

# Water Use Requirements and Physiological Response to Water Stress in Pistachio

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## INTRODUCTION

Sound irrigation management requires knowledge of crop water requirements and physiological responses to sub-optimal water application. This information is needed for both establishing irrigation schedules and predicting future water needs of an orchard. Although irrigation research on deciduous trees in California began in the 1930's, improved monitoring equipment and techniques coupled with an increased awareness of limited water resources and rising energy costs have focused renewed interest in the subject. Unfortunately, virtually none of the recent work has involved pistachio. Moreover, very little water relations information appears to be available from other pistachio growing countries. The situation is further complicated by the absence of a clear consensus of opinion among growers as to optimal water management strategies. It appeared timely, therefore, to conduct a study to evaluate the water needs and stress physiology of pistachio in California.

## OBJECTIVES AND METHODS

Water use in pistachio orchards is the result of two processes; evaporation from the soil surface and transpiration from the leaves. The summation of these processes is defined as evapotranspiration (ET) and can be thought of as the crop water require-

ment. Our first objective was to directly measure ET in a well-watered, mature orchard, and to correlate this crop water use with both evaporation from a standard evaporation pan and water use estimates of a standard reference crop. This would make our results useful to all California pistachio growers with access to historical or current pan evaporation or reference crop data.

Our other primary objective involved measuring ET and plant based parameters reflecting tree water status of mature trees that were subjected to progressively greater water stress throughout the season. Of primary importance were potential yield responses and these were evaluated by measuring dry matter accumulation in the kernels that developed under limited water availability. This information was compared with equivalent data taken from well watered trees. We were also interested in the relationship between plant water stress and blanking.

A soil water balance approach, which involved assessing the soil water status of the root zone periodically between irrigations, was used to evaluate ET. The accuracy of this method depends, in part, on having relatively uniform application of irrigation water, so we selected for our well watered study an orchard located south of Kettleman City that used hand move sprinkler irrigation. The

soil is classified as a Wasco sandy loam. The soil water balance procedure involves measuring changes in soil water content periodically; at least a few days after and immediately before each irrigation and assumes that the only process that removes water from the root zone is the absorption by plant roots and evaporation from the soil surface. Deep percolation of water below the root zone during the monitoring period must be independently measured or assumed to be negligible. Due to the consistently low water contents at the deepest zones monitored and the associated low values of hydraulic conductivity, we assumed negligible deep percolation. The soil water depletion was monitored using a neutron probe (Campbell Pacific Nuclear Corp. Model 503) with extreme care taken to accurately calibrate it for the experimental site.

Three trees (8-year-old 'Kerman' on *P. atlantica*) bordered on all sides by healthy pistillate trees were each instrumented with neutron access tubes placed approximately 3.0, 5.5, and 8.0 ft. away from the tree trunk and installed to a depth of 9 ft. Readings were taken in 1 ft. intervals, with the reading taken at 12 in. used to describe the water content in the top layer of the profile. The instrumented trees were first irrigated on June 9 and then generally every 18 days

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until August 3, the date of the last pre-harvest irrigation.

A similar access tube regime was installed in a 12-year-old 'Kerman' orchard in the same area that we designated for our stress physiology studies. The section of this orchard where our test trees were located was tarped for Verticillium wilt control and did not receive any additional water after an early June irrigation. Both the well watered and stressed orchards were on 17 by 17 ft. spacing.

To measure evaporative demand on the experimental site, a USWB Class A evaporation pan was placed in an appropriate grass environment and readings were taken frequently, mostly every other day. To more accurately assess reference crop ET, which relies on climatic measurements, an automated weather station was installed near the pan and should be on line for next season.

A pressure chamber (PMS Instrument Co. Model 600) and diffusion porometer (LI-COR Model LI-65) were used to measure, respectively, tree water status and leaf conductance—an excellent indicator of stomatal opening. Monitoring was conducted at frequent intervals on both the well water and stressed trees and the values reported are averages of at least four measurements. Initial attempts to measure leaf water potential by using excised leaves were unsuccessful due to the interference of exudates other than xylem fluid. Therefore, subsequent readings were taken using small stems composed of two to three leaves. A 0.5 in. section of bark was quickly removed from the cut end of the stem before placement in the chamber, and this method seemed to be an accurate and reproducible method of assessing tree water status. Although these readings actually monitored xylem pressure potential of the stems, we assumed only slight potential gradients existed between the stems and associated

leaves, and therefore, will refer to our measurements as leaf water potential.

Measurements of nut development were made by taking biweekly 40 nut samples each from four trees in both the stressed and well watered orchards for a total of 320 nuts per sampling. The nuts were immediately taken to the laboratory where they were cut open, the number of blanks recorded, the embryos (kernels) removed, and along with the shells and hulls, weighed to determine fresh weights. The samples were then dried in a forced air oven, reweighed, and dry weights recorded.

## RESULTS AND DISCUSSION

Although our goal was to monitor the experimental trees from leaf out to senescence, periodic soil water depletion measurements for ET calculation did not begin until mid June due to limited resources. Crop ET data was correlated with the pan evaporation data using the following relation:

$$ET_c = K_p \times E_{pan}$$

Where  $ET_c$  is the measured evapotranspiration,  $K_p$  is the crop coefficient that normally varies only with the stage of development of the orchard, and  $E_{pan}$  is the measured pan evaporation. Research has developed  $K_p$  information for most of the major crops grown in the San Joaquin Valley, and they provide a useful parameter to compare relative water use rates. For example, for mature almonds under clean cultivation, the greatest seasonal value of  $K_p$  is 0.75 and normally occurs from mid June to mid July. Our data from the current study indicate that potential pistachio ET rates are at least equivalent to and may exceed those of other deciduous tree species at similar stages of development. Rather than publish a list of  $K_p$ 's that is incomplete due to monitoring only part of the season, we will use next year's data to augment and verify our findings before disseminating water use estimates. However, it appears that under well watered conditions, pistachio can use large amounts of water. It should be emphasized that total seasonal water use depends not only on the daily ET

rate but also on how early in the season the canopy develops. Because leaf out in pistachio occurs late relative to most other deciduous trees, early season water use should be less.

The magnitude of soil water depletion determined at each access tube did not reveal any functional relationship between horizontal distance from the trunk and soil water uptake. Although water absorption rates of roots have been shown to decrease with distance away from the tree in young orchards, the mature trees in our study had apparently developed extensive root systems that resulted in water uptake rates being independent of horizontal distance.

We computed soil water extraction patterns for the soil profiles in both the well water and stressed orchards, and the data is presented in Figures 1 and 2, respectively. The pattern of depletion for the 13 day period following the July 16 irrigation in the well water orchard (Figure 1) shows that 86% occurred in the top 4.5 ft. of the profile. This pattern may be representative of orchards that have adequate water applications made on a timely basis. Even trees with deep root systems, such as pistachio, under high available soil water conditions throughout the profile, prefer to extract water in the upper part of the profile. This is simply because the greater the distance between the zone of extraction and the leaves, the greater is the driving force (energy) needed to transport a given amount of water. Because of this, trees deprived of irrigation will first deplete the upper layers of the profile before extracting water from deeper zones. This phenomenon is clearly illustrated if one considers Figure 2, which shows the extraction pattern in the stressed orchard from July 7 to August 30. Note that only 3% of the amount of water depleted during this time period was from the top 1.5 ft. layer and that most of the soil water depletion took place in the middle of the profile. When compared with well watered trees, a relatively large 26% was extracted between 6 and 9 ft. in the profile. These measurements indicate that some depletion must have

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occurred below our deepest zone monitored; thus, any future work requirement ET measurement of stressed trees should involve access tubes placed at least 15 ft. deep.

Even with a qualitative correction of our soil water depletion measurements on the stressed trees to take into account water extraction below the 9 ft. depth, our data show these trees used less than 3 in. of water between July 7 and August 30, the period in which most of the dry matter accumulation in the kernels took place. In contrast, the ET of the well-watered trees exceeded 13 in. over the same time period. Obviously, the stressed trees were controlling their water loss. Adaptation mechanisms to accomplish this include partial leaf defo-

liation, leaf rotation to avoid direct solar radiation, and stomatal aperture adjustment. Of these, the latter appears to be of primary importance in pistachio. Data in Table 1 confirm the fact that reduced availability of soil water was reflected in the plan based parameters than can indicate water stress: leaf water potential (both predawn and midday), leaf conductance, and leaf temperature.

These data show that reduction in leaf water potential in the stressed trees apparently brought about significant stomatal closure which was manifested by lower values of leaf conductance. Because leaf conductance is directly related to photosynthetic activity under water stress conditions, we conclude that CO<sub>2</sub> assimilation was reduced in the stressed trees. So although varying degrees of stomatal closure helped the trees limit water loss by reducing the transpiration rate, it also presumably limited the rate of photosynthesis. Since fruit development in most crops is directly related to photosynthetic activity,

water stress should be reflected in the kernel development data.

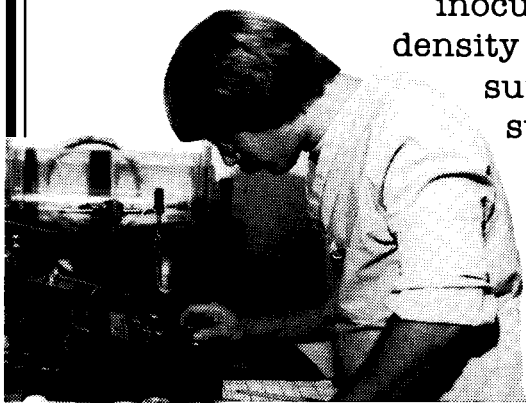
Figure 3 presents our measurements of dry weight accumulation of the kernels during July and August under both stressed and well watered conditions. In view of the large differences in crop water use and presumably photosynthate production, it is surprising that the two sets of data show relatively little disparity. While the dry weight accumulation in the stressed trees lagged during the early part of the kernel filling period, the August 30 measurement showed average kernel weights of 0.60 and 0.52 gms. for the well watered and stressed trees, respectively. The absence of subsequent sampling precludes evaluating the significance of this weight difference, but the data in Figure 1 fail to demonstrate that a strong relationship exists between ET and dry matter yield as has been found in most other crops. Certainly, pistachio kernel development appears less sensitive to water stress than other nut

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## ANALYSIS

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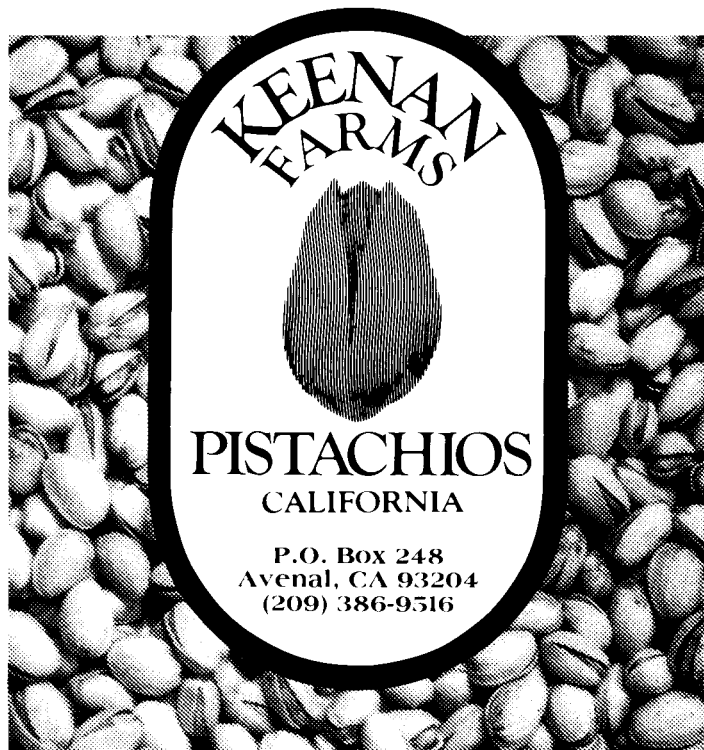


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species, notably walnut. This may be the basis for the popular belief that water use rates of pistachio are far lower than other deciduous trees. Our data show that there is, in fact, little relationship between the current season's tree water status and crop yield. Conceivably, however, a strong correlation may exist between current season plant water status and the following season's yield, even though no such relationship was observed in pistachio by Spiegel-Roy et al. (1977). Working with apricots, however, Uriu (1964) found that fruit yield was not closely related to current season soil water status but rather to that in the late summer of the previous season. He proposed that water stress during the period of floral bud development resulted in significant bud abscission and reduced the number of flowers produced the following season.

The basis for such a hypothesis in pistachio lies in the well documented observation that floral bud development, the precursor for the following year's crop, largely coincides with dry matter accumulation in the kernels during July and August (Crane et al., 1976).  $^{14}\text{CO}_2$  experiments have shown that the developing kernels are much stronger sinks for photosynthate than the buds (Takeda et al., 1980). Thus, carbohydrate deficiency in the buds themselves has been proposed as being responsible for bud drop and alternate bearing (Crane and Iwakiri, 1981). Most speculation on carbohydrate deficiency induced bud abscission focuses on the fact that the presence of a nut crop reduces the availability of photosynthate for floral bud growth and maintenance. This indicates that carbohydrate production may be of critical important in sustaining orchard productivity. Therefore, it appears to us that the carbon exchange rate between the leaves and the atmosphere must be maximized by preventing stomatal

closure due to plant water stress. This can be accomplished, in most cases, by good irrigation management.

Two other fruit development factors that affect yield are blanking and shell splitting (endocarp dehiscence). Our data show no correlation between current season tree water status and blanking. Shell splitting was not monitored this past season. Because it has been proposed that shell splitting is a biochemical phenomenon associated with kernel development (Crane and Iwakiri, 1981) and our studies showed little correlation between water status and nut development, it seems that shell splitting should not be related to water stress. However, because grower observations do not support this conclusion, research is needed to establish the relationship between these parameters.

### CONCLUSIONS

Evapotranspiration measurements made during the 1982 season indicate that the potential ET rate of pistachio during the peak seasonal evaporative demand is equivalent to or may exceed other deciduous tree species. Based on this data, it appears that many California pistachio orchards may currently be subjected to considerable water stress, especially for the periods before, during, and after harvest. Water deprivation resulted in significantly reduced ET, leaf conductance, and presumably  $\text{CO}_2$  assimilation. However, there was little correlation between current season tree

water status and dry matter accumulation in the kernels, indicating that the developing nuts are the preferential sink for photosynthate. Whether water stress results in significant detrimental effects on the following season's crop yield due to enhanced floral bud abscission remains an unanswered question.

### ACKNOWLEDGEMENTS

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**Table 1.** Soil and plant based measurements of water status on August 5 in well watered and stressed orchards.

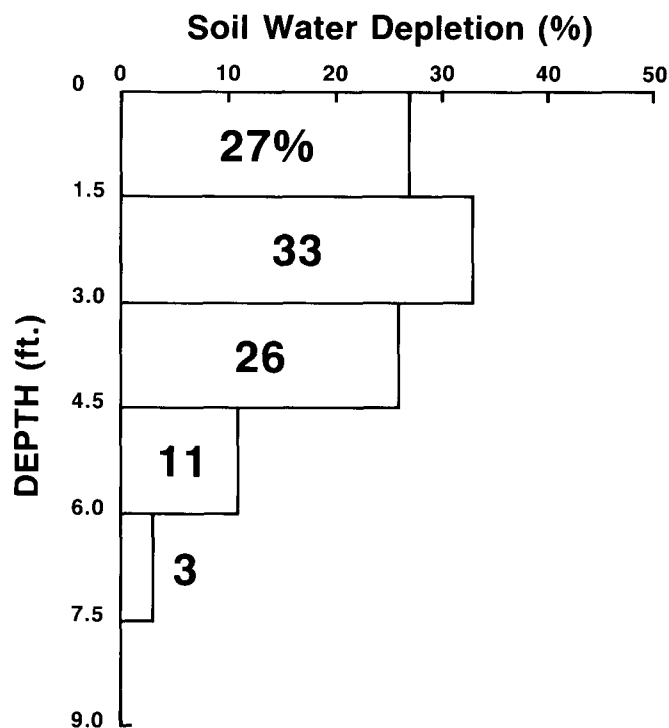
	% AW <sup>1/</sup>	LEAF WATER POTENTIAL (-BARS)		LEAF CONDUCTANCE (mm/sec)	MIDDAY LEAF TEMPERATURE (°C)
		PREDAWN	MIDDAY		
Well Watered	83.6	8.9	20.0	2.7	27.1
Stressed	6.4	13.8	26.9	1.1	32.5

<sup>1/</sup> Percentage of available water in the top 6 ft. of the profile.

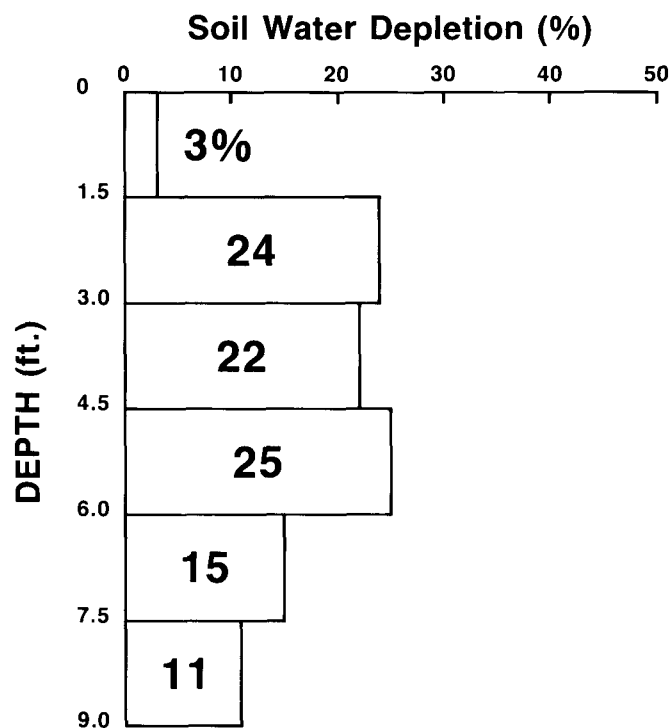
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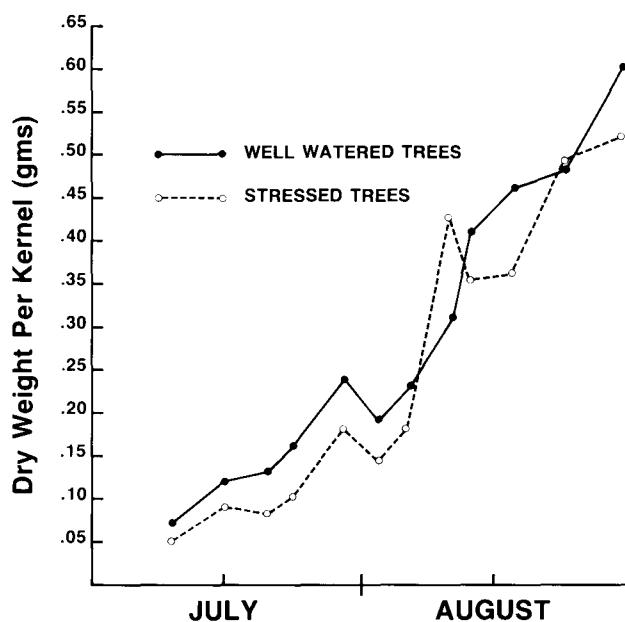
**Figure 1.** Soil water extraction pattern of 3.98 inches depleted in the well water orchard from July 20 (four days after irrigation) to August 2.



**Figure 2.** Soil water extraction pattern of 2.01 inches depleted in the stressed orchard from July 7 (30 days after irrigation) to August 30.

1980. Translocation and distribution of  $^{14}\text{C}$ -photosynthesis in bearing and nonbearing pistachio branches. J. Amer. Soc. Hort. Sci. 105:642-644.

Uriu, K. 1964. Effect of post-harvest soil moisture depletion on subsequent yields of apricots. Proc. Amer. Soc. Hort. Sci. 84:93-97.



**Figure 3.** Developing kernel dry weight as a function of time in both well watered and stressed orchards.