Tree Irrigation Requirements in the Semiarid Southwestern United States

Ursula K. Schuch¹

ADDITIONAL INDEX WORDS. landscape management, plant water use, drought, heat stress

SUMMARY. Several large cities in the southwestern United States have set a target to increase their tree canopy cover up to 25%, which often requires more than doubling the current canopy cover. A major goal is to alleviate high temperatures and support public health in addition to gaining all the other benefits conferred by urban forests. Rising temperatures, the arid climate, continued drought, increasing population numbers, and the growing urban forest in the southwestern United States fuel the demand for more water. Using water wisely to garner the benefits of trees requires the application of sufficient irrigation based on the water needs of different species. Current irrigation recommendations for trees are often based on expert consensus. Research-based results of tree irrigation studies from the southwestern United States are presented to give specific examples of how trees respond when they are exposed to different irrigation regimes.

Trees are an important component of urban landscapes and mitigate temperature and local microclimate effects, improve air quality by removing pollutants, store carbon and reduce carbon dioxide emission, and lower energy use for heating and cooling of buildings (Nowak, 1995). In addition to environmental benefits, trees also play an important role in supporting public health. A study relating the loss of 100 million ash trees (*Fraxinus* sp.) to the emerald ash borer (*Agilus planipennis*) found an increase in human mortality due to cardiovascular and lower respiratory tract disease (Donovan et al., 2013). This study found a significant relationship between tree loss due to the borer and increased human mortality while adjusting for many demographic covariates. In the southwestern United States, high temperatures in summer pose serious health threats to humans. Landscape designers and architects place trees

strategically to alleviate high temperatures in urban areas. In Phoenix, AZ, summer temperatures in lower socioeconomic neighborhoods with higher building density and less vegetation cover compared with highly vegetated neighborhoods had higher temperatures and exposed residents to heat indices associated with dangerous levels of heat disorders, especially during a heat wave (Harlan et al., 2006).

The role of trees in southwestern U.S. urban landscapes

In the southwestern United States, the cities of Tucson, AZ; Las Vegas, NV; and Phoenix, AZ, have developed plans to increase their tree canopy cover. The City of Tucson had a 10,000 Trees Campaign from 2013 to 2014 and reached that goal before the end of 2014. Subsequently, they expanded their plans to double the initial number of trees planted (City of Tucson, 2014). The City of Las Vegas started an urban forestry initiative in 2008, with the goal to double the average tree canopy to 20% by 2035 (City of Las Vegas, 2008). The goal of the City of Phoenix is a 25% tree canopy cover by 2030 compared with a 10% canopy cover in 2010

(City of Phoenix, 2010). This increase in tree canopy is critical, as Phoenix has the highest temperatures of all the major cities in the nation [National Oceanic and Atmospheric Administration (NOAA), 2017]. The City of Phoenix Cool Urban Spaces Project compared how cool roofs and urban forests affected temperatures in the city and found the greatest benefits of lowering temperature in neighborhoods with mesic landscaping and 25% tree canopy cover compared with bare neighborhoods without tree cover (Middle and Chhetri, 2014). The study found that increasing tree canopy cover from no trees to 10% lowered the temperature in residential areas by an average of 3.6 °F. A further increase in tree canopy to 25% resulted in a reduction of 7.9 °F or daytime temperatures of 99.5 °F compared with the residential area without trees, with average daytime highs of 111 °F.

The arid climate and warm temperatures in Arizona continue to attract more residents. Population in July 2017 was estimated at seven million (U.S. Census Bureau, 2018) and Arizona has been among the top 10 states in population growth in recent years. The growing population and demand for more trees in urban landscapes require the judicious use of water resources. Water use in Arizona is dominated by agriculture (74%), followed by municipalities (21%) and industry (5%) [Arizona Department of Water Resources (ADWR), 2017a]. Average residential water use in Arizona was 147 gal/capita per day in 2010, higher than in neighboring California (108 gal/capita per day) and Texas (92 gal/capita per day).

A number of factors influence how much water is used or conserved in residential landscapes. They include latitude, elevation, microclimate, and the landscape types preferred which may be more mesic near the coast or riparian areas, or more xeric at higher elevation and in semiarid or arid locations. Water use in urban areas increases during the growing season to irrigate landscapes and depends on the

School of Plant Sciences, University of Arizona, Tucson, AZ 85721

This article results from the workshop “Maintaining Healthy Landscapes Under Drought and/or Permanent Water Restrictions” held on 20 Sept. 2017, at the ASHS Annual Conference, Waikoloa, HI, and sponsored by the Ornamentals/Landscape and Turf (O/LT) Professional Interest Group.

The author acknowledges grant funding related to research reported in this article by the Bureau of Reclamation, University of Arizona Technology and Research Initiative Fund–Water Sustainability Program, and the Arizona State Forestry Division.

¹Corresponding author. E-mail: uschuch@email.arizona.edu.

<https://doi.org/10.21273/HORTTECH04045-18>

Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

evaporative demand and rainfall in a geographic area. In the arid mountainous western United States, irrigation can total up to one-third to almost one-half of the total municipal water use (Vickers, 1991). In Los Angeles, CA, single-family residences used about half of their water for landscape irrigation (Mini et al., 2014). Three cities in New Mexico showed different preferences for mesic or xeric landscapes based on their location, regional culture, education, and water cost (Hurd, 2006).

The southern areas of Arizona are characterized by some of the hottest and driest climates in the nation. Since 2000, the number of extremely warm nights more than 80 °F have increased, along with the summer daytime highs and nighttime lows (NOAA, 2017). By the middle of this century, unprecedented increases in temperature and extremely hot conditions are forecast for the urban Phoenix area. Although trees lower daytime temperatures, the urban heat island effect is expressed in higher nighttime temperatures in the city compared with the surrounding agricultural or desert areas and trees contribute to this by trapping heat in the canopy (Middle and Chhetri, 2014).

Precipitation in 14 of the last 20 years was below average levels in Arizona and many areas in the state and neighboring states were affected by different severity levels of drought during that time (NOAA, 2017). Forecasts predict that spring precipitation will be lower than average and winter droughts will become more common. This forecast extends to the neighboring states of California, New Mexico, and into Texas, with the southern portions of those areas affected more severely.

With the increase in the number of trees planted in urban areas in the southwestern United States and the need to conserve water, landscape managers need to know how to maintain healthy trees with minimum water in a hotter and drier climate. Longer hotter summers, higher night temperatures and higher respiration rates, warmer winter temperatures, and the likelihood of continued drought all raise the question, which tree species are best adapted to these conditions and which ones are most

likely to survive with the lowest amount of supplemental irrigation?

Recent tree issues in the desert southwestern United States

In recent years, Cooperative Extension personnel in Arizona have received a growing number of questions about why native or desert-adapted trees that were well established and ranged in age from less than 5 years to several decades old in landscapes declined or died. Although trees were inspected for disease organism or insect problems, in many cases, none was found and the conclusion was that abiotic factors caused the demise. These issues were found both in trees that may have received sufficient or insufficient irrigation. It is unknown whether some of the record high summer temperatures or multiple consecutive dry winters may have led to this situation, however, insufficient irrigation over a long period is often suspected of causing decline or death of trees. The warming climate is expected to detrimentally affect forests, especially in water-scarce areas such as the western United States. Although it is still not known how the future survival of sensitive tree species will be affected, a recent study addressed some of these uncertainties by determining the impacts of both drought and insects, two major factors affecting tree mortality, on forest health (Anderegg et al., 2015).

Pine trees have started to perform very poorly in the Sonoran Desert in recent years. Starting in 2014, mature, nonnative Aleppo pine (*Pinus halepensis*) and Afghan pine (*Pinus eldarica*) in Tucson started to decline and die within a few weeks. A pine engraver beetle (*Ips calligraphus ponderosae*), native to Arizona's higher elevations but never before found in nonnative pines (*Pinus* sp.) and at lower elevations ≈2400 ft, has been identified as the cause of death in many of these trees (Warren et al., 2015). The engraver beetles generally target trees that are stressed because of lack of water or physical damage. Prevention of drought stress is the recommended treatment to ensure healthy trees. Pines require year-round irrigation, and pine species from Mediterranean climates rely on sufficient moisture in winter, supplied by precipitation in their native environment. Higher tree mortality of

pine, aspen (*Populus* sp.), and juniper (*Juniperus* sp.) in forest ecosystems has been documented resulting from insect outbreaks, increasing temperatures, and drought (Anderegg et al., 2015). Future research needs to address how these factors interact in urban forests and how strategic management can keep trees healthy.

Brown needles on branch tips or entire branches dying on pine trees in the low desert of Arizona and Nevada have alarmed many residents, landscapers, and arborists recently. Pine blight is primarily found on Aleppo pine and symptoms start to appear in winter. The cause of this physiological disease is not known, but drought, extreme day or night temperatures during the previous summer, or a mite are suspected to trigger the symptoms (Olsen, 1999).

The environmental benefits from large canopied trees such as pine or palo verde (*Parkinsonia* sp.) are crucial to mitigate the high temperatures in the desert southwestern United States. The increased rate of decline or death caused by abiotic and biotic stressors puts future planting and survival of some large tree species at risk, especially if best irrigation and other cultural practices are not followed consistently. Landscape planners and maintenance personnel need to understand how much water is necessary and how to apply it appropriately to ensure that large-canopy trees, which constitute a significant long-term investment in a landscape, will thrive and provide optimal benefits.

Current irrigation recommendations for trees in the southwestern United States

The Southern Nevada Water Authority (2017) recommends watering depth for trees and a minimum number of emitters based on canopy size but does not provide specific amounts of water to be applied for landscape plants. The New Mexico Office of the State Engineer (2017) Water Use and Conservation Bureau recommends watering trees once per month in winter and every other week during the growing season, with frequency increasing to weekly irrigations during the hottest time of the year. They also recommend how deep to water and wetting the soil at and outside of the canopy drip line. Texas has tree irrigation recommendations from different

water organizations, such as the Texas Water Development Board, Water Departments from different cities, and the Texas A&M AgriLife Extension Service (Clatterbuck and Tankersley, 2009), providing general guidelines similar to those from Nevada and New Mexico.

In Arizona, irrigation recommendations for trees are available through the Arizona Municipal Water Users' Association (AMWUA, 2005). AMWUA represents 10 municipalities in the greater Phoenix metro area and promotes the responsible use of water. Their watering guide is based on classifying trees as either desert adapted or high water use plants. Recommendations include how often to water during the different seasons and the amount of water needed to wet the root zone of trees depending on their canopy diameter. These values were agreed on by experts working in horticulture, landscape irrigation, urban forestry, and arboriculture when the landscape watering guide was developed. The City of Tucson (2018) released landscape watering guidelines Water by the Weather, for trees categorized as low, medium, or high water users and growing in three typical soil types from silty clay to loamy sand. The number of irrigation days are given for each month and a constant runtime is recommended to ensure proper watering depth of the root zone.

Many agencies, organizations, or municipalities have developed plant lists and assigned low, medium, or high water use to individual species in all southwestern U.S. states. Low water use, drought tolerant plants are in the official regulatory list for the five active management areas (AMAs) managed by ADWR (2017b). AMAs were created in 1980 to ensure a long-term management and conservation of groundwater because the areas relied primarily on groundwater supplies and housed more than 80% of the population. These lists developed by experts with local knowledge in horticulture and urban forestry are used by municipalities and other organizations to establish and maintain landscapes with plants that foster water conservation. California uses Water Use Classification of Landscape Species (Costello and Jones, 2014) to recommend irrigation amounts needed for many plant species, some appropriate for the southwest low desert of California.

Scientific studies on the response of trees to different irrigation regimes in the southwestern United States

Previous studies conducted in the arid climate of the southwestern United States found that landscape trees do not always grow larger in response to increased irrigation (Devitt et al., 1995; Fox and Montague, 2009). Trees adapt to increasing drought by adjusting physiological responses to the lack of water and continue to transpire (Balok and St. Hilaire, 2002). A greater amount of irrigation did not translate to a higher rate of photosynthesis and growth of two cultivars of redbud [*Cercis* sp. (Fox et al., 2014)]. Tree water use under conditions that do not limit the amount of irrigation water trees receive showed that trees considered xeric-adapted, such as south american mesquite (*Prosopis alba* 'Colorado'), used more water than live oak (*Quercus virginiana* 'Heritage') that are adapted to mesic environments (Levitt et al., 1995).

An irrigation study was conducted with the objective to determine how nine species of commonly planted landscape trees perform with different levels of irrigation in the low elevation Sonoran Desert in Maricopa, AZ (Schuch and Martin, 2017). From May 2010 until Mar. 2014, trees planted in early 2007 and well established, were assigned treatments based on soil water depletion and irrigation as a percentage of reference evapotranspiration (ET_o). The ET_o data were obtained from the Arizona Meteorological Network (AZMET) weather station located within 600 ft from the study site. Irrigation using bubblers was activated when the available soil moisture in the root zone (6 ft diameter and 2 ft depth) was depleted by 50%. Water depletion was calculated based on the local reference ET_o from the nearby local AZMET weather station and the soil texture properties. Once this threshold was reached, three irrigation treatments were applied: wet, medium, and dry treatments consisted 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 reduced by one-half in the cool season to test whether plants can tolerate less supplemental water during the winter months when ET_o

demand is low. A simulated drought study was implemented from Apr. 2014 until Jan. 2015, when plants received no supplemental irrigation. Our objective was to determine how the trees would respond to being cut off from irrigation, a practice that is not uncommon especially for native or desert adapted trees.

Over the period of four growing seasons, no consistent differences in height, canopy area, trunk diameter, and annual tree ring growth were found for each of the nine tree species. Species in the study included arizona cypress (*Cupressus arizonica*), afghan pine, evergreen live oak, semi-deciduous texas ebony (*Ebenopsis ebano*), and palo verde hybrid (*Parkinsonia* thornless hybrid); and four deciduous species: desert willow (*Chilopsis linearis* 'Art's Seedless'), rio grande ash (*Fraxinus velutina* 'Rio Grande'), pistache (*Pistacia* × 'Red Push'), and velvet mesquite (*Prosopis velutina*) (Schuch and Martin, 2017). Similar results were reported for several growth parameters of trees cultivated in the southwestern United States (Devitt et al., 1995; Fox and Montague, 2009; Fox et al., 2014).

Even after three growing seasons, it was difficult to visually determine which treatment a particular plant received as all trees increased in size and most maintained good overall quality (Schuch and Martin, 2017). However, by the fourth growing season, differences in foliage density, branch dieback and declining overall quality became apparent on those trees that were intolerant of the dry or medium treatment. Afghan pine, arizona cypress, and rio grande ash under the dry or medium irrigation treatment started to decline in quality to a degree that threatened their long-term survival. Live oak started to show some leaf abscission and minimal branch dieback under the dry treatment, however, overall quality was still good. Conversely, palo verde, mesquite, pistache, desert willow, and texas ebony maintained excellent appearance with no detrimental effects in canopy density, foliage quality, or health for any of the three treatments from May 2010 until Feb. 2014. Even under the following growing season's simulated drought conditions, these species and the live oaks maintained acceptable quality ratings and showed no major adverse health effects. Quality of arizona

cypress, afghan pine, texas ebony, and rio grande ash dropped below the acceptable aesthetic and health minimum standards and would not be expected to survive long without supplemental irrigation. Texas ebony, native to northeast Mexico and known as a drought adapted tree, was unable to tolerate the lack of supplemental irrigation although it grew well for four seasons under the low irrigation regime.

Conclusions

Expanding urban forests in major southwestern U.S. cities will require judicious irrigation to ensure that new plantings will develop into mature, functional trees to meet the ambitious goals of increasing the tree canopy cover up to 25%. Irrigation recommendations of trees in urban landscapes in the southwestern United States are still primarily based on expert recommendations and require more refinement to realize the greatest benefit from applied irrigation water. Several studies showed that trees grow to similar size with only one-third of ETo compared with 80% to 100% of ETo. This means that up to three trees with concomitant canopies could be cultivated instead of one tree, provided the minimum amount of irrigation allows them to thrive. Questions about how the hotter climate might change irrigation requirements of these species will need investigation. Most studies evaluated young trees for sometimes only 1 or 2 years, and little is known about the effects of long-term low water regimes on mature tree growth and health.

Literature cited

- Anderegg, W.R.L., J.A. Hicke, R.A. Fisher, C.D. Allen, J. Aukema, B. Bentz, S. Hood, J.W. Lichstein, A.K. Macalad, N. McDowell, Y. Pan, K. Raffa, A. Sala, J.D. Shaw, N.L. Stephenson, C. Tague, and M. Zeppel. 2015. Tree mortality from drought, insects, and their interactions in a changing climate. *New Phytol.* 208:674–683.
- Arizona Department of Water Resources. 2017a. Arizona water facts. 10 July 2017. <<http://www.arizonawaterfacts.com/water-your-facts>>.
- Arizona Department of Water Resources. 2017b. Outdoor residential water conservation. 10 July 2017. <http://www.azwater.gov/azdwr/StatewidePlanning/Conservation2/Residential/Outdoor_Residential_Conservation.htm>.
- Arizona Municipal Water Users' Association. 2005. Watering by the numbers. 28 June 2017. <<http://wateruseitwisely.com/wp-content/uploads/2013/07/Landscape-Watering-Guide.pdf>>.
- Balok, D.A. and R. St. Hilaire. 2002. Drought responses among seven southwestern landscape taxa. *J. Amer. Soc. Hort. Sci.* 127:211–218.
- City of Las Vegas. 2008. Las Vegas urban forestry initiative. 15 Dec. 2016. <<https://www.lasvegasnevada.gov/cs/groups/public/documents/document/chjk/mdi4/~edisp/prd028350.pdf>>.
- City of Phoenix. 2010. Tree and shade master plan. 15 May 2017. <<https://www.phoenix.gov/parkssite/Documents/T%20and%20A%202010.pdf>>.
- City of Tucson. 2014. 10,000 trees. 15 May 2017. <<https://www.mayorrothschild.com/initiatives/10000-trees/>>.
- City of Tucson. 2018. Water by the weather. 8 Feb. 2018. <https://www.tucsonaz.gov/files/water/docs/Water_by_the_Weather_Card_web_1.pdf>.
- Clatterbuck, W.K. and L. Tankersley. 2009. Watering trees. Fact Sheet 3.4. In: M.R. Kirk, E.L. Taylor, and C. Mayfield (eds.). *Damage prevention and disaster recovery tree care kit: Trainers curriculum notebook*. 28 June 2017. <<http://agrilife.org/water/files/2013/04/how-much-to-water-trees.pdf>>.
- Costello, L.R. and K.S. Jones. 2014. WUCOLS IV: Water use classification of landscape species. 15 Dec. 2016. <<http://ucanr.edu/sites/WUCOLS/>>.
- Devitt, D.A., D.S. Neuman, D.C. Bowman, and R.L. Morris. 1995. Water use of landscape plants grown in an arid environment. *J. Arboric.* 21:239–246.
- Donovan, G.H., D.T. Butry, Y.L. Michael, J.P. Prestemon, A.M. Liebhold, D. Gatzolis, and M.Y. Mao. 2013. The relationship between trees and human health: Evidence from the spread of the emerald ash borer. *Amer. J. Prev. Med.* 44:139–145.
- Fox, L., A. Bates, and T. Montague. 2014. Influence of irrigation regime on water relations, gas exchange, and growth of two field-grown redbud varieties in a semiarid climate. *J. Environ. Hort.* 32:8–12.
- Fox, L. and T. Montague. 2009. Influence of irrigation regime on growth of select field-grown tree species in a semiarid climate. *J. Environ. Hort.* 27:134–138.
- Harlan, S.L., A.J. Brazel, L. Prashad, W.L. Stefanov, and L. Larsen. 2006. Neighborhood microclimates and vulnerability to heat stress. *Soc. Sci. Med.* 63:2847–2863.
- Hurd, B.H. 2006. Water conservation and residential landscapes: Household preferences, household choices. *J. Agr. Res. Econ.* 31:173–192.
- Levitt, D.G., J.R. Simpson, and J.L. Tipton. 1995. Water use of two landscape tree species in Tucson, Arizona. *J. Amer. Soc. Hort. Sci.* 120:409–416.
- Middle, A. and N. Chhetri. 2014. City of phoenix cool urban spaces project. 15 May 2017. <https://static.sustainability.asu.edu/docs/dcdc/website/documents/NOAA_PHX_UrbanSpaces_Rep.pdf>.
- Mini, C., T.S. Hogue, and S. Pincetl. 2014. Estimation of residential outdoor water use in Los Angeles, California. *Landscape Urban Plann.* 127:124–135.
- National Oceanic and Atmospheric Administration. 2017. State climate summary Arizona. 10 July 2017. <<https://statesummaries.ncics.org/az>>.
- New Mexico Office of the State Engineer. 2017. A waterwise guide to trees. 28 June 2017. <<http://www.ose.state.nm.us/WUC/PDF/TreeBrochure.pdf>>.
- Nowak, D.J. 1995. Trees pollute? A “tree” explains it all, p. 28–30. In: C. Kollin and M. Barratt (eds.). *Proc. 7th Natl. Urban For. Conf., Amer. Forests, Washington, DC*.
- Olsen, M.W. 1999. Diseases of urban plants in Arizona. *Univ. Arizona Coop. Ext. Publ.* AZ1689.
- Schuch, U.K. and E.C. Martin. 2017. A study of irrigation requirements of southwestern landscape trees. *Univ. Arizona Coop. Ext. Publ.* AZ1741.
- Southern Nevada Water Authority. 2017. Landscape irrigation tips. 28 June 2017. <<https://www.snwa.com/conservation/conservation.html>>.
- U.S. Census Bureau. 2018. Quickfacts Arizona. 12 Feb. 2018. <<https://www.census.gov/quickfacts/AZ>>.
- Vickers, A. 1991. The emerging demand-side era in water management. *J. Amer. Water Works Assn.* 83:38–43.
- Warren, P.L., T.M. Quist, U.K. Schuch, C. Erickson, B. Celaya, and J. Richardson. 2015. Pine engraver beetles in the low elevation Sonoran desert in Tucson. *Univ. Arizona Coop. Ext. Publ.* AZ1124.