health included four Texas ebony, one Rio Grande ash, one live oak, and one Afghan pine. Plants from the previous medium treatment with unacceptable appearance included three pines, two Texas ebony, two Rio Grande ash, and one Arizona cypress. Plants from the previous dry treatment had the fewest ratings of 5 (excellent quality and appearance). Only pistache, mesquite, four desert willow and two live oaks received this high rating while most plants received ratings of 3 or 4. A total of eight trees under the previous dry treatment were rated as unacceptable overall quality: four Afghan pines, two Texas ebony, and two Arizona cypress.

Summer rains starting in July 2014 caused a flush of new foliage in several trees followed by milder decline (Fig. 6). Heavy rains totaling 1.4 inches from September 27 to October 8, 2014, helped many trees recover and cooler temperatures in fall slowed the decline. Afghan pine, Arizona cypress, and Rio Grande ash trees lost more foliage during the drought (Fig. 5, 8). Some live oak also dropped leaves and had some branch tip dieback. Texas ebony had been performing well under all three irrigation treatments until the onset of drought. Trees started to fold their leaves, then lose their leaves and developed branch dieback starting at the terminal end (Fig. 7). One tree from the previous dry treatment died and several others sustained major branch and trunk dieback. The September rain likely saved several of the trees of this and other species from further decline. Some Texas ebony were however, damaged beyond complete recovery and likely would have declined further had the experiment continued. The fact that Texas ebony does not seem to tolerate sudden drought is surprising since it is native to the Southwestern United States, though not the Sonoran Desert where this study was done.

By the end of the year as temperatures were cooling and aided by the fall rains, some plants recovered and grew new foliage. However, overall quality of most pine, cypress, ash, and some Texas ebony remained unacceptable.

Survival

At the conclusion of the study in January 2015, all trees of mesquite, desert willow, pistache, and Southern live oak survived. (Table 4). Survival of Texas ebony and Afghan pine was 94% (one tree died) and survival of ash, palo verde, and Arizona cypress was between 78% and 89%. Of the eleven trees that died, four trees each were in the wet and medium, and three trees were in the dry irrigation treatment. Three palo verde trees were lost due to a microburst in the second year of the study which was unrelated to irrigation treatments. The Texas ebony and the Afghan pine died after the irrigation was suspended in 2014.

Root Growth

Irrigation treatments followed by one year without supplemental irrigation had no effect on root diameter or qualitative root characteristics when compared for each species. Root size and morphology differed between species. The fast growing species palo verde (Fig. 9), mesquite, desert willow, and pistache (Fig. 10), had similar root diameter for the ten largest roots we measured, between 35 to 39 mm.

Fig. 5. Trees in June 2014, previously under the dry (top) and medium (bottom) treatment, and without irrigation since the beginning of March 2014.

Fig. 6. Summer rains resulted in some trees growing new foliage and recovering from the drought by August 2014.

Fig 7. A healthy and a dead Texas ebony (top). By June 2014 several Texas ebony trees showed partial defoliation, branch dieback, and damage to the trunk (bottom).

Fig. 8. Rio Grande ash canopy healthy (left) and increasing stages of defoliation and leaf burn (middle and right).

The range of root diameter was between 20 mm and 64 mm for these species. Roots of live oak (Fig. 11) and ash (Fig. 12) were on average 20 mm and 17 mm in diameter.

The two conifers had the most fibrous root system with average root diameter of the ten largest roots at 11 mm for the Afghan pine and 12 mm for the Arizona cypress (Fig. 11). The systems were almost exclusively composed of very small diameter roots. Contrary, the root systems of desert willow, ash, palo verde and mesquite consisted mainly of large diameter primary roots with very few fibrous roots.

Root girdling and deformations leading back to pot bound conditions at the time of transplanting were severe in ash (Fig. 12) and may have contributed to their poor growth performance throughout the study. Arizona cypress, live oak, and Texas ebony also showed some of these defects, but not to the degree observed in the excavated root systems of ash trees.

All excavated root systems had horizontally spreading roots outside of the originally planted root ball. This indicated that the trees had established well at the beginning of the study and we found no evidence that any irrigation treatment affected the horizontal root growth. Palo verde was the only species where greater numbers of roots grew vertically from the original root ball. The two conifers had almost no vertical roots growing from the original root ball and the other species had only a few.

Summary and Conclusions of the Irrigation Study

- After 4 years of irrigating trees at half or three quarter of the highest treatment, the following species were not significantly smaller in size with less water: mesquite, palo verde thornless hybrid, 'Red Push' pistache, Desert willow 'Art's Seedless', Texas ebony, and Southern live oak.
- All species increased in height, canopy area, and trunk diameter with few significant differences for the same species receiving different irrigation treatments. Southern live oak under the dry treatment developed a smaller canopy area than under the wet treatment.

Fig. 9. The coarse root system of palo verde had the largest diameter roots and the greatest number of roots growing straight down into the soil.

Fig. 10. Desert willow (left), mesquite (middle), and Red Push pistache (right) developed large diameter roots that grew primarily horizontally and well beyond the irrigated area. Desert willow and mesquite had a coarse root system with few fibrous roots, while the pistache root system had more fibrous roots.

Fig. 11. Live oak (top left) and Texas ebony (top right) root systems had a few larger diameter roots and were intermediate in fibrosity. Afghan pine (bottom left) and Arizona cypress (bottom right) root systems had the smallest diameter roots and the greatest percentage of fibrous roots. Root systems of live oak, Texas ebony, and Afghan pine were sprayed with white paint to improve the visibility of the roots.

Fig 12. Roots of Rio Grande ash were severely root bound and girdled.

- Severe symptoms of deficit irrigation (leaf burn and abscission, branch dieback, plant death) started to develop on Arizona cypress, Afghan pine, and Rio Grande ash, especially under the dry and sometimes medium treatment even before the onset of drought.

Summary and Conclusions of the Simulated Drought Study

- Mesquite, desert willow 'Art's Seedless', 'Red Push' pistache, palo verde thornless hybrid, and Southern live oak maintained good quality during the simulated drought in the 2014 growing season.
- Overall quality of Afghan pine, Arizona cypress, and Rio Grande ash was unacceptable at ratings below 3.0 for most of the trees.
- Texas ebony had ratings below 3 during the summer months but recovered in fall. Texas ebony could not tolerate an abrupt lack of irrigation once accustomed to regular irrigation.

Table 4. Overall quality rating of trees in February 2014 after four growing seasons of irrigation treatments and in January 2015 after one season without supplemental irrigation, survival rates in January 2015 and recommended irrigation rates. Quality rating scale is 1-5 with 1=dead, 3=minimum acceptable, 5 = excellent.

Species	February 2014			January 2015				Recommended irrigation ET_o rate*	Comments
	Dry 40/20**	Medium 60/30	Wet 80/40	Dry 40/20	Medium 60/30	Wet 80/40	Survival (%)		
Palo verde hybrid	5.0	4.8	5.0	3.4	3.8	4.0	83	40/20	After establishment, plant may thrive with less than recommended rate.
Velvet mesquite	4.7	4.5	4.8	4.3	4.2	4.2	100	40/20	
Red Push pistache	5.0	5.0	5.0	4.8	4.3	4.2	100	40/20	
Desert willow	5.0	5.0	5.0	4.5	4.0	4.5	100	40/20	
Texas ebony	4.5	4.8	5.0	4.2	3.8	3.2	94	40/20	After establishment, plant may thrive with less than recommended rate but cannot tolerate abrupt lack of irrigation.
Live oak	3.8	4.5	5.0	3.5	3.8	4.8	100	60/30	Plant may benefit from higher irrigation rates in winter than used in this study.
Arizona cypress	3.3	4.0	3.2	3.0	3.6	2.0	89	60-80 year-round	Conifers may benefit from more irrigation in winter than used in this study.
Afghan pine	2.8	3.0	4.4	1.8	2.2	3.3	94		
Rio Grande ash	3.0	3.3	3.4	1.8	2.6	2.3	78	60-80/30-40	Study results not conclusive because of root system defects preventing trees from thriving.

* 40/20 refers to 40% ET_o from May to October and 20% ET_o from November to April.

Irrigation Recommendations

- Irrigation application treatments for this study were calculated based on the reference evapotranspiration ET_o at the site. ET_o was obtained from the AZMET weather station located close to the experimental site (http://ag.arizona.edu/azmet/). There are more than 25 AZMET weather stations primarily located in southern and central Arizona. To find your local ETo use data from the station closest to your location.
- This study was conducted on trees that received ample irrigation for the first three years after transplanting to ensure their root systems were well established. In this study the wetted soil surface area was not increased over time. As trees grow and further increase in canopy size, the irrigated area and the amount of water they receive at each irrigation needs to be increased.
- Each irrigation event in this study applied between 48 to 58 gallons per tree which filled the soil volume in an area of a 6 feet diameter circle to a depth of 2 feet. The amount of water applied was calculated based on the soil texture and soil water holding capacity at the study site. The amount of water to be applied at any site will depend on the soil texture and the volume of soil to be irrigated at each cycle.
- For species tolerating the low or medium irrigation treatment (mesquite, desert willow, palo verde, pistache, Texas ebony, and Southern live oak), irrigation with 40% ET_o from May to October and 20% ET_o from November to April, or 10 to 16 irrigation events per year depending on ET_o, resulted in healthy trees of similar size compared to trees in the wet treatment.
- During the period of highest evapotranspiration in summer, irrigation applied every 8 to 14 days was sufficient for trees tolerating low or medium irrigation treatment.
- The evergreen conifers Afghan pine and Arizona cypress likely would benefit from receiving more irrigation in winter compared to the deciduous or semi-deciduous trees in this study. They should receive

irrigation based on 60-80% of ET_o at their location year round to remain functional and healthy.

- If irrigation needs to be cut back or eliminated for any reason, providing the conifers (pine and cypress) and Texas ebony with some supplemental irrigation will be critical to maintain their long-term health and survival.

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