

PHYSIOLOGICAL RESPONSE OF PISTACHIO

TO SEVERE WATER STRESS — BY DAVID A. GOLDHAMER, ROGER KJELGREN, ROBERT BEEDE, J. MARK MOORE, JOE MENEZES, JR., AND GARY WEINBERGER, UNIVERSITY OF CALIFORNIA, PARLIER

Field studies continued during the 1983 season to evaluate pistachio water requirements (ET) and tree performance under water-limiting conditions. A major part of this year's work involved intensive instrumentation and frequent samplings to determine ET of mature trees. Field work continues to obtain the necessary soil hydraulic properties to complete these estimates and, thus, this information will be reported at a later date. Therefore, this paper will compare and contrast the tree and crop behavior under both optimal and limiting soil water conditions.

Pistachios have a reputation for being drought-resistant. This indicates the existence of mechanisms to avoid and/or tolerate water stress; avoidance associated with responses that limit plant water loss and tolerance involving adjustment of intercellular composition to allow plant survival. The relative importance of these adaptations in pistachio is unknown. The objective of this study was to examine the effect of severe water stress on internal plant water status and stomatal behavior and on subsequent water use, tree growth and cropping.

METHODS

The experimental site located south of Kettleman City and described in last year's report was expanded this season. Five pistillate trees (nine-year-old "Kerman" on *P. atlantica*), in addition to last season's original three trees, were each instrumented with three neutron access tubes. Soil water status was assessed twice weekly throughout the growing season with readings taken every 12 inches to a depth of ten feet. The surface soil water status was evaluated by collecting gravimetric samples. Irrigations with hand-move sprinklers began on May 1, and continued until August 17, generally being applied every 18 days. Care was taken to insure that these trees were adequately supplied with water, and thus, were designated as well-watered trees.

A group of 120 trees located 11 rows

away was used for the water stress evaluation. Three trees were instrumented with access tubes, mostly to a depth of 15 feet, and weekly soil water readings recorded. These trees (hereafter referred to as the stressed trees) were not irrigated throughout the growing season, and thus, relied entirely on winter rainfall stored in the soil profile to meet their water requirements. Evaporation rates from a USWB Class A pan located in a grass environment nearby were recorded twice weekly.

Extensive plant-based measurements on each block were taken throughout the season. Leaf water potential (ψ_l) was evaluated from measurements of xylem pressure potential with a pressure chamber (PMS Model 600), as outlined in the 1983 report. Concomitant measurements of leaf stomatal conductance (g_l) were made on both sides of exposed, sunlit leaves with a steady state diffusion porometer (Licor Model 1600). Hourly recordings of ψ_l and g_l were frequently conducted. These diurnal measurements began before dawn, and continued until at least one hour after sunset. Additionally, predawn and midday ψ_l and g_l were taken weekly throughout the growing season.

Tree trunk radius changes were measured to an accuracy of 0.01 mm with a Karlberg microdendrometer periodically on 15 trees in each block. Terminal shoot growth was measured weekly from April 25 on 10 preselected shoots equally divided between bearing and nonbearing branches of three trees.

Nut development was evaluated based on sampling begun in early June. Twice a week, 40 nut samples were collected from each of four randomly selected trees in each block. Nut sampling continued after the September 26 harvest from four trees in each block that remained unharvested.

The nuts were immediately removed to the laboratory where hull (mesocarp), shell (endocarp) and kernel (embryo) weights were determined. Composition of each sampling in terms of split, nonsplit and

blank nuts (embryo abortion and vegetative parthenocarpy) was also evaluated.

Commercial harvesting equipment was used to determine yields of 40 randomly selected trees in each block. Detailed analysis described above was made of 200 nut samples taken from both the harvested nuts and those remaining in the tree after shaking on eight trees in each water regime.

RESULTS AND DISCUSSION

Winter rainfall amounts stored in the root zone were not nearly enough to meet the water requirements of trees in the stressed block. Therefore, rather than follow the typical bell-shaped ET pattern associated with adequately irrigated crops, water use decreased with time during the season in the stressed block. This is illustrated by the soil water extraction patterns presented in Figure 1 for two 15-day periods; one early in the season and the other midseason. Soil water depletion measurements, which represent water uptake by roots, for the May 16 to 31 period show that the bulk of extraction took place in the upper six feet of the profile. A total of 1.48 inches was used in the 15-foot profile over this 15-day period. On the other hand, total water use in the stressed block from July 18 to August 2 totalled only 0.42 inch and occurred mostly in the lower parts of the root zone. The difference in extraction patterns is consistent with previously reported data that shows that when deprived of adequate irrigation, trees will first deplete the upper layers of the profile before extracting water from deeper zones. This preferential use of water is due to the greater driving force needed for the tree to transport water from lower depths. Of greater interest in Figure 1 is the large disparity in tree water use, especially in view of the relationship between indicated ET and evaporative demand. Since potential transpiration is directly proportional to evaporative demand,

the soil water status measurements strongly suggest the presence of severe plant water stress.

As plants extract a limited supply of water, cells are subject to increasing amounts of dehydration as the leaves lose water faster than it's being extracted from the soil. Left unchecked, the massive concentration of intracellular solutes would result in cell, and eventually, plant death. However, water loss from leaves can be limited by a variety of mechanisms, with stomatal control generally the most important. Figure 2 shows seasonal stomatal behavior as indicated by midday (solar noon) g_L measurements for both stressed and well-watered trees. Midday g_L increased steadily in both well-watered and stressed blocks from mid April to early June most likely in response to progressively higher levels of solar radiation. At that point, g_L in the stressed trees declined rapidly attaining a minimum value of 0.09 cm/sec on September 6. Subsequent modest increases in stomatal aperture reflect the occurrence of some late season rainfall. Well-watered values, on the other hand, continued to increase to approximately 0.85 cm/sec in mid June and maintained this level with moderate variation until the end of September. At that point, leaf senescence and lower net solar radiation resulted in a fast rate of g_L decline.

The stressed trees' efforts to conserve water was also manifested in the diurnal pattern of g_L , in addition to midday magnitudes. Figure 3 presents a comparison of

well water and stressed g_L measurements taken hourly from 0500 to 2200 on July 11. Note that in the well-watered trees, g_L increased after sunrise, reached a maximum (0.75 cmg/sec) by 1000 and remained relatively constant until 1700. This contrasts sharply with the stomatal activity of the stressed trees, that showed maximum aperture ($g_L \cong 0.44$ cm/sec) at 0800 that declined thereafter, except for slight increases at 1800 and 1900. Thus, the stomata remain partially open for only a short time during the early morning hours when environmental conditions are less severe and begin to close rapidly when evaporative demand increases. In the late afternoon, stomatal opening also slightly increases. This pattern of stomatal opening allows the tree to assimilate the maximum amount of CO_2 while losing the minimum amount of water. It's interesting to note that the well-watered trees do not show any evidence of the partial midday stomatal closure associated with other deciduous trees, including almond and walnut, under non-limiting soil water conditions. It appears, therefore, that even though pistachio can effectively control transpiration when deprived of adequate water, it consumes water at a high rate when it's in abundant supply.

Because of their influence on transpiration and CO_2 assimilation, the relationship between ψ_L and g_L is important. The data presented in Figure 2 showed that midday stomatal response did not vary between the different water regimes until ear-

ly June. Nearly equivalent midday g_L values obtained on June 6 were associated with ψ_L of -16.9 and -27.9 bars, respectively, for the well-watered and stressed blocks. The precipitous drop in g_L thereafter was not accompanied by an equivalent change in ψ_L . Apparently, only a slight ψ_L decrease in excess of -28 bars resulted in a large concomitant decrease in guard cell turgor that translated into a large reduction in g_L . It's recognized, however, that a unique relationship between g_L and ψ_L of -28 bars does, most likely not exist. In other words, a ψ_L of -28 bars may not always signal the beginning of stomatal closure. As with other species that undergo osmotic adjustment, the ψ_L associated with stomatal closure depends on the tree's immediate stress history.

The significant stomatal differences represented in Figures 2 and 3 indicate reduced transpiration rates for the stressed trees, and indeed, their seasonal water use totaled only 7.15 inches based upon soil water depletion measurements. So by controlling stomatal aperture, pistachio makes the best of an unfavorable situation. It limits water loss while at the same time, unavoidably limiting CO_2 assimilation. Since photosynthesis depends upon CO_2 , stomatal closure has been shown to decrease dry matter accumulation, which consequently affects tree growth and crop yield.

Expansive growth has long been considered a more sensitive indicator of plant water stress than stomatal behavior. Figure

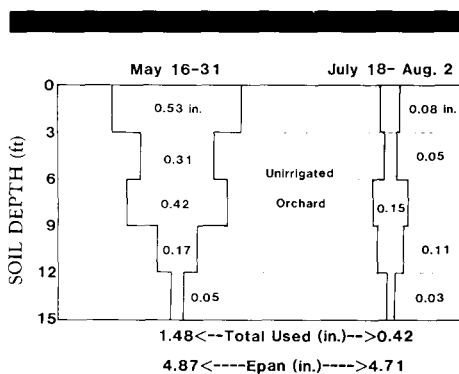


FIGURE 1. Soil water extraction patterns and amounts in the stressed block for early and mid-season 15-day periods. Depletion values are averages of measurements taken at one-foot intervals from six access tubes.

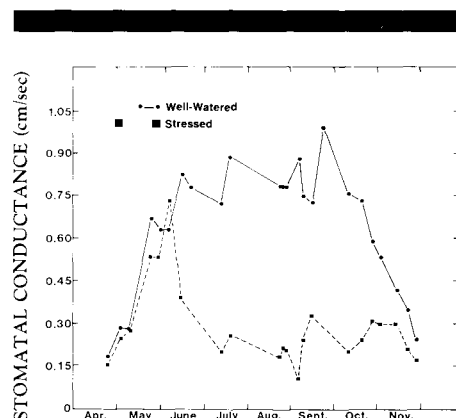


FIGURE 2. Seasonal mid-day (solar noon) values of stomatal conductance for well-watered and stressed pistachio. Each point is the average of two measurements taken on four trees.

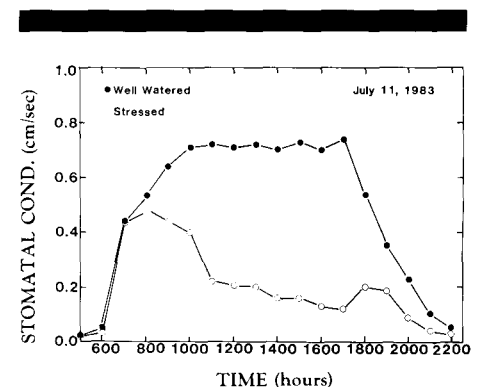


FIGURE 3. Hourly measurements of stomatal conductance taken on July 11 in well-watered and stressed trees. Each point is the average of two measurements taken on four trees.

SEVERE WATER STRESS

4 shows accumulated radial trunk growth assessed from the end of June through mid August in both blocks. It clearly shows that, while overall trunk growth was relatively low even in the well-watered trees, the severe water stress resulted in trunk contraction (negative growth) during July. Shoot growth measurements taken from April 25 to November 6 showed negligible growth in both blocks. This is not surprising because others have found shoot growth occurs predominantly from late March to late April.

Kernel development expressed as dry matter accumulation in filling nuts under both stressed and well water conditions is presented in Figure 5. This data confirms our observation of last season that even under severe stress, there was relatively little difference in dry weight gain through the end of August. Remember that significant disparity of g_d and presumably net photosynthesis began in early June. This clearly illustrates that the developing nuts are strong photosynthetic sinks. Figure 5 shows that maximum kernel weight occurred in late September and decreased slowly thereafter. At harvest, stressed kernels weighed about 16% less than well-watered (0.58 vs. 0.69 gms/kernel) on a dry weight basis. Lower kernel weights were the results of smaller nut size in the stressed trees, rather than incomplete filling. This is evidenced by the dry weight percentage of kernel to nut in harvested, split nuts; 53.2 and 54.9% in the well-watered and stressed trees, respectively. Direct measurements of longitudinal and radial nut size verified the existence of smaller nuts in the stressed trees. This is somewhat surprising in that

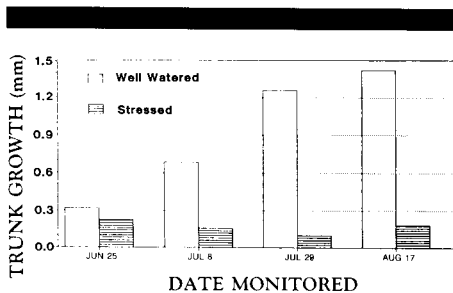


FIGURE 4. Accumulated expansive radial trunk growth from late June to mid-August in well-watered and stressed trees. Data represent averages of 15 trees per block.

it's been reported that ultimate shell size is attained in May, well before significant differences in stomatal behavior was observed. On the other hand, since shell enlargement is an expansive growth process, it should be sensitive to mild plant water stress that occurs before stomatal changes are observed.

Rather than dry weight accumulation in the filling kernels, the biggest difference in nut development between the well-watered and stressed trees occurred in the relative percentages of split and unsplit nuts. Figure 6 illustrates the fate and composition at harvest of the average overall tree nut load, on a numerical basis, in the well-watered trees. Of the total load, 79.8% was removed by the harvest, leaving 20.2% in the trees—most of these were blanks. The harvested nuts consisted of 69.0% splits, 21.4% non-splits, and 9.6% blanks. This contrasts sharply with equivalent data for the stressed trees shown in Figure 7. Only 59.7% of the nuts were removed by shaking and of these, a much smaller number were splits (39.4%). Similarly, a much larger percentage (44.8 vs. 19.4%) of nuts that remained in the tree were also non-splits. The total amount of blanking in both water regimes was similar.

The large amounts of non-splits in the stressed trees was most likely due to the fact that shell splitting is a biochemical reaction associated with kernel growth and development. Therefore, lower net photosynthesis not only reduced dry matter accumulation in the nut, but delayed

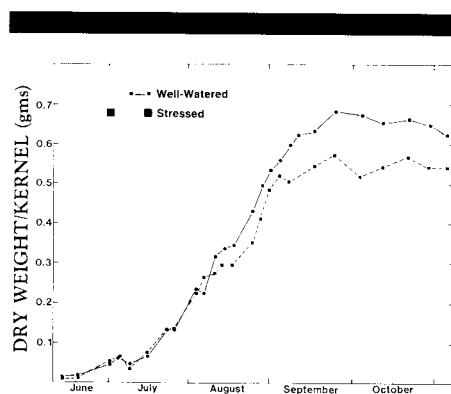


FIGURE 5. Developing kernel dry weights in filling nuts in both well-watered and stressed trees. Data points are based on 40-nut samples collected from each of four trees.

the biochemical processes necessary for shell splitting in a large percentage of the crop. Data (not shown) indicated that shell splitting continued in the stress nuts through the last sampling (November 11). It should also be noted that the hulls of the stressed nuts generally remained tightly bound to the shells through harvest (September 26), and only from mid October on did a majority of the nuts attain "physiological maturity" as defined as easy separation of the hull from the shell.

Table 1 presents harvest data expressed on a weight per tree basis for the different yield components. It shows that gross yields in the stressed trees were 40.6% less than the well-watered trees. Of greater importance, the yield expressed as dry, in-shell splits was 68.8% lower in the stressed trees. It's important, however, to make the distinction between harvested amounts and total nut production. Our measurements show that when considered in terms of total biomass produced in the nuts, both those remaining in the tree and harvested, there was only 14.7% less production in the stressed trees. This, again, demonstrates that nut development is the preferential carbohydrate sink, but also indicates that one of the other sinks, most like tree

WELL-WATERED

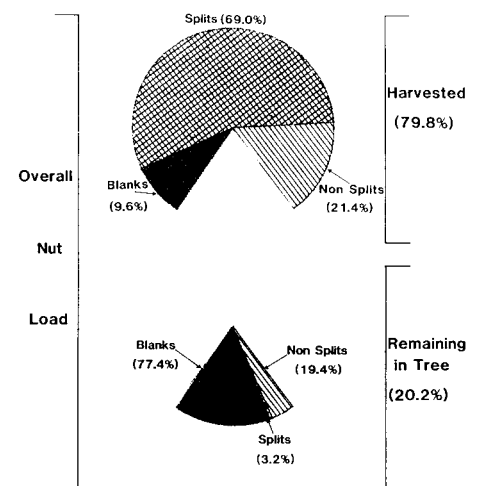


FIGURE 6. Fate and composition at harvest, on a numerical basis, of crop load of well-watered pistachio. Values in parenthesis represent averages of eight trees, 200-nut samples taken from both harvested nuts and those remaining in the tree after shaking.

storage, will suffer. Since floral bud differentiation, maintenance, and retention requires carbohydrates, serious effects on next year's growth and yield are possible. We anticipate continued monitoring of the stressed trees by splitting the block to assess the effects of both continued water deprivation and a resumption of well-watered conditions.

CONCLUSIONS

Imposing severe water stress on mature pistachio trees resulted in significantly reduced ET, seasonal stomatal conductance (and presumably net photosynthesis), leaf water potentials, tree growth, and crop yields. Lower crop yields resulted from two factors; lower dry matter accumulation in the nut (the stressed nuts filled completely, but the reduced shell size dictated a smaller kernel), and a higher proportion of nuts remaining in the tree after shaking. However, total nut biomass produced in the stressed trees was only marginally less than that of the well-watered trees. Harvested nut quality decreased sharply due to the higher percentage of unsplit nuts caused by stress-induced delay in the biochemical processes involved in shell splitting. Indeed, stressed nuts at harvest appeared to be phy-

siologically "younger" than well-watered nuts, especially in terms of hull slippage.

It's remarkable that mature trees grown on a relatively low water holding capacity soil that remained unirrigated throughout the season did not significantly defoliate and produced a modest crop. We are not suggesting, however, that top performance can be obtained if trees are subject to water limiting conditions. Because of the indicated reduced net photosynthesis in the stressed trees, it remains to be seen which carbohydrate-requiring process will be most adversely affected next season.

ACKNOWLEDGEMENTS

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TABLE 1. Harvest yields and quality expressed at five percent moisture content for well-watered and stressed trees. Numbers in parenthesis are percentages of total yield. Total yields are each averages of 40 trees and components are averages of 200-nut samples from eight trees.

	Lbs/Tree				
	Total Yield	In-Shell Splits	Non-Splits	Blanks	Hulls
Well-Watered	36.7	22.4 (61.2)	6.8 (18.4)	2.2 (6.0)	5.3 (14.4)
Stressed	21.8	7.0 (32.1)	11.0 (50.5)	0.7 (3.2)	3.1 (14.2)

STRESSED

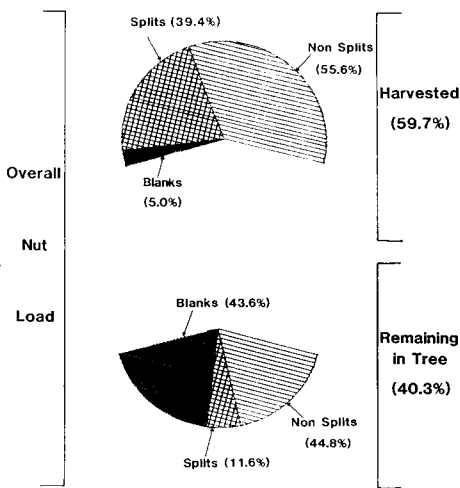


FIGURE 7. Fate and composition at harvest, on a numerical basis, of crop load of stressed pistachio. Values in parenthesis represent averages of eight trees, 200-nut samples taken from both harvested nuts and those remaining in the tree after shaking.

NUT CONSULTING

PISTACHIO EQUIPMENT DESIGN AND LAYOUT
 PISTACHIO OPERATIONS: HULLING, DRYING & FINISHED PROCESSING
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