Second Year Effects of Deficit Irrigation on Walnut Tree Performance

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ABSTRACT

The response of 6th year hedgerow-planted cv. Chico walnut to irrigation rates of 100, 66, and 33% of full ET (crop water use) was evaluated for a second consecutive year in 1987. We found that predawn plant water status (leaf water potential) better reflected the severity of the deficit irrigation relative to midday measurements. This indicates that predawn measurement of leaf water potential is a better index than midday values for irrigation scheduling. Midday stomatal conductance declined after early June in all irrigation regimes, presumably due to leaf aging or possible feedback inhibition of stomatal opening due to lower demand for carbohydrates. Indeed, the major vegetative and reproductive growth processes peaked by late June.

Diurnal measurements of tree behavior showed that cv. Chico is sensitive to changes in evaporative demand. Hot, dry conditions resulted in more rapid midday stomatal closure, especially in the deficit irrigation plots. Strong stomatal control of the tree water balance, while allowed the tree to survive drought, also presumably limited CO_2 assimilation. This, coupled with lower plant water status levels, reduced the rates and seasonal amounts of the various growth processes, including trunk, shoot, and nut development.

Yield of dry in-shell nuts was 3.8, 3.2, and 2.6 tons/acre in the 100, 66, and 33% ET regimes, respectively. These differences were due primarily to smaller nuts produced under deficit irrigation. Kernel percentage ranged from 52.7% for 100% ET to 46.4% for 33% ET. The number of nuts per tree was lower by approximately 10% only at the most severe water deprivation level. Harvest indexes, expressed both a nut number and nut yield per unit shaded area of the orchard floor, were only marginally different between treatments. This indicates that no major effects of water stress on fruiting density have yet occurred.

Yield differences between the 100% ET hedgerow plots and the fully irrigated conventional-spaced trees (3.1 tons/acre) narrowed considerably. The conventional density yield was 82% that of the hedgerow after this year, compared with 27% last season.

OBJECTIVES

A number of long term goals have been established for this continuing project studying various plant water relations aspects of cv. Chico walnuts. These include:

1) determining evapotranspiration (ET) of both hedgerow and conventionally-spaced walnut trees from planting to orchard maturity,

2) establishing the relationships between ET, tree productivity, and the rate of orchard development, and

3) evaluating the effects of sustained plant water stress on tree performance.

The latter study began in 1986. This report contains the results of the second stress year. A separate report covers the relationships between nut temperature (kernel and hull) and pelicle quality.

PROCEDURE

Three irrigation rates (33%, 66%, and 100% of full ET) were applied throughout the season to sixth year high density (11 x 22 ft) Chico walnut trees which comprise half of a 2.5 acre orchard at the Kearney Agricultural Center. The other section is conventionally-spaced (22 x 22 ft) trees that are being irrigated at 100% ET and will only be briefly mentioned in this report. ET was estimated from the on-going crop water use study, which includes adjustment based on a soil water balance technique. The irrigation regimes are replicated three times in a randomized design. Each replication consists of 4 x 6 trees; the outside trees in each direction being guards resulting in eight monitored trees per plot.

Water is applied using circular pattern low volume sprinklers positioned in the tree rows 5.5 ft from each tree. The various irrigation regimes are accomplished by using different size sprinkler heads and water applied to each plot is measured with water meters. All plots are irrigated with the same frequency; generally two to four times per week.

Tree response to the deficit irrigation was monitored weekly at midday by leaf measurements of water potential (pressure chamber) and stomatal conductance (steady state porometer). The former measurements were taken on single leaves on each of four trees per replication (12 per irrigation regime), and three leaves on each of the same trees (36 per irrigation regime) were monitored for the latter measurement. On June 25 and July 30, diurnal measurements of leaf water potential and stomatal conductance were taken.

Radial trunk growth was measured monthly during the season on eight trees per replication with a microdendrometer. Canopy site was assessed after development was complete by determining the shaded area of the orchard floor at 1:00 p.m. in late July. Measurements were made by counting the shaded squares of a grid drawn on a tarp and placed beneath the trees. Nut growth was evaluated by taking caliper measurements on 80 nuts per replication over the season. Nut samples (24 per replication) were also collected and dried to determine the rate of dry weight accumulation.

The orchard was harvested on September 10 with a commercial shaker and individual tree field weights determined. Nut subsamples were collected (200 nuts per replication) and removed to the laboratory where the nut component weights (hull, shell, and kernel) and nut size (width and length) were evaluated. Additional subsamples were analyzed commercially by Diamond Walnut Growers, Inc. for nut size (five category breakdown) and nut quality (6 category breakdown).

Leaf samples were collected on July 20 and evaluated for macro and micro elements. To assess vegetative growth, pruning weights of individual trees were taken following mechanical hedging of the east side of tree rows in late 1987.

RESULTS AND DISCUSSION

During 1987, the irrigation regimes labeled as 100, 66, and 33% ET received a total of 42.0, 28.2 and 17.4 inches of water, respectively. This includes rainfall, which was assumed to be 50% effective. Thus, 41% ET was actually applied to the middle treatment.

Although much effort was made to apply water in the 100% ET plots at exactly the rate that the orchard was using water, some under and over-irrigation occurred. This is reflected in the predawn leaf water potential values shown in Figure 1. While 100% ET plot values were generally in the -1 to -2 bar range throughout the season, an irrigation system breakdown in mid-July resulted in a short-term depression of predawn leaf water potential. More drastic deviations from mean seasonal values were observed in the 66 and 33% ET treatments during this system breakdown. However, when viewed as a continuum over the season, predawn leaf water potential ranged from -2 to -3 bars at 66% ET and -4 to -5 bars, at 33% ET. These values are indicative of the lower soil water levels monitored in the deficit ET regimes (data not presented).

Midday leaf water potentials measured throughout the season are shown in Figure 2. Distinct separation generally existed between the irrigation regimes; 100% ET being the least negative and 33% ET being most negative. There was a gradual decline in midday leaf water potential with time over the season in all treatments. The scatter in the data can be attributed primarily to fluctuations in soil water levels (the mid-July system breakdown is clearly evident in relatively low midday values) and day-to-day variations in evaporative demand, which will be discussed later.

Whereas midday leaf water potential decreased gradually with time, midday stomatal conductance decreased at a much more rapid rate throughout the season in all irrigation regimes. After reaching a peak value of 1.2 cm/s in early June, 100% ET stomatal conductance dropped consistently, attaining a low of 0.2 cm/s near harvest (September 10). Similar relative patterns were observed for the deficit irrigation regimes, although maximum values were achieved a month earlier in the deficit irrigation plots than under full ET. Possible explanations for the declining trend in the magnitude of midday stomatal conductance include leaf aging or feedback inhibition of stomatal opening due to declining carbohydrate sink demand, which will be discussed later. It's interesting to note that larger differences in stomatal conductance occurred during June than either earlier or later in the season. The time-averaged stomatal conductance values indicate that CO_2 assimilation was appreciably restricted in the 66 and 33% ET plots.

Diurnal measurements of plant behavior are useful in evaluating tree response to its environment; both soil water and atmospheric. This data was collected twice in 1987; on relatively hot (June 25) and cool (July 30) days, to compare the effect of evaporative demand on tree response.

Hourly measurements of leaf water potential and stomatal conductance taken on June 25 are shown in Figures 4 and 5, respectively. Leaf water potential showed relatively large differences predawn (-1, -2, and -5 for the descending ET levels, respectively), followed by uniformly rapid decline. Maximum negative values were achieved near 3:00 p.m. and varied by slightly more than one bar. This suggests that midday leaf water potential may not be a good indicator of the adequacy of irrigation.

Midday stomatal conductance reached a maximum value in the 100% ET regime at 11:00 a.m. (1.0 cm/s) followed by a rather rapid decline to 0.45 cm/s near 5:00 p.m. Maximum stomatal conductance was achieved much earlier in the 66% ET regime (0.7 cm/s at 9:30 a.m.) and 33% ET treatment (0.5 cm/s at 8:00 a.m.). Decline rates similar to that observed at full ET were also present in these treatments. For example, at 2:00 p.m., when the air temperature was 95°F, stomatal conductance was 0.25 and 0.15 cm/s in the 66 and 33% ET plots, respectively.

The steep decline in stomatal conductance after maximum values were attained did not occur on July 30, as shown in Figure 6. Although maximum values were somewhat less, reflecting the progressive drop over the season discussed earlier, the decrease in stomatal conductance occurred at slower rates. At 2:00 p.m. (88°F), stomatal conductance was 0.45 and 0.3 in the 66 and 33% ET plots. These values are almost double those found on June 25 at this time. Clearly, walnut stomatal behavior depends not only on soil water levels but on the evaporative demand of the tree.

Growth rates of the trunks and nuts are shown in Figures 7 and 8, respectively. Trunk growth rate peaked in early June (June 3 is Julian day 154) and declined rapidly thereafter. Growth directly reflected ET levels. Shoot growth was also reduced in proportion to the degree of water deprivation, as is shown by the pruning weights (Table 1). Nut growth reached maximum rates in late April, which were similar for all irrigation regimes, and was complete by late May. Thus, the biofixes used with the walnut phenology model which are based on nut size and strength showed little difference between irrigation levels.

Table 1. Harvest and productivity-related data from the hedgerow deficit irrigation study.

Treatment	Yield Dry In-Shell[1] (lbs/tree)	Fruit Load (nuts/tree)	Shaded Area[2] (ft^2)	Harvest Index (lbs/ft^2)	Harvest Index ($nuts/ft^2$)	Pruning Weights[3] (lb/tree)
100% ET	42.0	3100	175.0	0.24	17.7	8.5
67% ET	35.1	3018	154.9	0.23	19.5	7.6
33% ET	29.0	2703	146.2	0.20	18.5	4.7

[1] At 8% water content
[2] Measured on July 27
[3] Fresh weight basis

The dry weight accumulation rate of the nut was somewhat erratic, with the highest measured rates in late May and late June (Figure 9). By early July, the rate of dry matter accumulation had fallen considerably. The fact that the major growth processes in walnut occur before mid-July may be, at least in part, responsible for the relatively low stomatal conductance values observed after this time. Even though other energy-requiring processes occur later in the season, such as lipid formation in the kernels, the possibility of feedback inhibition of stomatal opening due to low carbohydrate demand exists.

Walnut hydration levels with time differed only slightly among the ET levels (Figure 10). Nevertheless, consistently higher hydration was found in the 100% ET nuts. Hydration levels declined gradually with time through the end of August, when the decline accelerated in all ET plots.

Harvest and other productivity-related data are presented in Table 1. Yield of dry, in-shell nuts was 3.8, 3.2, and 2.6 tons/acre in the 100, 66, and 33% ET regimes, respectively. These differences were due mostly to smaller nuts resulting of the deficit irrigation-induced plant water stress. Fruit load (nuts/tree) differed only marginally, especially between 100 and 66% ET. Indeed, harvest index values expressed both as harvested nut number per unit shaded area and harvested nut weight per unit shaded area were similar. Thus, the yield differences were primarily the result of smaller canopy size; simply smaller trees. After two years of stress, we have not observed a major effect on fruiting density.

Table 2. Nut component weights, kernel percentage, and industry size classifications for the harvested nuts.

Treatment	Component wt. of nuts Hull	Shell	Kernel	% Kernel	Nut Size Classification Jumbo	Large	Medium	Baby	Peewee
	----- (gm/nut) ------				---------------- % ----------------				
100% ET	0.90	2.68	2.98	52.7	3.0	8.2	25.9	21.5	41.4
67% ET	0.58	2.40	2.46	50.6	0.1	0.3	15.7	83.7	0.2
33% ET	0.51	2.40	2.08	46.4	1.3	4.9	10.9	38.6	44.3
Conventional (100% ET)	2.03	4.2	4.95	54.1	38.7	31.1	19.5	4.1	6.6

Table 3. Industry walnut harvest quality parameters for each irrigation regime.

Treatment	Edible Yield[1]	Large Sound[1]	Off-Grade[2]	Internal Damage[3]	Inset Damage[4]	"New" RLI[5]
	------- % by weight		-------	-------- % by number		--------
100% ET	47.6	13.9	4.1	2.2	0.0	52.4
67% ET	45.9	0.5	2.8	0.0	0.0	52.5
33% ET	41.6	6.7	7.0	0.0	0.0	50.2
Conventional Spacing (100% ET)	49.6	73.0	1.3	1.2	0.0	52.8

1 Sample is dry in-shell
2 Sample is dry kernel
3 Sample is large externally sound
4 Total sample
5 Reflective light index. The higher the RLI, the lighter the kernel color.

Walnut quality and component composition data are presented in Tables 2 and 3. Plant water stress resulted in smaller nuts with a lower kernel percentage, which ranged from 52.7 to 46.4% for the 100 and 33% ET regimes, respectively. Nut sizes indicated by the standard industry classification system were small for all treatments, although Jumbo and Large nuts totaled 11.2% of the nuts produced at 100% ET versus 62.9% for the total of Baby and Peewee nuts. Equivalent data for 33% ET was 6.2% for Jumbo + Large and 82.9% for Baby + Peewee. Large category nut production was markedly reduced from last season even at 100% ET, when the light crop resulted in large nuts. This also occurred this year in the conventionally-spaced trees, where a yield of 3.13 tons/acre resulted in 69.8% Jumbo + Large nuts. The deficit irrigation also reduced edible yield and large sound nut production, while off-grade values did not vary consistently with irrigation level.

Only a small amount of internal damage was found at 100% ET, and none in the deficit ET plots. No insect damage occurred regardless of the irrigation level. RLI was only mildly reduced at 33% ET and unchanged at 66% ET, indicating that plant water stress (and elevated nut temperatures) did not markedly affect kernel color. This subject is discussed in the separate report on temperature/nut quality interactions.

Leaf samples taken in late July and analyzed for chemical composition showed no difference in nitrogen or phosphorus on a dry weight basis. In fact, of all elements analyzed, only three showed any difference between treatments. Potassium was lower in the stressed trees (1.30, 1.20, and 1.07% for the 100, 67, and 33% ET treatments, respectively). Manganese levels were higher in the deficit irrigated plots, while copper was lower when both were expressed on a dry weight basis.

CONCLUSIONS

Predawn measurement of leaf water potential appears to be a better indicator of soil water status than midday determination and, therefore, is more useful in guiding irrigation scheduling.

Diurnal measurements of tree behavior showed that midday values of stomatal conductance are sensitive to changes in evaporative demand. More rapid midday stomatal closure was observed under hot, dry conditions, especially in the deficit irrigation regimes. Seasonally, there was a gradual decline in midday stomatal conductance after maximum values were attained in early June. This may be due primarily to leaf ageing. Peak daily stomatal conductance was directly correlated with the severity of the water deprivation.

Over all irrigation levels, peak vegetative and reproductive growth rates were achieved before mid-June. This, at least in part, may account for the decline of stomatal conductance with time through feedback inhibition due to lower carbohydrate demand. Reduced stomatal opening and low nut dry matter accumulation later in the season suggest that plant water stress during this period may not be of critical importance.

Yield reductions of 16 and 32% with the 66 and 33% ET treatments, respectively, were due primarily to smaller nut and tree size. Only minor differences in fruiting density were observed. Kernel percentage declined with the severity of the water deprivation. Nut quality was virtually unaffected by the plant water stress, indicating that cv. Chico is relatively insensitive to heat-related injury.

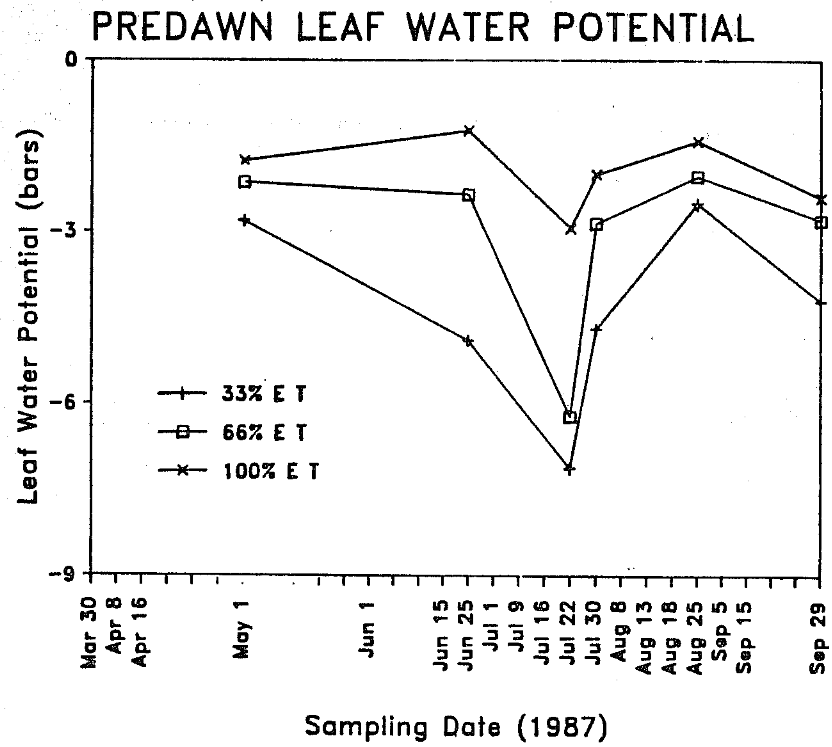

Figure 1. Measurements of predawn leaf water potential with time in the three ET regimes.

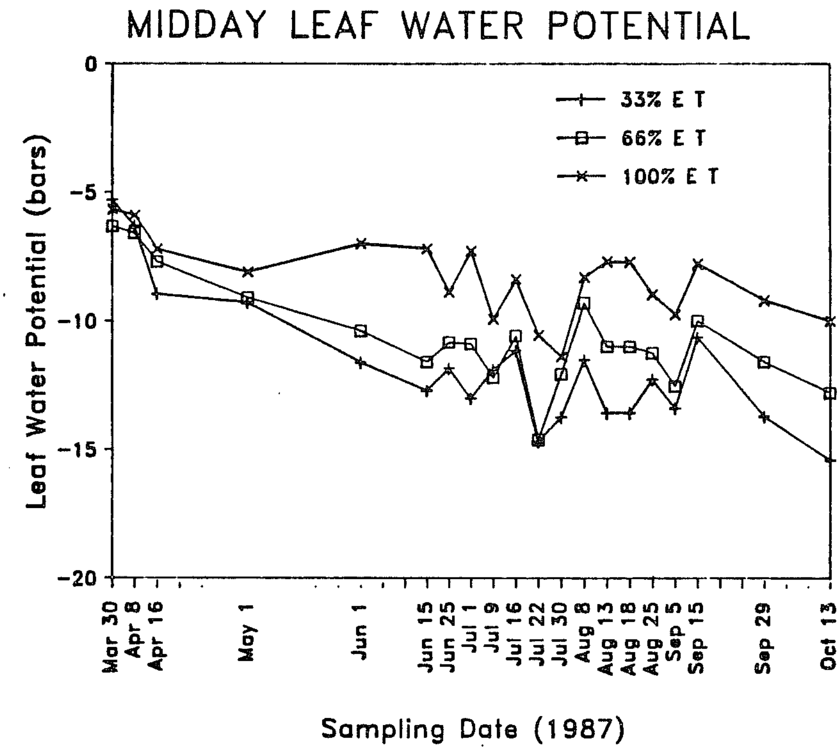

Figure 2. Midday leaf water potential with time in the hedgerow deficit irrigation study.

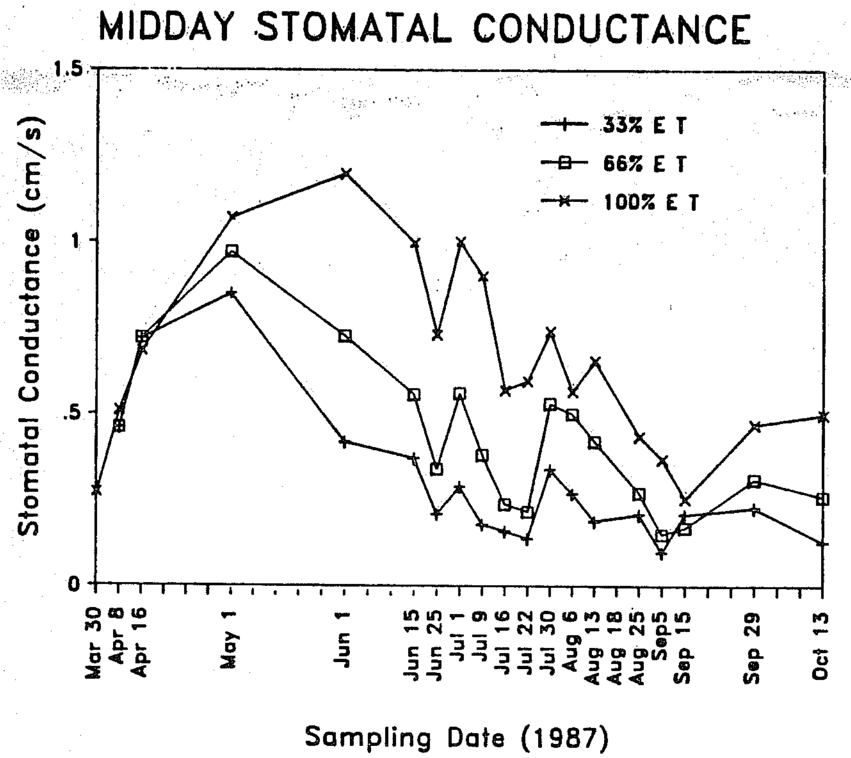

Figure 3. Midday stomatal conductance with time for the 33, 66, and 100% ET treatments.

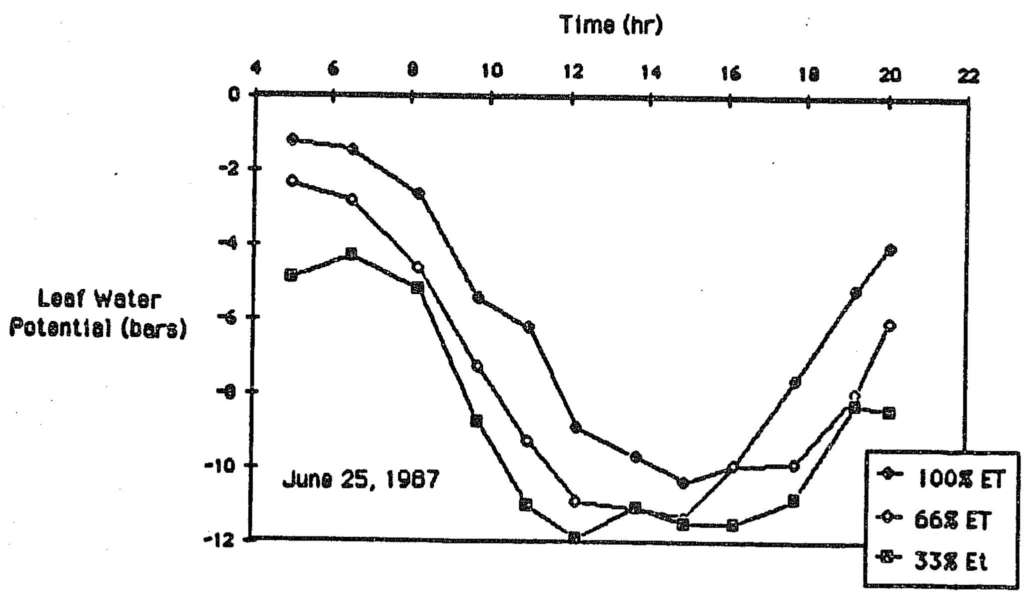

Figure 4. Diurnal measurements of leaf water potential taken on June 25; a relatively high evaporative demand day (99^{O}F peak temperature).

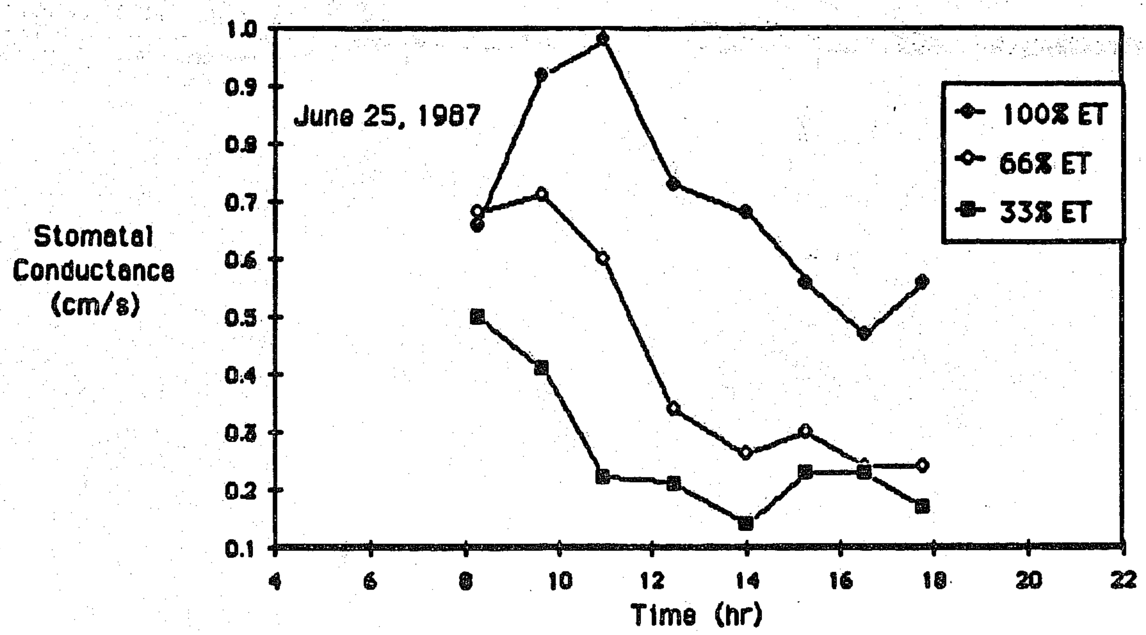

Figure 5. Diurnal measurements of stomatal conductance taken on June 25.

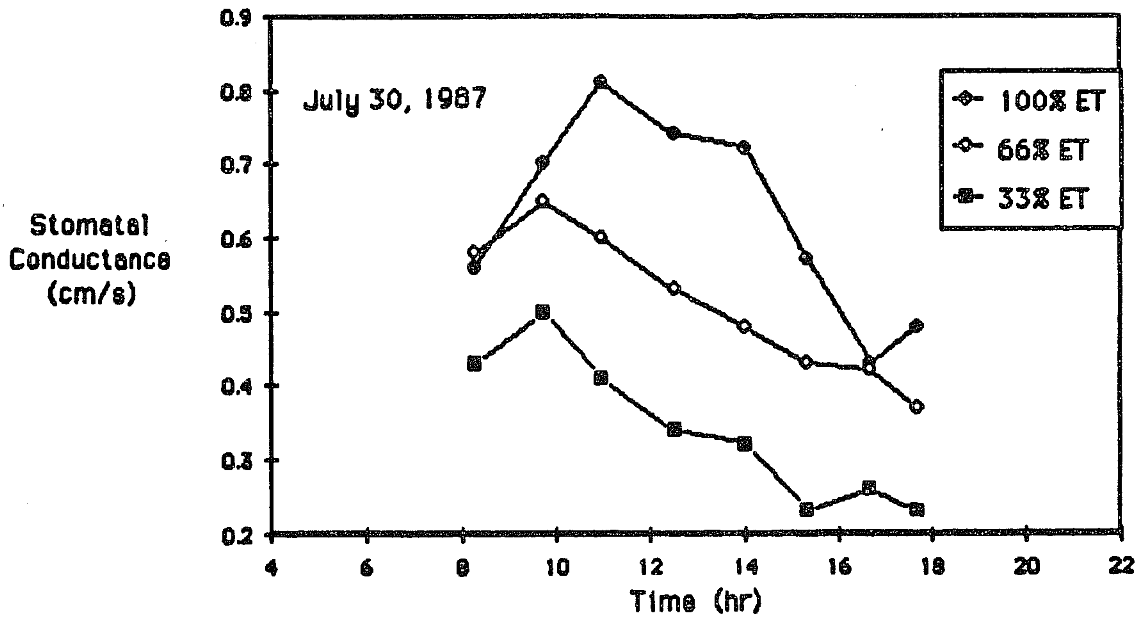

Figure 6. Diurnal measurements of stomatal conductance taken on July 30; a relatively low evaporative demand day (91^{o}F peak temperature).

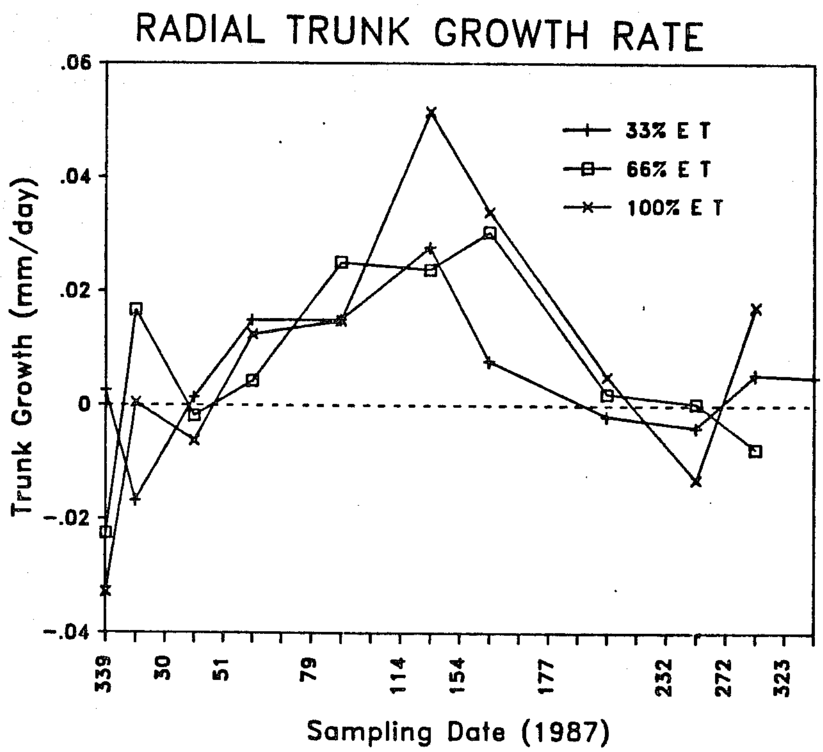

Figure 7. Radial trunk growth rate throughout the season for the three irrigation regimes (Julian day 154 was June 3).

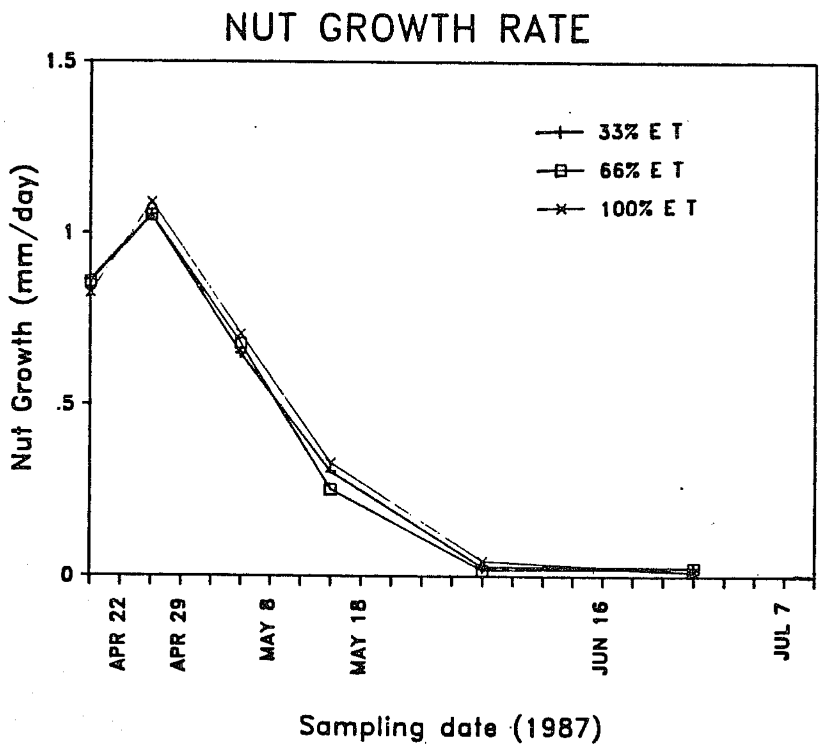

Figure 8. Nut diameter growth rate throughout the season for the different irrigation regimes.

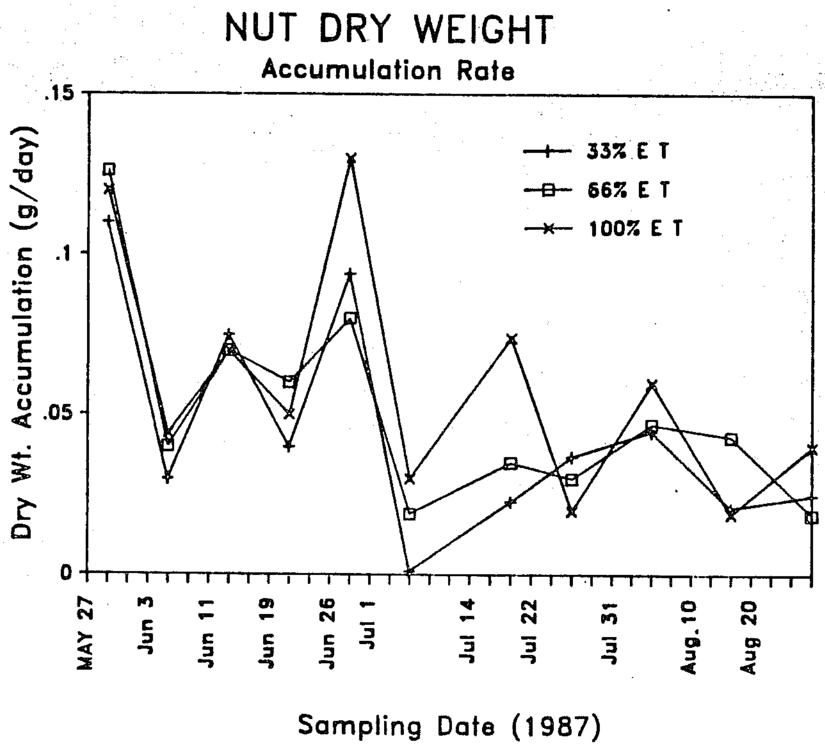

Figure 9. Dry weight accumulation rate throughout the season.

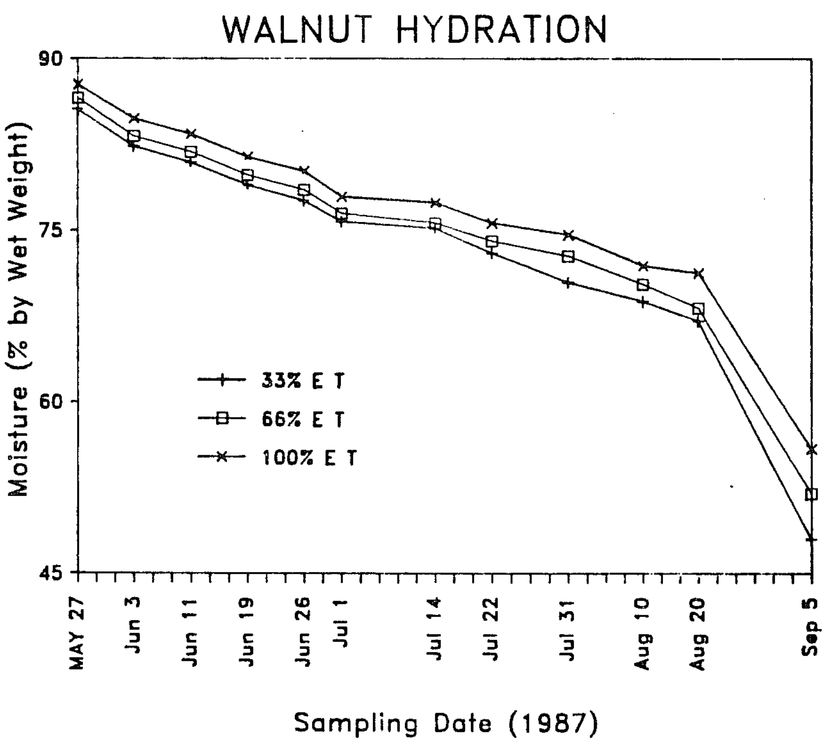

Figure 10. Nut hydration on a wet weight basis with time.