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Drought and Extreme Heat: Plant Responses and Landscape Maintenance Practices

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Drought and heat conditions are becoming more common in the southwestern United States with below average annual rainfall, highly variable local and regional rainfall patterns, and warmer than normal temperatures. Drought conditions are characterized by a prolonged period of less than normal rainfall in the environment, or lack of surface or ground water. In arid climates, drought is common as the amount of annual evapotranspiration, the combined loss of water through the soil evaporation and through plant transpiration, is greater than the amount of rainfall. Although many plants are adapted to dry conditions, prolonged drought and varying degrees of severity may cause irreversible damage or mortality to plants, including our native vegetation.

Rainfall generally occurs in seasonal patterns; in Arizona we have a bimodal precipitation pattern meaning that we have two rainy seasons: winter/spring and summer monsoons. Generally, about half of our rain falls during the summer and the other half during winter (AZMET, 2020). In the Mediterranean climate of Southern California and the Mediterranean region in Southern Europe, the majority of rain occurs from November to March with prolonged periods of drought in the summer (CIMIS, 2020). Plant species that evolved in these different climates and are grown in landscapes throughout the southwest rely on moisture being available during their rainy seasons, such as pines which require water during the winter season.

Heat often accompanies drought, especially in summer, worsening conditions for plant growth and survival. Heat waves are periods of consecutive days where temperatures are excessively hotter than normal (Teskey et al., 2015). Higher than normal temperatures have become more common in many areas; in the southwest this means more days with temperatures exceeding 110°F and night temperatures above 95°F or 100°F (AZMET, 2020). Heat further accelerates the loss of water through higher transpiration demand by plants and more evaporation from the soil.

Heat stress occurs when temperatures rise above a threshold level long enough to cause irreversible damage to plants. The severity of heat stress depends on the duration, intensity, and time of year when high temperatures occur, the condition of the plant, and their immediate environment (Teskey et al., 2015). A heat wave in early spring may cause damage at much lower temperatures than in summer. Plants that are isolated and grow without other plants nearby, such as trees in urban landscapes, are more exposed to extreme temperatures than plants growing in groups. Single trees surrounded by asphalt and growing in parking lots or next to large buildings with reflective surfaces are at much greater risk for heat stress than trees surrounded by other landscape plants or even bare soil.

How plants respond to drought and heat stress

Water is essential for plant growth and is taken up from the soil through the roots. Water moves through the plant into the leaves where stomata, tiny openings in the leaves, regulate water loss. When stomata are open, water is lost through transpiration while carbon dioxide enters into the leaves. Carbon dioxide is necessary for photosynthesis, producing the plant's energy, which can occur through different pathways. The majority of plants produce carbohydrates through the C_3 photosynthesis pathway, which is efficient when stomata are open during the day, water is available to the plant, and temperatures are cool. C_3 plants, which include trees, rice, and wheat, have no special features to minimize photorespiration, a process that uses energy during carbon dioxide fixation especially under hot and dry conditions. Some plants have developed special adaptations to minimize photorespiration by using the CAM (crassulacean acid metabolism) or C_4 pathway to maintain efficient photosynthesis when it is hot and dry. CAM plants open their stomata at night when water loss through transpiration is minimal and fix the carbon dioxide taken up at night during the day. Cacti, agave, and orchids are CAM plants and thus are well adapted to very hot and dry environments. C_4 plants separate their carbon fixation between different cell types and keep their stomata open during the day. Photosynthesis of C_4 plants such as corn, sugarcane, and Bermuda grass is most efficient under warm temperatures, and less efficient under cool conditions.

Plants have evolved with two general strategies to deal with dry conditions, drought avoidance and drought tolerance (Fig. 1).

Drought avoidance - Plants avoid drought by closing their stomata to prevent water loss once a certain threshold level of stress is reached. This protects the plant from further water loss and dehydration damage. The disadvantage of this response, typical for trees, shrubs, and other C_3 plants, is that when stomata are closed, photosynthesis and carbohydrate production stop and the plant uses carbohydrate reserves for respiration to maintain its metabolism and growth. Warm nights increase respiration rates and further deplete the stored energy. If drought conditions persist over prolonged periods of time, the plant will die of carbon starvation as the energy use exceeds the energy produced by photosynthesis.

Drought tolerance - Plants tolerating drought continue to keep their stomata open and allow water to become depleted in their water conducting tissue. Their advantage is that they continue photosynthesis and carbohydrate production at the risk of severe dehydration and potential cell death. Ultimately, during extended drought and heat, these plants can die from dehydration.

Many desert plants are adapted to drought by using the CAM or C_4 photosynthesis pathway and through anatomical adaptations such as fleshy leaves, small leaf area, and leaf surfaces that minimize transpiration. By minimizing water loss, these plants can thrive in hot and dry environments.

However, drought avoidance and drought tolerance are not used exclusively in one species and some plants, including some trees, have adapted to switch between these two strategies. Regardless of the adaptation strategy, low water content in plant tissue limits metabolism and results in low production of carbohydrates, resins, and secondary metabolites that usually help plants to defend themselves from insects and pathogens. Irrigation during severe long-term drought conditions is an important preventative measure to maintain healthy plants.

Heat stress - Prolonged extreme high temperatures negatively affect cell function, growth, and survival (Fig. 1). Under high temperatures, water loss from plants and soil is accelerated due to higher rates of evapotranspiration. Higher temperatures, especially at night, lead to faster respiration rates and lower photosynthesis, depleting carbohydrate reserves faster than they are replenished. High temperatures alone, even in the absence of drought, can damage the photosynthesis system, resulting in cell injury with severe reduction in photosynthesis or cell death. In addition to starvation, plants may produce compounds such as reactive oxygen species, which can be toxic to the plant cell and cause further damage. Plants with greater heat tolerance produce heat shock proteins, allowing them to continue metabolic processes and photosynthesis, though at lower rates. Leaves and branches can be scorched, die and fall off, and eventually the entire plant will die. Tolerance to extreme high temperatures differs between plants and depends on many factors including species, cultivar, plant health status, and weather conditions before the heat stress event.

Indicators of drought and heat stress

Typical signs of drought and heat stress include wilting leaves, drying and browning leaves, leaf drop, branch dieback, sunscald on branches and trunks, reduced or no new growth, and potential plant death (Fig. 1). While some symptoms will be apparent during or soon after extended drought or extreme heat conditions, in trees, reduced growth or mortality may also occur in subsequent years.

Recovery of plants after an extended period of drought and heat can be slow and will depend on the extent of damage, remaining carbohydrate reserves, water availability and temperatures. If roots have shrunk from the surrounding soil

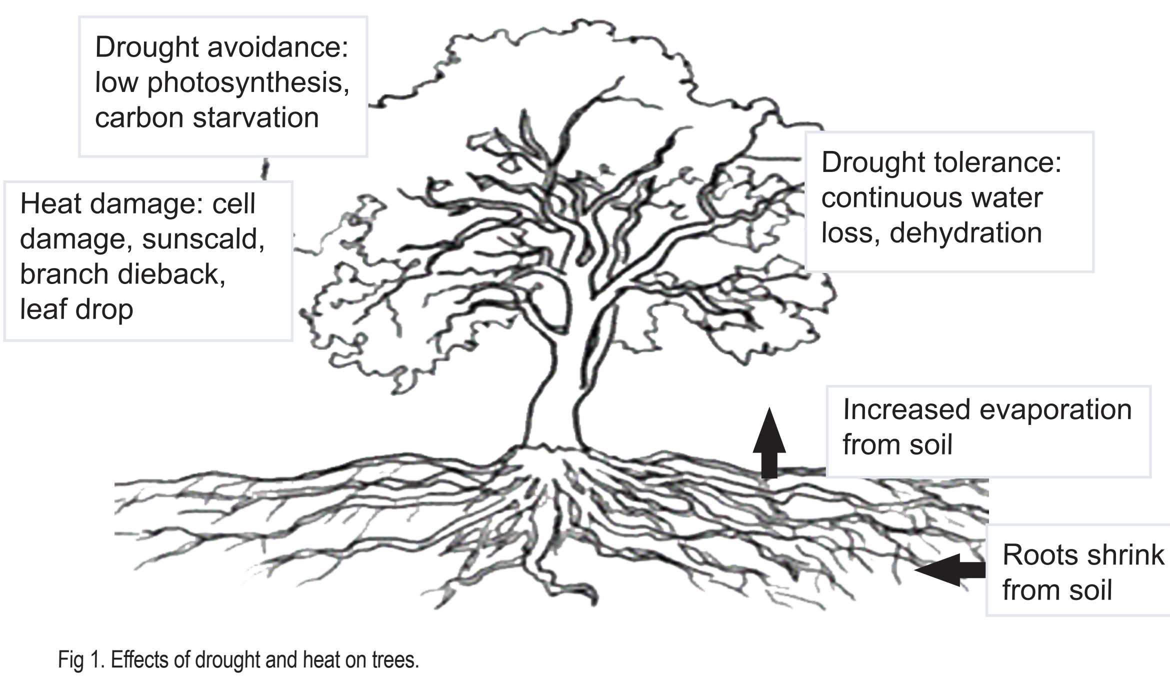

Fig 1. Effects of drought and heat on trees.

(Fig. 1), moisture uptake may be slow until the soil profile in the root zone is fully recharged with water again.

Maintain the backbone of the landscape during drought and heat: trees and shrubs

Providing sufficient irrigation to landscape plants is one of the highest priorities throughout the year, but especially during episodes of drought and heat. The root zone of trees and shrubs should be watered to the appropriate depth and allow some drying of soil between irrigations as described below. When water is in short supply due to lack of precipitation, extended drought, or watering restrictions, irrigation of trees and shrubs should be prioritized over herbaceous landscape plants. Trees are the longest living plants in a landscape and provide the structural backbone. They often have important functions such as shading, screening, or defining an area. Watering of trees should never be neglected such that their health might be jeopardized as they take many years to reach mature size. Shrubs, especially large ones that perform similar functions to trees such as hedges, should also be prioritized for irrigation during a drought to survive without lasting damage.

Other landscape plants including cacti, succulents, and herbaceous perennials (ornamental grasses), and annuals (bedding plants) should be irrigated according to their specific needs, which is as deep as their root zone and allowing the soil to dry between irrigations. Cacti and succulents are prone to overwatering and damage if the root zone is consistently kept wet.

How much, how often, and where to irrigate?

How much water do trees need to thrive or survive? This depends on the species, the size of the tree, and the weather. During the hot summer months, trees need the greatest amount of water because of the high evapotranspiration; lowest demand is during the cooler winter months when evapotranspiration is low. Watering needs to cover a sufficient area of a tree's root zone to ensure their survival when irrigation for other plants has been discontinued.

The majority of the root zone of trees such as mesquites, oaks, and pines extend horizontally from the trunk, two to three times the width of the canopy and vertically two to three feet or deeper into the soil, provided there are no barriers such as hardscapes and no compacted or impenetrable soil. As trees get larger, the roots next to the trunk will not need irrigation anymore as they will become woody and do not take up water. Water needs to be applied further away from the trunk and outside of the canopy drip line, the soil under the outer circumference of the tree canopy, where it will be taken up by the fine roots (Fig. 2a).

The amount of water that needs to be added at each irrigation event should be sufficient to wet the root zone to a depth of 2-3 feet (Call and Daily, 2017). During the hottest time of summer, irrigation may be needed every 4-7 days, while in winter irrigation intervals can vary from 4 to 10 weeks. Some native plants may be able to survive without additional irrigation once they are established. Irrigation amount and frequency will depend on soil type, plant species and size as well as rainfall at the site.

Palms are an exception to the tree irrigation recommendations above due to their fibrous root system. The majority of palm roots usually grow horizontally within 2 to 3 feet from the trunk and about one-foot deep, although some palm roots are found further away from the stem and at greater depth (Hodel et al., 2005). Palms require deep watering to stay healthy and grow. Irrigation should be applied in a ring one to three feet from the trunk and to a depth of two feet (Fig. 2b). In summer, irrigation should be applied every 2-4 weeks, in winter every 6-8 weeks, depending on the soil type and weather.

Figure 2. Root zone area to irrigate for trees with a. spreading root systems (left) and b. palms (right).

Current irrigation schedules may over- or underwater plants in the landscape. Before further cutting the amount of water a tree receives, it is important to find out what the minimum amount of water is to keep the tree alive without lasting damage. Some tree species are better adapted to receiving low amounts of irrigation water than others (Arizona Dept. Water Resources, 2020).

Converting from irrigating the entire landscape to selective plants

When water is abruptly turned off over an entire landscape site that may have a mixture of turfgrass, trees, shrubs, and other plants, the site needs to be evaluated to determine the location of tree roots and roots of other large plants that will be irrigated. Identifying where tree and shrub roots are growing will ensure that irrigation for individual plants is applied in the area where their roots can take up the water. Similarly, in landscapes that received flood irrigation, the root zone of trees requires diligent attention and well-planned irrigation for safe transition from an irrigation schedule that broadly applied water to the root zone of many plants that trees may have tapped into. Irrigating a sufficient area of each tree's root zone is essential to maintain healthy, thriving plants.

How to water if the irrigation system will be turned off

If trees are irrigated with an automated system and if they are on a separate valve, then irrigation can be continued after reviewing and optimizing the schedule. Other large plants that will also be watered may be added to this valve to simplify the operation. However, if the irrigation system for the entire landscape will be turned off, provisions need to be made to deliver water to each tree root zone. Soaker hoses laid over the root zone and connected to a garden hose is one way to deliver water to the tree (Fig. 3a). Creating a basin that can be flooded with a hose or from a reservoir such as a rainwater harvesting tank is another option (Fig. 3b). For smaller, more recently transplanted trees, tree aprons provide water that slowly seeps through the bottom of a bag, which surrounds the trunk (Fig. 3c).

Did it rain enough to skip an irrigation?

The amount of water from a single rain event can vary dramatically between sites that are in close proximity. Depending on the intensity of precipitation, soil type, and soil moisture, rain of more than half an inch can replenish soil moisture in the upper part of the soil profile and irrigation may be delayed. Testing how deep the moisture is available in the root zone of trees is the best way to decide when the next irrigation is necessary. This can be determined by using a soil sampling tube to extract soil or a metal rod that is pushed into the soil. Moist soil is easy to penetrate but drier soil will slow or stop these tools. Testing the soil moisture under the canopy of a tree can be important, especially for species with dense canopies such as live oak or conifers that may deflect the rain and exclude it from a large part of the tree root zone.

General maintenance during drought and heat

Slow, deep irrigation to wet the root zone to the proper depth is vital in keeping trees and shrubs healthy during dry, hot conditions in summer and during dry conditions in winter. Sufficient soil moisture is the most important factor to maintain healthy plants in the southwest during drought and heat. However, overwatering plants can damage roots due to the lack of air in the soil and can lead to diseases and poor growth. Soil should be allowed to dry between irrigations to allow sufficient air in the root zone and to prevent permanently wet conditions. Avoid or minimize pruning during drought and excessive heat. Removing branches can expose other branches that were previously shaded to direct sun and lead to sunscald. If too much of the canopy is removed through pruning, the plant has less foliage for photosynthesis. Do not shear plants in dry, hot weather as this will cause additional stress by removing foliage that may be scarce already and stimulate new growth. Minimize or skip fertilizing which increases the salinity in the root zone and can further stress salt sensitive plants.

Cacti and succulents can be covered temporarily with 30% shade cloth to prevent sunburn during excessively high temperatures. This shade cloth needs to be removed once the

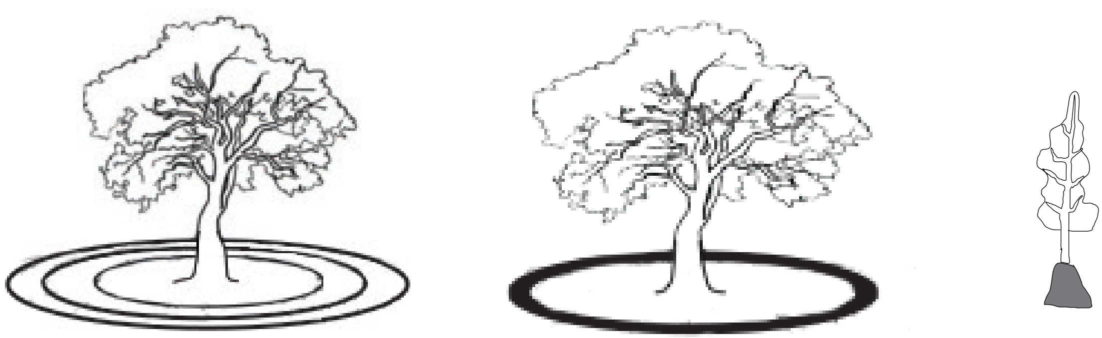

Fig. 3. Irrigating individual trees with a. a soaker hose (left), b. a basin that will be filled with water (middle), or c. a tree apron (c. right) around the base of the trunk of small trees.

extreme heat has passed to ensure that plants can resume normal photosynthesis in full sun. Smaller plants in pots can be protected from excessive heat by moving them to a shaded area, especially during the hottest part of the day.

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