WATER USE REQUIREMENTS OF PISTACHIO TREES AND RESPONSE TO WATER STRESS

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One of the most fundamental management decisions California pistachio growers must make involves water management; specifically, when to irrigate and how much water to apply. The objective of good water management is to supply the trees' water needs for optimal tree growth, nut yield, and nut quality. Since water is both scarce and expensive in many major pistachio growing areas, it's important to obtain the most efficient use of water possible in order to maximize bottom-line profits. Just how much water can pistachio trees use? What are the consequences of not meeting this potential evapotranspiration (ET) in terms of tree performance; both short and long term? And what tree processes are most affected by varying levels of plant water stress?

To answer these questions and to broaden our understanding of pistachio plant water relations, a large scale field project was established in a commercial orchard in southern Kings County. This paper reports selected 1984 findings.

DESCRIPTION OF EXPERIMENT

Research Sites

The experiment is being conducted in a 10 year-old planting of "Kerman" of *P. atlantica*. The soil is classified as Wasco sandy loam. This year's work took place in the following three adjacent sites:

Site 1: Well water (no plant water stress) trees under hand move sprinkler irrigation. Crop water use estimates were made on eight trees instrumented with a total of 28 neutron probe access tubes to a depth of 10 ft. This site is described in detail in last year's report and is referred to as the well-watered block.

Site 2: A block of 120 trees that were subjected to severe water stress in 1983 by depriving them of summer irrigation. Half of these trees were equipped with microsprinklers in 1984 and received full ET (their full crop water use requirement). The other half was deprived of summer irrigation for the second consecutive year in 1984.

Site 3: A five acre block, hereafter referred to as the ET rate experiment, that was divided in 1984 into five plots, each approximately 3/4 acre. The objective was to apply water at various percentages of full ET uniformly over the season. Actual applied water rates, corrected for estimated 5% spray evaporation loss, were 0, 25, 50, 70, and 100% of full ET.

This was accomplished by installing a microsprinkler systems equipped with electronic controllers that allowed each plot to be irrigated with the appropriate amount of water. The sprinklers were placed in the tree row midway between trees and wetted a 15 ft diameter circular pattern. The application rate was 10.7 gph. The microsprinklers were managed to apply water twice per week with the duration of application set to apply the desired percentages of full ET. Weekly estimates of full ET were made using preliminary crop coefficient values and pan evaporation data collected in a grass environment nearby.

PROCEDURES

Crop Water Use

A soil water balance approach described in detail in the 1983 annual report was used to evaluate ET. Briefly, frequent monitoring of soil water status in the upper 10 ft of the profile between irrigations was conducted in Site 1. The disappearance of soil water is due to uptake by the trees, evaporation from the soil surface, and deep percolation of water below the deepest soil depth monitored. Using soil hydraulic conductivity data generated during a winter study, we were able to quantify the magnitude of deep percolation during the season. Factoring this out of the soil water balance enabled calculation of orchard water use.

Crop ET data was correlated with pan evaporation to develop crop coefficients (K_p) using the following relation:

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

where ET_c is the measured crop water use and E_{pan} is USWB Class A pan evaporation measured in a nearby grass environment. Both 1983 and 1984 data were used to develop bimonthly K_p values. Since K_p depends largely on the rate of canopy development, the 1984 data was retarded by one week to normalize the affects of the unusually hot weather.

Photosynthesis

Net CO_2 assimilation rate was measured periodically during the season on individual leaves. Measurements were made with an open gas exchange system. CO_2 was monitored with an ADC Mark III infrared gas analyzer. Leaf temperature, photosynthetic photon flux density (PPFD) and water vapor entering and exiting the leaf chamber also were measured. The leaf chamber consisted of two compartments, enclosing both the upper and lower leaf surfaces simultaneously. Surface area enclosed by the leaf chamber was approximately 7.0 cm^2. Rates of carbon uptake represented the sum of both surfaces. Stomatal conductance measurements made with this system compared favorably to those taken with a LiCor 1600 steady state porometer. All measurements were taken at PPFD's greater than 1.0 $mmol/m^2$-sec.

Trunk Growth

A microdendrometer, an instrument that assesses radial trunk growth and is accurate to more than .001 of an inch, was used to take twice monthly measurements on 30 trees in each experimental plot.

Nut Development

Beginning in early June, 40 nut samples were collected from each of four randomly selected trees in each experimental plot. These nuts were immediately removed to the laboratory where hull (mesocarp), shell (endocarp), and kernel (embryo) weights, both fresh and dry, were determined. After harvest, four trees in each plot (that were left unharvested) were sampled on September 24, October 12, and November 1 to assess both nut development and shell splitting.

Nut Yields and Quality

Commercial harvesting equipment was used to determine gross yields of 40 selected trees in each plot. Selection was based on the trees being immediately surrounded by healthy pistallate trees. Harvest subsamples (200 nuts) were collected from 10 trees in each plot. These nuts were dissected and analyzed for:

1) percentages of blanks (no embryo growth), aborts (evidence of terminated embryo growth), unsplit nuts, and split nuts; and

TABLE 1.
Bimonthly values of pistachio tree ET for a normal evaporative demand year in the San Joaquin Valley. Crop coefficients (K_p) were determined from neutron probe data adjusted for deep percolation, and ET estimates made using long term average pan evaporation.

CROP WATER USE (ET) OF PISTACHIO TREES FOR A NORMAL YEAR
— Mature, Clean Cultivated Orchards —

	K_p[1]	ET (in)	ET (in/day)	ET (gal/tree/day)[2]
April 1-15	0.06	0.17	.011	2
April 16-30	0.35	1.14	.076	14
May 1-15	0.55	2.09	.139	25
May 16-31	0.75	3.41	.213	38
June 1-15	0.88	4.12	.275	49
June 16-30	0.94	4.62	.308	55
July 1-15	0.96	4.72	.315	57
July 16-31	0.96	4.83	.302	54
August 1-15	0.96	4.15	.277	50
August 16-31	0.90	3.70	.231	42
September 1-15	0.80	2.71	.181	33
September 16-30	0.70	2.02	.135	24
October 1-15	0.54	1.26	.084	15
October 16-31	0.40	.76	.048	9
November 1-15	0.28	.36	.024	4

[1] Crop coefficient for pan evaporation. Current (real time) crop water use can be determined using:

$$ET_{crop} = K_p \times E_{pan}$$

[2] Based on 17 x 17 ft tree spacing. The following equation can be used to calculate individual tree water use for other spacings:

$$\text{gal/tree/day} = \text{ET (in/day)} \times \text{spacing (ft}^2) \times .622 \text{ (gal/in-ft}^2)$$

2) fresh and dry weights of hulls, shells, and kernels.

The harvested split nuts were additionally analyzed to determine relative nut size. Each shell half recovered in the above mentioned analysis was passed through a leaf area meter to determine their cross-sectional areas.

Harvestability

To determine the percentage of total tree nut load that was removed by the mechanical harvest, intensive analysis of the nuts left in the tree after shaking was conducted on eight trees per plot.

Immediately after harvest, all remaining nuts were removed by hand and gross weights measured. Detailed examination of nut quality (described above) was conducted on 200 nut samples. With this information, the total number of nuts harvested and remaining in the tree were calculated.

RESEARCH RESULTS AND DISCUSSION

Crop Water Use

Crop water use estimates for mature pistachio trees (greater than 60 percent area of the orchard floor shaded by tree canopies midday during the summer) for a normal year are presented in Table 1. These estimates assume clean cultivated conditions; no cover crop or actively growing native weeds or grasses. The crop coefficient (K_p) increases from 0.06 during April 1-15 to a maximum value of 0.96 in early July reflecting rapid canopy development. Maximum K_p values continue through mid August followed by a decline to 0.28 during November 1-15 due to leaf senescence. Using long term average pan evaporation for the San Joaquin Valley and assuming a 17 x 17 ft tree spacing results in crop water use values for a normal year that range from 2 gal/tree/day in early April to 57 gal/tree/day in early July, decreasing to 4 gal/tree/day in early November. Average ET from June through August is 52 gal/tree/day. For the season, Table 1 shows a cumulative crop water use value of 40.1 inches for an average year.

The information presented in Table 1 can be used to schedule irrigations in pistachio orchards. One must be aware, however, that "normal" year seldom occurs, so using long term historical ET data may not reflect conditions during particularly hot or cold seasons. It's best to utilize current (real time) pan evaporation information if it's available. Other indices of evaporative demand, including so-called "reference crop" ET, which is calculated from weather data, can also be used. In many areas of California, various public agencies make these estimates and they are often available to the public. Reference crop values are commonly reported as ET_0 (also called ET_r) which approximates the ET of tall grass, or ETP, which approximates the ET of full cover alfalfa. In order to use the K_p data in Table 1 with ET_0 reference crop values, it's necessary to multiply the K_p by 1.24, and for ETP, multiply by 1.15.

Regardless of the method used to calculate pistachio ET, it's important to recognize that it represents the amount of water the orchard can use. The amount of water that must be applied to meet this crop water use requirements must be greater than ET to account for losses that invariably result during an irrigation; mainly deep percolation of water below the rootzone and runoff.

One can determine how much extra water is needed with knowledge of the irrigation application efficiency (E_a). This term is commonly used to express how effectively water is applied and is related, in part, to the irrigation method. Consult your local farm advisor for E_a information. Guidelines for using ET information in irrigation management can be found in the following publications: Basic Irrigation Scheduling (UCCE leaflet #21199, $1.00 per copy) and Irrigation Scheduling Guide (available from the State of California, Dept. of Water Resources, Office of Water Conservation, $12.50 per copy).

Seasonal pistachio ET slightly exceeds published water use values for other deciduous trees. For example, ET for almonds is approximately 38 inches for a normal season. However, it must be emphasized that pistachio leaf out, and therefore, crop water use, begins much later than almond. Seasonal pistachio ET is greater because the peak transpiration rates of the tree are remarkably high. This is reflected by the previously mentioned peak K_p value of 0.96 versus 0.75 for almonds. By comparison cotton has a K_p of 1.0 under full cover, non-limiting soil water conditions. Thus, it's clear that pistachio trees can use large amounts of water relative to other crops.

Since both water loss to the atmosphere and CO_2 uptake from the atmosphere occur through leaf structures known as stomata, a linear relationship exists between CO_2 assimilation and stomatal conductance (a measure of stomatal aperture) in most agronomically important plants. Thus, photosynthesis, the process that converts CO_2 to the sugars required to build and maintain plant material, and transpiration are also usually linearly related. Plants limit water loss by controlling stomatal opening. High ET rates, therefore, are usually associated with high rates of photosynthesis. This is normally reflected by rapid plant growth, either vegetative, reproductive, or both. But pistachio trees are notoriously slow growing. Do high water use rates correspond with high levels of CO_2 assimilation in pistachio?

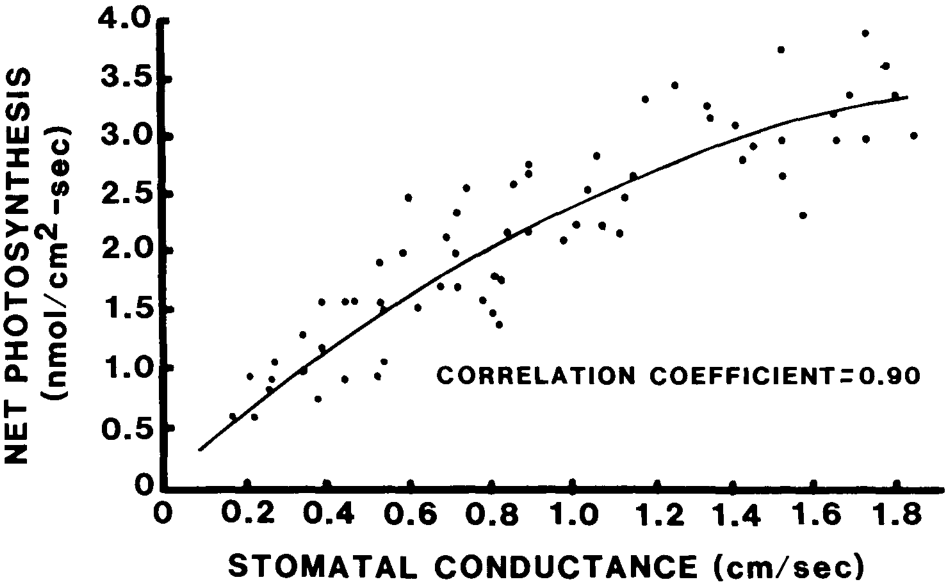

Figure 1.
Relationship between net leaf CO_2 assimilation rate and stomatal conductance. Each data point is the sum of both upper and lower leaf surfaces. Data was taken on July 11, 1984 from ET rate plot. Curve is the best fit second order regression.

Figure 1 shows the relationship between net photosynthesis and stomatal conductance. Note that these parameters are not linearly related, but that the mathematical description of best fit is curvilinear. This results in progressively smaller increases in photosynthesis for each incremental increase in stomatal conductance. Again, if one assumes that transpiration is controlled largely by stomatal aperture, this suggests that CO_2 assimilation rate increases do not keep pace with increases in water use. In other words, high water use rates are not manifested by equally high photosynthetic rates. Apparently, the law of diminishing returns applies to the relationship between CO_2 uptake and water use. This raises the question of whether it's necessary for pistachio trees to consume the large amounts of water they are capable of using, or can optimal orchard growth and productivity be achieved at something less than full ET. The following results of the ET rate experiment and subsequent monitoring of this block should provide the answer.

First Year Effects of Different ET Levels

The influence of various ET rates on current season nut quality and harvestability are shown in Figure 2. It manifests striking differences in the relative percentages of split and unsplit nuts. Split nuts accounted for 13.6, 44.9, 73.4, 74.8, and 77.9 percent of the total number of nuts (the sum of those harvested and left in the tree) for the 0, 25, 50, 70%, and full ET levels, respectively. On the other hand, non-splits made up 56.6, 36.8, 8.8, 7.0, and 10.9 of the tree nut load in the respective ET plots. Clearly, severe water stress, imposed under the 0 and 25% ET regimes, delayed the biochemical processes necessary for shell splitting in large percentages of the crop. These processes were only mildly affected at 50 and 70% ET.

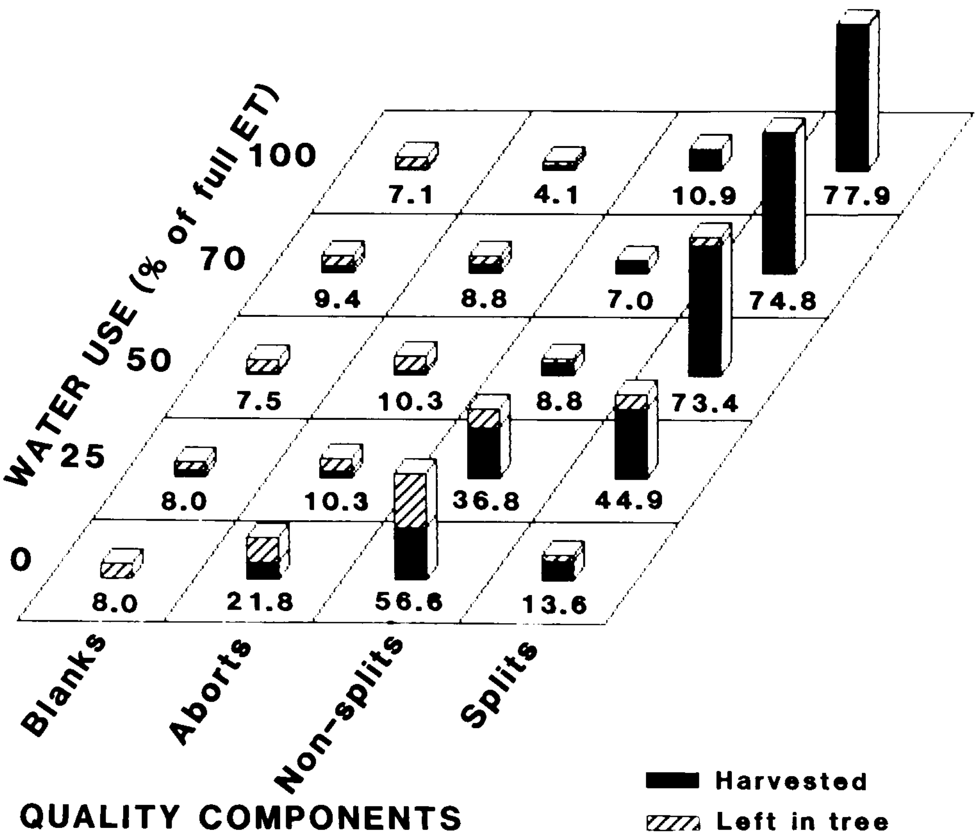

Figure 2.
Affect of ET levels on current season nut quality and harvestability. Column heights and numbers in grid squares represent total tree nut load percentages (both harvested and left in tree after shaking) of each quality component for a particular ET rate. Data are averages of 200 nut samples from each of 10 trees per plot.

Figure 2 shows that blanking was similar in all irrigation regimes. However, embryo abortion was appreciably greater at the 0 ET level, accounting for 21.8% of the total nut load. The relative amount of the nut load that remained in the tree after mechanical shaking, illustrated in Figure 2 as the cross-hatched areas of the columns, was noticeably lower at 50% or less of full ET.

Nut harvest component data, expressed on a dry weight basis per tree, is presented in Figure 3. It shows that *total* harvest weights generally increased with increasing ET levels. The increase in harvest weights of *dry in-shell splits* is even more dramatic; 2.5, 12.3, 19.8, 28.4, and 31.7 lbs/tree at 0, 25, 50, 70 and 100% ET, respectively. This corresponds to decreases in harvested dry in-shell splits relative to full ET of 92.1, 61.2, 37.5, 10.4% for the respective ascending ET levels.

Figure 4 shows the sensitivity of four tree performance parameters to the different ET levels in terms of relative performance under full ET. In addition to harvest yields of dry in-shell splits, the performance parameters are:

1) Radial trunk growth from March 1 through October 31;

2) Nut biomass; the total dry weight of the tree nut load, both harvested and left in the tree after shaking, regardless of nut quality; and

3) Nut harvestability; the percentage of the tree nut load removed by shaking.

The figure illustrates that the two most sensitive parameters to plant water stress are yield (dry in-shell splits) and trunk growth. For example, at 50% ET, radial trunk growth was 51.2% that of full ET, whereas nut biomass and harvestability were 68.3 and 88.1%, respectively, of values obtained under full ET. Even at 70% ET, trunk growth was 12.2% less than full ET. This is not surprising in that expansive growth has been shown to be one of the most sensitive plant processes to water stress. Reduced tree growth can have at least two important negative ramifications. First, it will slow the rate of development of young trees and, therefore, decrease yields in the early years of an orchard and lengthen the time for orchard maturity. Additionally, reduced shoot growth in trees of all sizes may decrease the number of fruiting positions and/or cluster size, again reducing yield.

Harvestability increased with increasing ET. Figure 4 shows that 51.5, 77.2, 88.1, and 96.6% of full ET harvested percentage came off the tree at 0, 25, 50, and 70% ET, respectively. Again, the plant processes involved in forming the nut abscission layer were adversely affected by water stress.

The least sensitive performance parameter shown in Figure 4 was biomass accumulation in the nuts. This verifies our observation of previous seasons that the developing nuts are strong photosynthate sinks. Indeed, in terms of harvested split nuts on a dry weight per nut basis, virtually no differences existed at 50, 70, and 100% ET. Corresponding nut weights (sum of kernel and shell) were 1.17, 1.17, and 1.18 gms/nut, respectively. This information is presented in Table 2, in addition to relative nut size data.

On a per nut basis, harvested split nuts in the 0 ET plot weighed 28.8% less than those under full ET (.84 versus 1.18 gms/nut). Equivalent data at 25% ET reveals a 9.3% lower nut weight (1.07 versus 1.18 gms/nut). Lower nut weights resulted from smaller nut size, rather than incomplete filling. Besides visual observations during nut dissections, this conclusion is supported by the shell cross-sectional areas relative to full ET shown in Table 2; (76.2 and 94.0% for the 0 and 25% ET levels, respectively). Even though it's been reported that ultimate shell size is attained in May, shell enlargement apparently was reduced by water stress at these lower ET levels even during the early part of the season. This is not surprising since shell enlargement is an expansive growth process and, therefore, quite sensitive to even mild plant water stress.

Second Year Affects of Severe Water Stress

Depriving selected trees in Site 2 of summer irrigation for a second consecutive year allowed the affects of continuing severe plant water stress on nut development and tree performance to be observed. Figure 5 illustrates the impact on nut quality. Data for a single year of severe water stress (the 1984 0 ET plot) and non-stressed conditions (the 1984 100% ET plot) are included for comparison.

Surprisingly, nut quality was quite similar for both one and two years of severe stress. Indeed, the total tree nut load percentages of split nuts were almost identical; 13.6% for one year and 13.8% after two years. The same is true for unsplit nuts; 56.6 and 56.1% after one and two years, respectively. Nut abortion was relatively high in both years (21.8% in year one and 17% in year two). Blanking, which Figure 2 showed was negligibly affected by current season water stress, was a relatively high 13.1% of the tree nut load after two years of stress. This indicates a possible carry-over effect of water stress on the processes responsible for blanking.

While nut quality was little changed between one and two years of severe water stress, other aspects of tree performance did show marked differences. Figure 6 presents data on trunk growth, biomass accumulation in the nuts, harvestability, and yield (dry in-shell splits) for one and two years severe stress and one year stress followed by a return to full ET conditions (no stress). By far, the parameter most influenced was trunk growth where the second year stressed trees had only 13.4% as much growth as well-watered trees. One year of stress followed by adequate irrigation resulted in nearly a complete recovery in the rate of trunk growth (87.3% of the growth of well-watered trees).

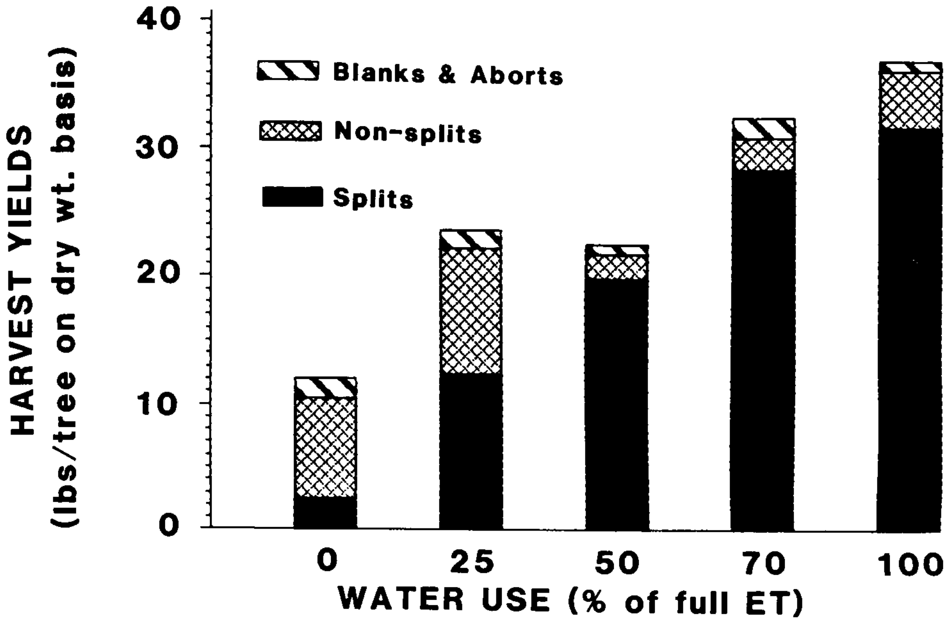

Figure 3.
Harvest yield components on a dry weight basis for different ET levels. Data are averages of 40 trees per plot.

TABLE 2.
Nut component dry weights (shell and kernel) and relative sizes of harvested, split nuts for different ET levels. Data represent averages of 200 nuts collected from each of 10 trees.

Water Use Rate (% full ET)	Shell	Embryo	Total	Relative Shell Size[1] (%)
		gm/nut		
0	.40	.44	.84	76.2
25	.50	.57	1.07	94.0
50	.54	.63	1.17	99.2
70	.55	.62	1.17	99.0
100	.55	.63	1.18	—

[1] Values are expressed as percentages of shell cross sectional areas relative to value obtained under full ET.

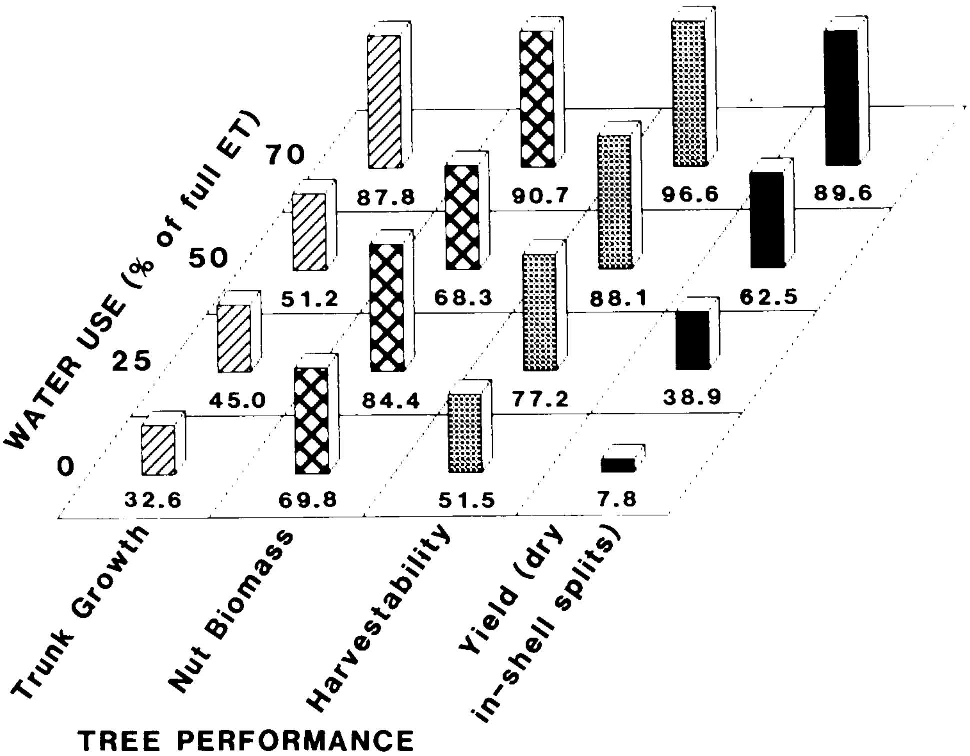

Figure 4.
Relative influence of ET levels on selected current season tree performance parameters. Column heights and numbers in grid squares represent percentages of values obtained under full ET. Performance parameters are described in detail in the text.

A return to non-stressed conditions did not result in dry in-shell split yield (52.8% of 100% ET yield) recovering as much as trunk growth. This was due to a greater percentage of both aborted nuts and blanks, as well as to slightly less nut splitting and harvestability. In fact, blank nuts totalled 14.8% of the total tree nut load compared to 7.1% under full ET. This, again, indicates that carryover effects of severe water stress on blank nut production, regardless of the irrigation conditions following the stress.

The remarkable strength of the nuts as photosynthate sinks is shown in the nut biomass data in Figure 5. The total tree nut weight, without regard to quality, was only marginally less after two years stress compared to one year. There was actually a greater total nut weight after one year stress than after a return to full ET. Besides the ability of the stressed nut to accumulate dry matter, this was due mainly to greater blanking and nut abortion in the year following one year of severe stress.

Harvestability after two years stress actually improved relative to one year, which at first appears to contradict previously mentioned data. This phenomenon was due to the breakage of complete rachises during tree shaking resulting in whole nut clusters being harvested rather than individual nuts. The hulls of these nuts remained tightly bound to the shells.

It should be emphasized that since no summer irrigation was applied to the severe stress plots, what little water that was used came primarily from winter rainfall. Water use totalled only 9.9 inches for the trees stressed for two consecutive years and 3.0 inches for the single year of stress. Water use estimates were made by monitoring to a soil depth of 20 ft in these plots. Figure 7 shows the seasonal soil water depletion pattern for the second year stress plot. The trees extracted water throughout the entire monitored profile. However, the pressence of significant depletion in the 17 to 20 ft layer suggests that additional water was extracted below 20 ft. The magnitude of this unmeasured water use is unknown.

CONCLUSIONS

Pistachio trees can use large amounts of water. Midsummer ET (June through August) under normal conditions averages 52 gal/tree/day for clean cultivated mature trees on a 17 x 17 ft spacing. Seasonal crop water use is 40.1 inches for a normal year in the San Joaquin Valley. Both peak and seasonal ET exceeds that of other deciduous trees.

Field measurements of CO_2 assimilation from trees under different irrigation regimes showed that net leaf photosynthesis and stomatal conductance (an indice of stomatal opening and water use) are curvilinearly related. This differs from the linear relationship of most crops and suggests that carbohydrate production increases do not keep pace with increases in ET. Further study is needed to examine whether this indicates that sustained satisfactory orchard productivity can be obtained at crop water use rates less than full ET.

Under differential water application amounts, harvest yields (dry in-shell splits) increased with increasing ET. Tree water use of less than 50% ET (20 inches for a normal year) resulted in appreciably reduced shell splitting. A less severe impact was observed on harvestability. Water stress, no matter how severe, only negligibly affected the current season blank nut production. Embryo abortion was greater only at the lowest ET level.

Progressively greater water stress appears to affect the following current season tree performance parameters in descending order of severity (i.e., most sensitive listed first): yield (dry in-shell splits), radial trunk growth, harvestability, and biomass accumulation in the nuts. The size of the harvested split nuts was reduced by relatively severe water stress (0 and 25% ET) due to the severity of shell enlargement to early season stress during May.

Second year affects of continued severe water stress (no summer irrigation) on nut quality, yield, and harvestability were little changed from the first year results. It's remarkable that trees under two years of severe stress (9.9 inches of total ET) survived, let alone produced nuts, although leaf size and canopy density were reduced. Also, premature leaf yellowing followed by partial defoliation occurred. Trunk growth also decreased dramatically.

Trees severely stressed for one year and then irrigated the following season at full ET approached complete recovery with respect to growth and harvestability. However, yield (dry in-shell splits) and biomass accumulation in the nuts only partially recovered due to a greater amount of nut abortion and blanking. This indicates some carryover effects of severe water stress on blanking, regardless of irrigation levels in the season following the stress.

ACKNOWLEDGEMENTS

Numerous people made outstanding contributions to this project, without which this work would not have been possible. The authors wish to acknowledge the cooperation of Donnie Rose, Louie Ontiveros, and Charlie Rose of S & J Ranch, Inc., managers of the orchard where this work was conducted. Thanks also go to owner Bill Fong. We appreciate their interest in and support of this work. Al and Greg Linden of VineTree Harvesting, Inc., graciously donated the equipment and operators used during harvest. Eric Muller and Larry LeMay of Salyer-American provided much needed equipment at a critical time. This help was particularly outstanding, especially since they are not involved in the pistachio industry. Literally hundreds of hours were spent installing equipment, assessing nut quality, and processing data. We acknowledge the contributions of Suzanne Coberly, Lori Scherlin, Tracy Moore, Kathlyn Loya, Mark Vosler, and Diana Nix.

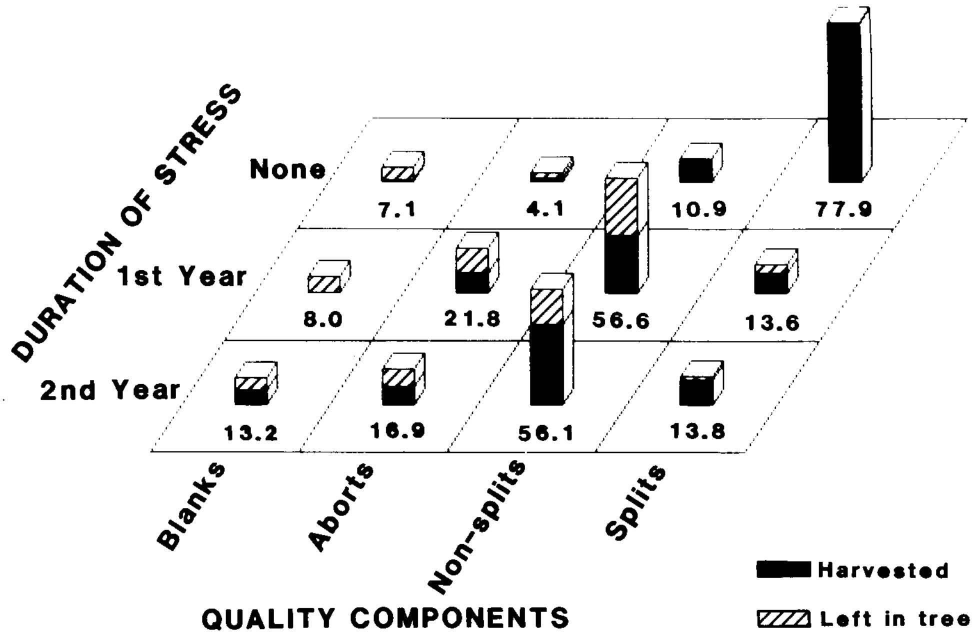

Figure 5.
Severe water stress affects (no summer irrigation) for one and two years on nut quality and harvestability. Full ET values are shown for comparison. Column heights and numbers in grid squares represent total tree nut load percentages (both harvested and left in tree after shaking) of each quality component for a particular ET rate. Data are averages of 200 nut samples from each of 10 trees per plot.

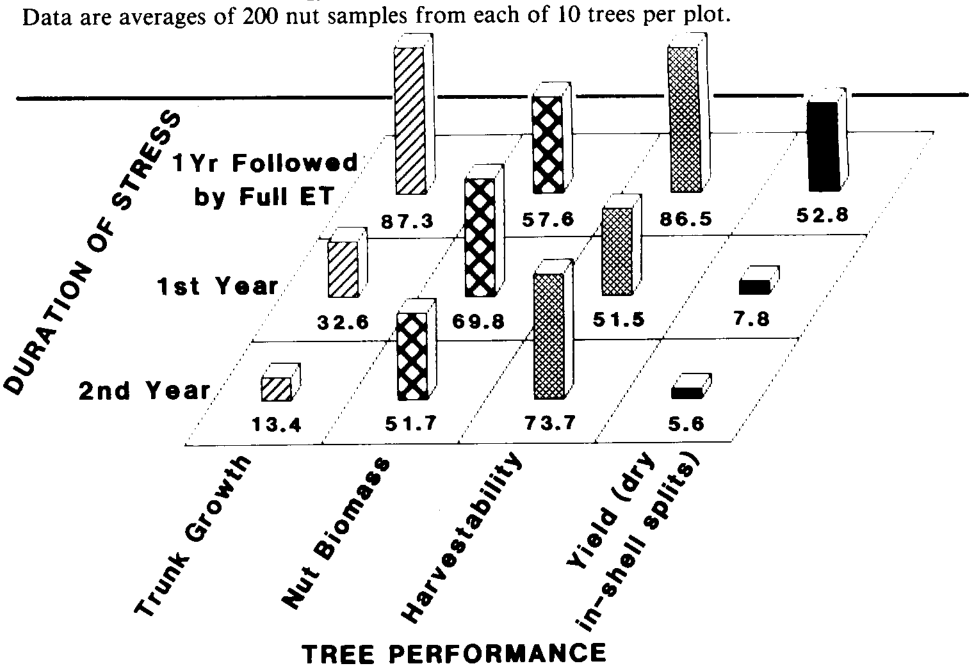

Figure 6.
Effects of severe stress for one year, two years, and one year followed by full ET on selected current season tree performance parameters. Column heights and numbers in grid squares represent percentages of values obtained under full ET. Performance parameters are described in detail in the text.

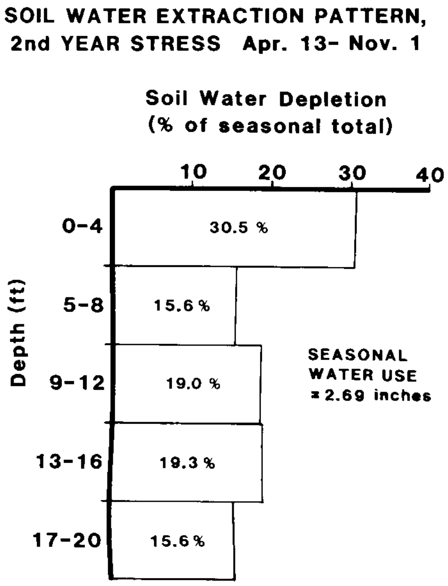

Figure 7.
Pattern of seasonal soil water extraction during 1984 by trees deprived of summer irrigation for two seasons beginning in 1983.

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