J. AMER. SOC. HORT. SCI. 123(1):150–155. 1998.

Effect of Fall Irrigation Level in 'Mauritius' and 'Floridian' Lychee on Soil and Plant Water Status, Flowering Intensity, and Yield

R.A. Stern[1] **and M. Meron**
MIGAL, Galilee Technology Center, Kiriat Shmona, P.O. Box 90000, Rosh Pina 12100, Israel

A. Naor
Golan Research Institute, P.O. Box 97, Kazrin 12900, Israel

R. Wallach
The Sigrham Center for Soil and Water, The Hebrew University of Jerusalem, Faculty of Agriculture, Rehovot 76100, Israel

B. Bravdo and S. Gazit
The Kennedy-Leigh Centre for Horticultural Research, The Hebrew University of Jerusalem, Faculty of Agriculture, Rehovot 76100, Israel

ADDITIONAL INDEX WORDS. leaf water potential, stem water potential, *Litchi chinensis*, water stress

ABSTRACT. The effect of fall irrigation level in 'Mauritius' and 'Floridian' lychee (*Litchi chinensis* Sonn.) on soil and plant water status, flowering intensity, and yield the following year was studied in a field during 2 consecutive years. At the end of the second vegetative flush after harvest (1 Oct. 1994 and 10 Oct. 1995), four irrigation treatments were initiated: 0.5, 0.25, 0.125, and 0 Class A pan evaporation coefficients designated 100%, 50%, 25%, and 0%. The three lower irrigation levels effectively stopped shoot growth, suggesting the 50% treatment to be the threshold for shoot growth cessation in both years. For both years, flowering intensity and yield in the 100% treatment were lower than those following the other three treatments. Soil and plant water-stress indicators responded to the water-stress irrigation treatments. However soil water-potential values were highly variable relative to plant water potentials. Stem water potential differed more markedly between treatments than leaf water potential. Midday stem water potential appeared to be the best water-stress indicator for irrigation control. Midday stem water potential in both years was correlated with midday vapor-pressure deficit, suggesting that the threshold for irrigation control should take into account evaporative demand.

Low yield (<0.5 t·ha^{-1}) is a major problem in lychee worldwide (Batten, 1986; Degani et al., 1995; Galan-Sauco and Menini, 1989; Joubert, 1986; Menzel, 1983, 1984; Stern and Gazit, 1996; Stern et al., 1993a, 1993b, 1996, 1997a). It is thought to be related to poor flowering intensity (Stern and Gazit, 1993; Stern et al., 1993a) and significant fruitlet abscission (Stern et al., 1995, 1997b). Fall vegetative growth is assumed to decrease differentiation and flowering (Menzel, 1983; Menzel and Simpson, 1994). Fall water-stress prevents continuous vegetative flushing, and consequently enhances flowering intensity and increases yield (Stern and Gazit, 1993; Stern et al., 1993a). However, excessive water stress may result in root death, leaf drop, chlorophyll destruction, and a significant reduction in assimilation rate (Menzel and Simpson, 1994; Menzel et al., 1995; Roe et al., 1995). Thus, it is not surprising that severe damage to lychee trees occurred when fall water stress was applied carelessly (Stern et al., 1993a). Fall water stress therefore needs to be optimized and water-stress indicators need to be developed for irrigation control.

There are several irrigation-control criteria based on soil and plant water status. Measurements of soil water status have been widely used for irrigation scheduling in orchards. However, determining soil-water availability requires many discrete spatial measurements (Warrick and Nielsen, 1980). The number of required measurements is particularly large under drip irrigation, where three-dimensional gradients of water exist in the soil. Several physiological water-stress indicators, such as trunk and fruit growth (Assaf et al., 1982; Kalmar and Lahav, 1977; Tromp, 1984), predawn leaf water potential (Xiloyanis et al., 1980), midday leaf water potential (Erf and Proctor, 1987; Naor et al., 1993), and midday stem water potential (Garnier and Berger, 1985; McCutchan and Shackel, 1992; Naor and Wample, 1994), have been proposed as irrigation-scheduling indicators. A comparison between soil, leaf and stem water potentials in apples showed that midday stem water potential is better correlated with yield and fruit size distribution (Naor et al., 1995), as well as with stomatal conductance (Naor et al., 1995).

The objectives of this project were to study the effects of fall water regime on vegetative growth, flowering intensity, yield and water relations in field-grown lychee trees.

Materials and Methods

EXPERIMENTAL SITE. The irrigation experiment was conducted in a 6-year-old commercial 'Mauritius' and 'Floridian' lychee orchard at kibbutz Lavi in the Lower Galilee in Israel ($\approx$200 m above sea level). Trees were spaced 4 × 5 m. This area is semiarid with an annual precipitation (November to April) of $\approx$550 mm. The soil consisted of 0.8-m deep, well-drained basaltic protgromosol (65% clay) on basaltic rocks. Soil pH is 7.6 and $CaCO_3$ content is $\approx$7%.

The drip-irrigation system consisted of one lateral pipe per row, having 4-L·h^{-1} pressure-compensated drippers spaced 1 m apart.

Received for publication 18 Feb. 1997. Accepted for publication 16 June 1997. Contribution from MIGAL. We thank D. Stern, R. Hallel, and T. Sarig for their valuable assistance. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

[1] To whom reprint requests should be addressed.

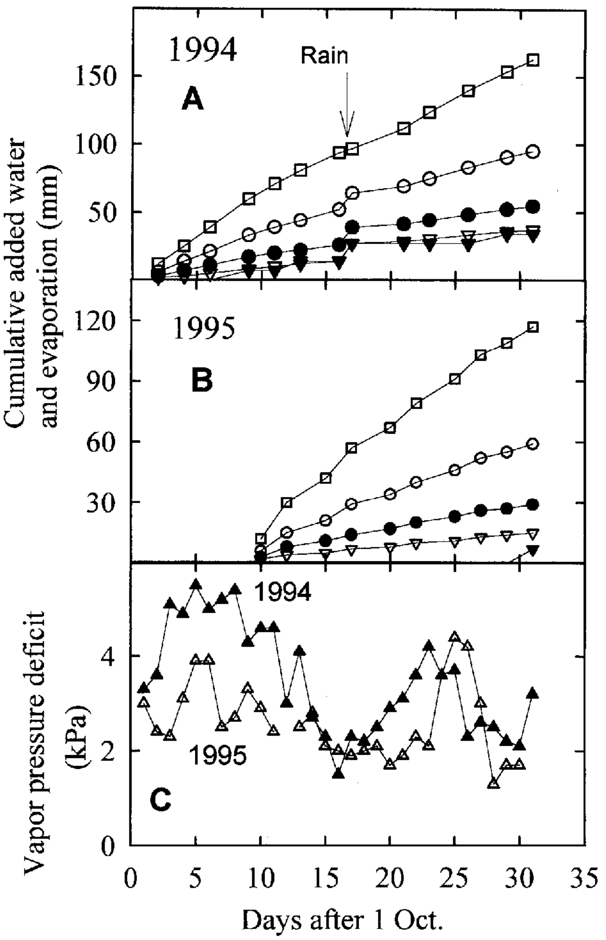

Fig. 1. Cumulative Class A pan evaporation (□) and cumulative irrigation during the fall period of 1994 (**A**) and 1995 (**B**) for four irrigation treatments: 100% (control, ○); 50% of control (●); 25% of control (∇); 0% (▼). Maximal daily vapor-pressure deficit in 1994 (▲) and 1995 (Δ) (**C**).

The orchard was fertilized proportionally through the irrigation system using an AMIAD fertilization pump (Kibbutz Amiad, Israel). Irrigation was applied at 2-d intervals from April to November. Irrigation levels increased gradually from a Class A pan evaporation coefficient in April of 0.3 to 0.6 at harvest (July) in 1995 and up to 0.8 at harvest (July) in 1996. Higher pan evaporation coefficients were used in 1996 due to the larger tree and crop sizes. The pan evaporation coefficient from harvest to the start of differential irrigation treatments in October was 0.5 for both years. The orchard was continuously fertilized from April to mid-September with a $12N–2P_2O_5–8K_2O$ composite liquid fertilizer. NO_3-N concentration in the irrigation water was 20 ppm.

Treatments. At the end of the second vegetative flush after harvest (1 Oct. 1994 and 10 Oct. 1995), four irrigation treatments were initiated: 0.5, 0.25, 0.125, and 0 Class A pan evaporation coefficients designated 100%, 50%, 25%, and 0%. The 0% treatment received three and one supplementary irrigations of 7 mm (70 $m^3 \cdot ha^{-1}$) in 1994 and 1995, respectively, when leaflet edges became necrotic.

Treatments were replicated four times in a complete randomized-block design, with each plot consisting of three adjacent rows, each with five trees. The three inner trees in the central row were measured. The border rows consisted of 'Floridian' trees.

Measurements. Meteorological data were recorded by a standard electronic weather station located 3 km from the orchard. Parameters measured included air temperature and humidity, wind speed 2 m above the ground, daily values of maximum temperature, maximum vapor-pressure deficit, average wind speed, and daily potential evapotranspiration (calculated according to Penman's equation). A Class A evaporation pan was located at the experimental site.

Soil water potential. Three tensiometers (IRROMETER, Riverside, Calif.) were installed in each replicate at 30-, 60-, and 90-cm depths, 25 cm from the drippers. Readings were taken before irrigation at 0700 HR.

Leaf water potential. Leaf water potential was measured on fully expanded leaves facing the sun. The leaves were detached and immediately placed in plastic bags, and leaf water potential was determined in a pressure chamber (Ari-mad; Kefar Charuv Inc., Israel) (Scholander et al., 1965).

Stem water potential. Stem water potential was measured on leaves from the inner canopy. The leaves were enclosed intact in a plastic bag covered with aluminum foil and left for 90 min to allow the leaf water potential to equilibrate with that of the stem (McCutchan and Shackel, 1992; Naor et al., 1995).

Midday measurements of leaf and stem water potentials were taken two or three times a week during the differential irrigation period, always a day before irrigation. Two leaves per replicate were used for each measurement. Diurnal measurements of leaf and stem water potentials were taken on 2 Nov. 1994 from 0500 to 1700 HR in 2-h intervals.

Gas-exchange measurements. Gas-exchange parameters were measured on 31 Oct. 1995 for all treatments using a portable photosynthesis system (LCA2; ADC, Hoddesdon, U.K.). The same leaves were used to measure stomatal conductance and leaf water potential.

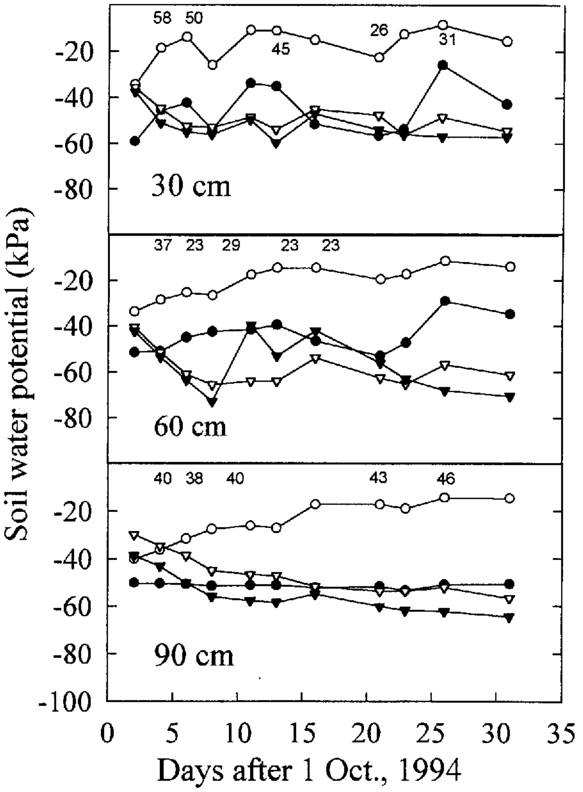

Fig. 2. Soil water potential at depth of 30, 60, and 90 cm, 25 cm away from the dripper, in 1994, for four irrigation treatments: 100% (control, ○); 50% of control (●); 25% of control (∇); 0% (▼). Numbers represent the least significant difference by Duncan's multiple range test ($P = 0.05$).

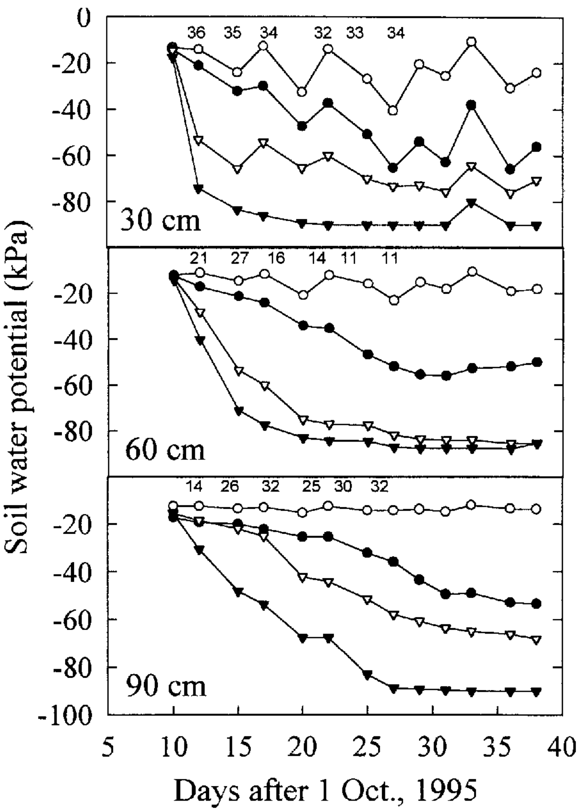

Fig. 3. Soil water potential at depth of 30, 60, and 90 cm in 1995 for the four irrigation treatments described in Fig. 2. Numbers represent the least significant difference by Duncan's multiple range test ($P = 0.05$).

Shoot growth. Ten shoots per replicate were tagged at the beginning of the differential irrigation treatments. Shoot length was measured at 10-d intervals.

Tree dimensions. Maximal tree length, width, and height were measured on 1 Oct. 1996 on one tree per replicate.

Flowering intensity. Inflorescence intensity was estimated on each 'Mauritius' and 'Floridian' tree in mid-April using a 0–3 ranking scale (0 = no flowering; 1 = poor, 2 = medium, 3 = full flowering).

Yield. Fruit was harvested from 'Mauritius' and 'Floridian' trees at the end of July. The fruit from each tree were weighed separately and 50 fruit/tree were sampled to determine fruit mass.

Statistical analysis. Data was analyzed for statistical significance using the general linear model (GLM) procedure (SAS Institute, Cary, N.C.). Duncan's multiple range test was used to compare treatments when ANOVA showed significant differences among means. Correlations between measured parameters were calculated using the CORR procedure (SAS Institute).

Results

Cumulative irrigation amounts up to the start of the differential treatments were 540 and 700 mm in 1994 and 1995, respectively. Cumulative irrigation levels during the differential treatment periods in 1994 and 1995 are presented in Fig. 1 A and B, respectively. Actual pan evaporation coefficients in 1994 were 0.47, 0.27, 0.18, and 0.17 in the 100%, 50%, 25%, and 0% treatments, respectively, whereas in 1995 the respective actual coefficients were 0.50, 0.25, 0.12, and 0.06. Evaporative demand in 1994 was higher than in 1995 (Fig. 1C), resulting in the need for supplementary irrigations in the 0% treatment (Fig. 1 A and B), due to leaflet browning. Leaf browning was first observed 9 d after the start of the differential treatments in 1994 and 21 d after in 1995.

A steep decrease in soil water potential at all depths was apparent in 1994 relative to 1995 (Figs. 2 and 3, respectively). The increased soil water potential in the 100% treatment in 1994 suggests that the irrigation level in this treatment was in excess (Fig. 2). The lower soil water potentials in 1995 are probably due

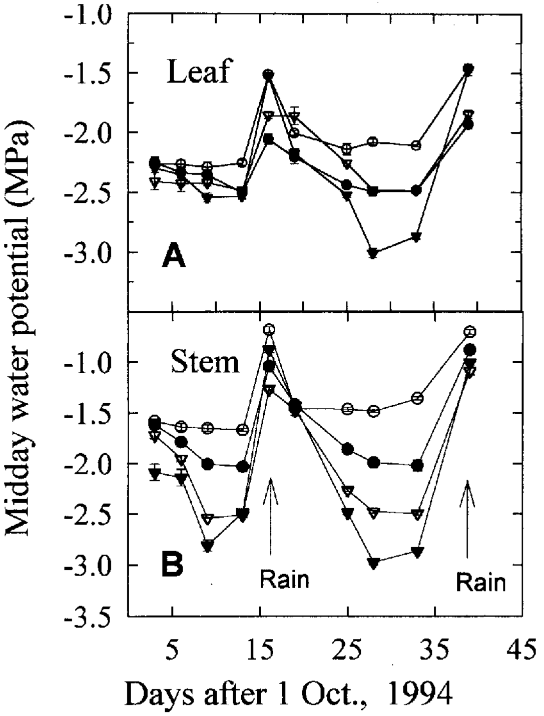

Fig. 4. Midday leaf (**A**) and stem (**B**) water potentials in 1994 for four irrigation treatments: 100% (control, ○); 50% of control (●); 25% of control (▽); 0% (▼). Bars denote standard error when larger than symbol size.

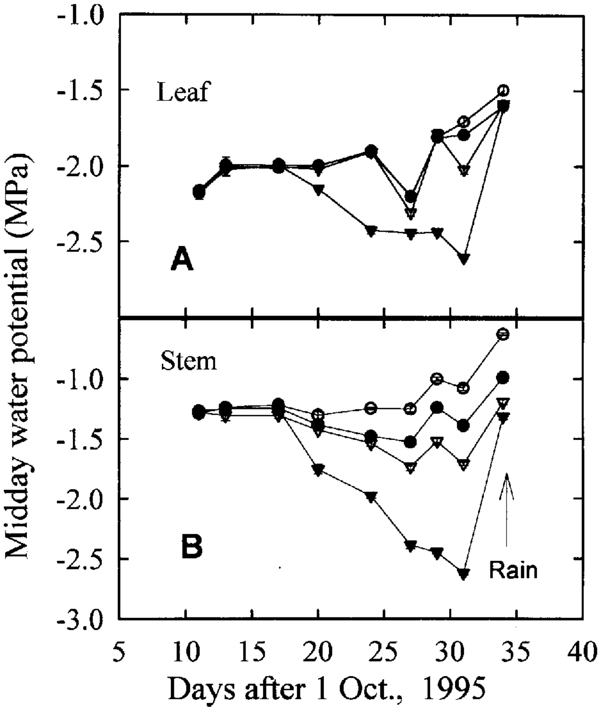

Fig. 5. Midday leaf (**A**) and stem (**B**) water potentials in 1995 for the four irrigation treatments described in Fig. 4. Bars denote standard error when larger than symbol size.

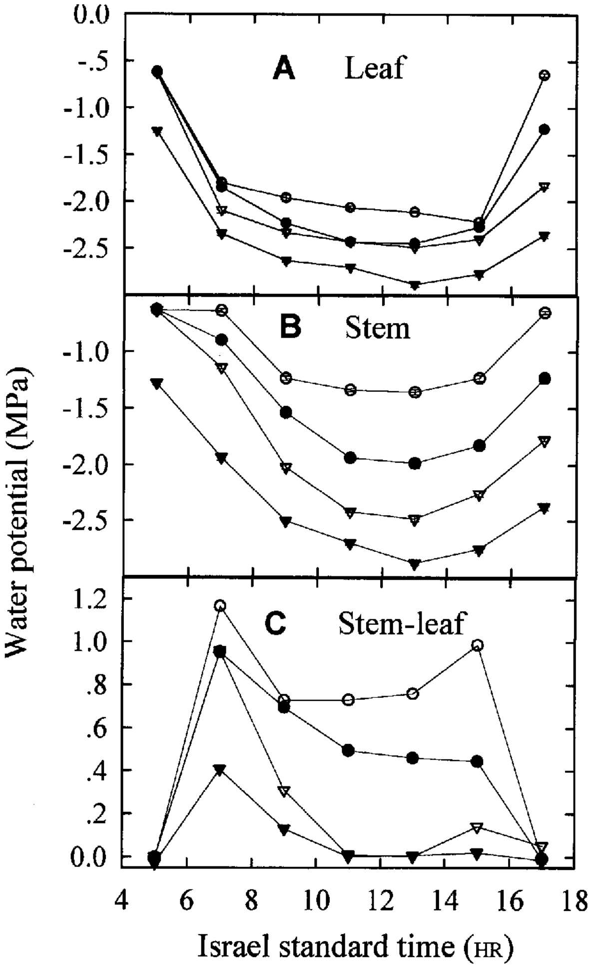

Fig. 6. Diurnal patterns of leaf (**A**) and stem (**B**) water potentials, and stem to leaf water potential differences (**C**) on 2 Nov. 1994 for four irrigation treatments: 100% (control, ○); 50% of control (●); 25% of control (∇); 0% (▼). Standard errors were always smaller than symbol size.

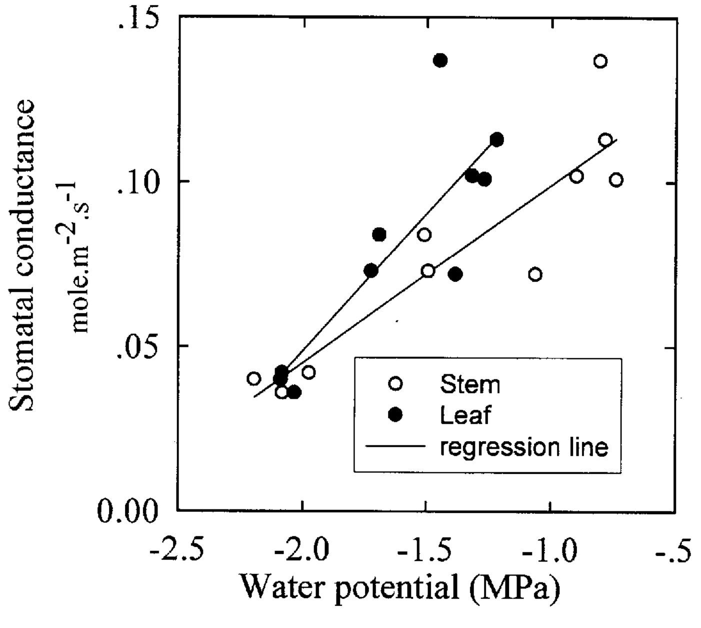

Fig. 7. Stomatal conductance as a function of leaf (●; r^2= 0.72) and stem (○; r^2= 0.84) water potentials on 31 Oct. 1995.

to increased tree size that year. The similar soil water potentials in the 25% and 0% treatments in 1994 (Fig. 2) are related to the similar cumulative irrigation levels (Fig. 1A) due to supplemental irrigations.

The tensiometer readings reflected the various irrigation treatments in 1995 better than in 1994 (Figs. 3 and 2, respectively). The dynamics of soil water uptake by the tree roots is illustrated well in Fig. 3, especially for the drier treatment. In 1995, water was first extracted by the roots from the upper soil layer (0 to 60 cm), whereas water uptake from the deeper 60- to 90-cm layer started ≈10 d after the beginning of the treatments when water uptake from the upper layers slowed down. Unfortunately, the high variability of the data in Fig. 3 did not enable us to draw any further conclusions regarding the level of matrix potential that should be kept for optimum stress.

Midday stem water potential was more sensitive to the irrigation treatments than midday leaf water potential in both years (Figs. 4 and 5). The smaller differences in leaf and stem water potentials between treatments in 1995 were probably related to lower evaporative demand (Fig. 1C). Differences between treatments were also higher in 1994 than in 1995. An increase in stem water potential for all treatments was caused by rain in 1994 (16 Oct.) and 1995 (3 Nov.) and by low vapor-pressure deficit values from 28–30 Oct. 1995 (Fig. 1C).

Differences in leaf water potential between treatments (Fig. 6A) were smaller than those of stem water potentials (Fig. 6B) on a diurnal basis. Differences between stem and leaf water potential (Fig. 6C) decreased with irrigation level. Because stem-to-leaf water potential differences have been correlated with actual hydraulic gradient (Naor and Wample, 1994), a lower stem-to-leaf

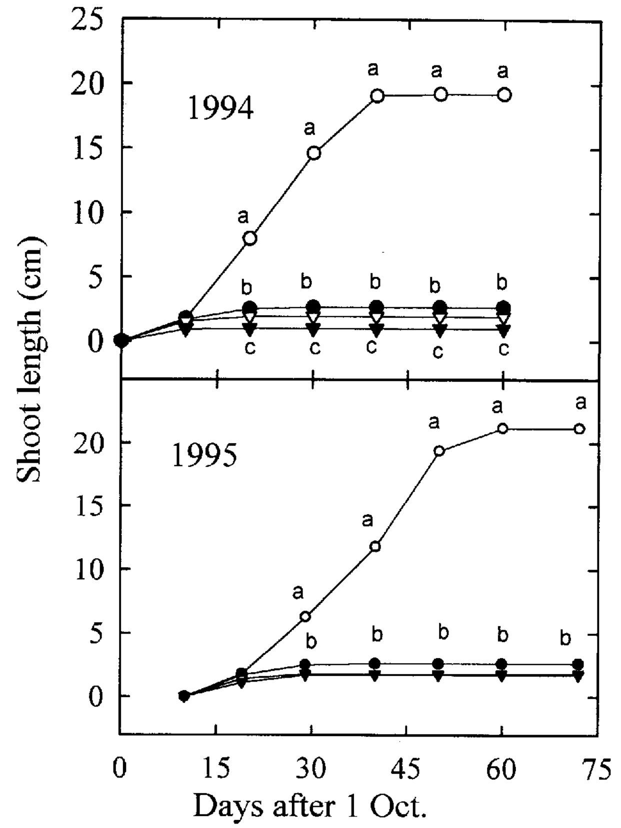

Fig. 8. Shoot length during Fall 1994 and 1995 for four irrigation treatments: 100% (control, ○); 50% of control (●); 25% of control (∇); 0% (▼). Different letters at each measurement date denote significant differences between means calculated by Duncan's multiple range test, $P = 0.05$.

Table 1. Tree length, width and height measured on Oct. 1 1996 with the four fall irrigation-rate treatments (percentage of control).

Irrigation treatments (%)	Length (m)	Width (m)	Ht (m)
100	3.9 a[z]	3.2 a	2.8 a
50	3.6 ab	3.1 a	2.5 b
25	3.5 b	3.0 a	2.4 b
0	3.0 c	2.7 a	1.8 c

[z] Results within a column followed by different letters differ significantly by Duncan's multiple range test, $P = 0.05$.

water potential difference may indicate lower stomatal conductance. Simultaneous measurements of leaf and stem water potentials and gas-exchange parameters were performed on 31 Oct. 1995. Stomatal conductance (Fig. 7) was better correlated with stem water potential ($r^2 = 0.84$) than leaf water potential ($r^2 = 0.72$). Zero stomatal conductance is expected to occur at a stem water potential of –2.83 MPa according to the extrapolated regression line. The leaf-to-stem water potential difference increased with increasing stomatal conductance (Fig. 7). All treatments exhibited similar assimilation rates for stomatal conductance (data not shown), indicating no damage to the photosynthetic apparatus in any of the treatments.

The 0%, 25%, and 50% irrigation levels effectively stopped shoot growth (Fig. 8), suggesting a threshold for shoot growth cessation at 50% of control irrigation (100%) in both years. Tree length and height, measured on 1 Oct. 1996, increased with irrigation level (Table 1).

Flowering intensity of the 100% treatment was lower than that of the other three treatments in both years and for both cultivars (Fig. 9). The 100% treatment produced the lowest yield for 'Floridian' in 1994–95 and 1995–96 (Fig. 9). 'Mauritius' yield in 1994–95 was lower with the 100% than with the 25% treatment. The 50%, 25%, and 0% treatments produced similar yields in 1994–95 for both cultivars. The 0% treatment produced a lower yield than the 50% and 25% treatments in 'Floridian' in 1995–96. A similar trend of lower yield for the 0% treatment relative to the 50% and 25% treatments was observed in 'Mauritius' in 1995–96. Irrigation levels did not affect fruit mass (data not shown).

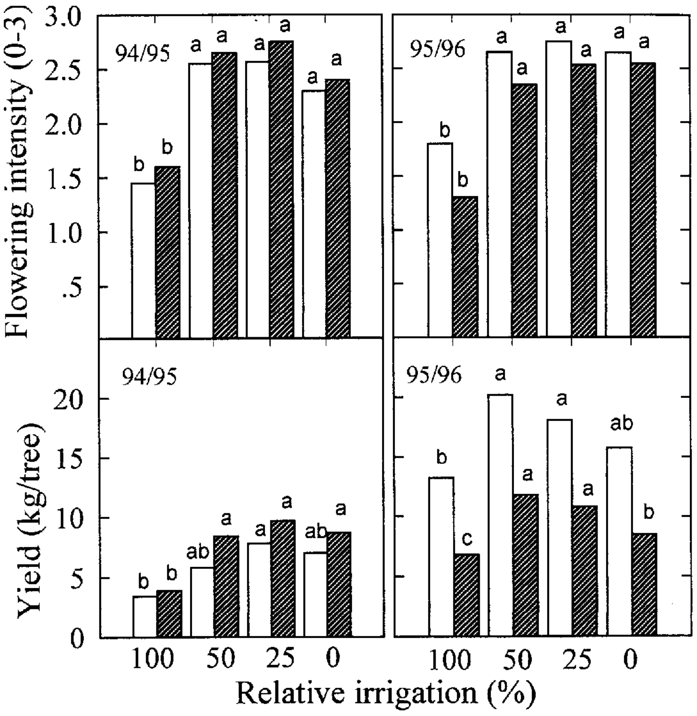

Fig. 9. Flowering intensity during the 1994–95 and 1995–96 seasons, and yield during the 1994–95 and 1995–96 seasons as a function of relative irrigation rates (percentage of control) in 'Mauritius' (open bars) and 'Floridian' (close bars) lychee trees. Inflorescence intensity was estimated in mid-April using a 0–3 ranking scale (0 = no flowering; 1 = poor; 2 = medium; 3 = full). Different letters at each cultivar denote significant differences between means calculated by Duncan's multiple range test, $P = 0.05$.

Discussion

Tree performance. All three irrigation-stress treatments (0%, 25%, and 50%) effectively reduced the length of the vegetative flush (Fig. 8) in both cultivars, and were associated with higher flowering intensity and higher yields (Fig. 9) compared to the control (nonstress irrigation treatment, 100%). Excessive fall vegetative flush appears to decrease flower-bud initiation and, consequently, flowering intensity and yield (Chaikiattioys et al., 1994; Menzel, 1983; Menzel and Simpson, 1994; Stern et al., 1993a).

The 0% treatment produced a lower yield despite a similar flowering intensity to the 50% and 25% treatments (Fig. 9). The 0% treatment also produced a smaller canopy size (Table 1), which was related to less canopy growth after harvest (before the start of the differential treatments). The lower yield and canopy size in the 0% treatment suggest that excessive fall water stress reduces tree vitality, and this is expressed throughout the following season.

Fall root growth has been reported in apples (Forshey and Elfving, 1989; Head, 1967, 1969), grapevines (Freeman and Smart, 1976; Richards, 1983), and avocado (Whiley and Schaffer, 1994). Root growth after harvest may have been significantly decreased in the 0% treatment. It should be noted that soil cracks that may cause root tearing were observed only in the lowest (0%) irrigation treatment.

Midday stem water potentials in the low-irrigation treatments (0%, 25%, and 50%) (Figs. 4–6) were associated with low stomatal conductance (Fig. 7). Under such conditions, the transpiration rate is low and the leaves are more sensitive to heat injury, which may result in leaf browning. Supplementary irrigations due to leaf browning were applied three times in 1994 and once in 1995. Leaf browning was associated with midday stem water potentials lower

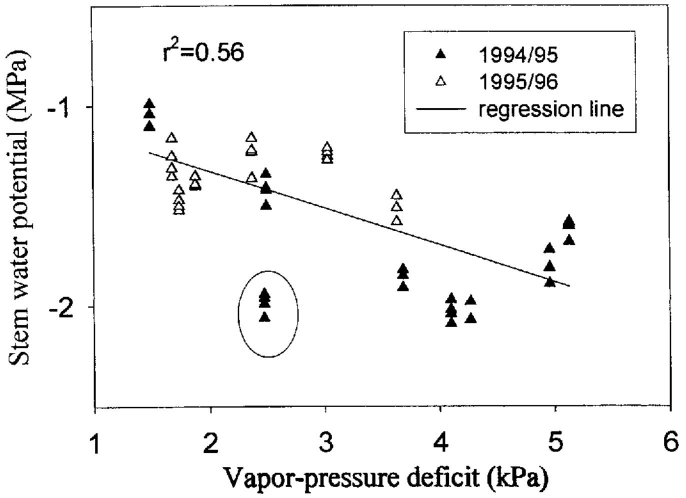

Fig. 10. Midday stem water potential as a function of maximal daily vapor-pressure deficit in the 50% of control irrigation treatment in 1994–95 and 1995–96. Encircled single date measurements were excluded from the regression analysis.

than –2.8 MPa, suggesting that such midday stem water potentials are detrimental.

The water stress inflicted in the 0% treatment, which is a common agricultural practice (Stern et al., 1993a), appeared to be too severe. Our data suggest that a moderate water stress consisting of a 50% reduction in irrigation rates is optimal for the fall irrigation regime. This treatment efficiently increased yield without any concomitant tree damage.

WATER-STRESS INDICATORS. An attempt was made to find a reliable water-stress indicator for irrigation control during the fall water-stress period. Soil and plant water-stress indicators responded to the irrigation-stress treatments. However, soil water potential values were highly variable (Figs. 2 and 3), probably due to the spatial variability of the soil's hydraulic properties (Warrick and Nielsen, 1980). Plant water potentials were less variable and differences between treatments were highly significant compared to soil water potentials (Figs. 2–5). Midday stem water potentials differed more markedly between treatments than leaf water potentials (Figs. 4–6). Midday stem water potential may therefore be the best water-stress indicator for irrigation control.

Average midday stem water potentials for the 50% treatment were –2.0 and –1.5 MPa in 1994 and 1995, respectively (Figs. 4 and 5). The average maximal temperature in October 1994 was 32.5 °C, which was higher than that in October 1995 (28.0 °C). This was accompanied by higher vapor-pressure deficits in 1994 relative to 1995 (Fig. 1C). Midday stem water potential in both years was correlated with midday vapor-pressure deficit (Fig. 10). This suggests that the midday stem water potential threshold set for irrigation control should take into account the evaporative demand. However, further research is needed to correlate meteorological conditions to the midday stem water potential threshold.

Conclusions

Reduced irrigation in the fall stopped fall vegetative flush and resulted in a significant increase in flowering intensity and yield. Our data suggest that midday stem water potential should be considered as an irrigation control criterion.

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