Effect of Post-Véraison Irrigation Level on Sauvignon blanc Yield, Juice Quality and Water Relations

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Low (L), medium (M) and high (H) post-véraison daily irrigation levels (1 mm, 2 mm and 3,5 mm, respectively) were applied in a Sauvignon blanc vineyard in the Golan Heights of Israel. Juice Brix levels were higher in the H treatment than in the L treatment. Yields were higher in H treatment than in L treatment in years with high crop level. Shoot elongation ceased at véraison in all three treatments. Average midday leaf water potential (LWP) was -1,4 MPa and -1,9 MPa in the H and L treatments, respectively. Lower stomatal resistance (R_S) was found in the H treatment compared to those in the L and M treatments. A negative correlation between R_S and LWP was observed. Leaf temperatures were higher in the L treatment than in the H treatment. This was mainly attributed to the difference in R_S between treatments. The apparent relationship between R_S and LWP suggests the use of canopy heat balance for irrigation management in warm regions, provided that satisfactory methodologies for boundary-layer resistance and the evaluation of net radiation in vineyards are developed.

Water relations in grapevines have been extensively investigated over the past two decades. Various plant parameters, such as pre-dawn and midday leaf water potential (LWP), stomatal resistance (R_S) to water vapour diffusion, leaf-to-air temperature gradient, shoot elongation, and diurnal changes in stem diameter have been studied. The data reported in the literature relate to a wide range of climatic regions, soil moisture regimes and phenological stages, and thus comparisons are difficult to make. Moreover, most reports lack detailed meteorological data.

Pre-dawn LWPs in irrigated vines have been found to be higher than those in non-irrigated vines, regardless of whether sprinkler (Van Zyl & Weber, 1981), drip (Hardie & Considine, 1976) or flood irrigation (Kliewer *et al.*, 1983) was used. The same has been found for midday LWPs (Smart, 1974; Kliewer *et al.*, 1983; Matthews *et al.*, 1987). Mean values of midday LWP in non-irrigated vines have been reported as -1,6 MPa or lower, with some exceptions (Giulivo & Ramina, 1981; During & Loveys, 1982; Dundon & Smart, 1984). Midday LWP values are either almost constant throughout the ripening season (Matthews *et al.*, 1987) or variable due to variations in climatic conditions (Van Zyl, 1986).

Leaf temperature is a function of net radiation, air temperature, air water vapour pressure and boundary-layer resistance. The difference between leaf and ambient temperature has been used to establish a Crop Water Stress Index (Jackson *et al.*, 1981). Stomatal resistance affects leaf temperature via the control of transpiration and consequently of latent heat flux. Stomatal resistance in vines increases significantly as the LWP decreases below -1,3 MPa (Kriedemann & Smart, 1971; Liu *et al.*, 1978). Since R_S affects the leaf's heat balance, leaf temperature is expected to be sensitive to changes in LWP between -1,3 and -1,9 MPa, the range in which significant changes in R_S occur.

In intensively irrigated, low-cropped vines, shoots may continue to grow throughout the entire season (Vaadia & Kasimatis, 1961; Christensen, 1975; Wildman *et al.*, 1976; Bravdo *et al.*, 1985; Hepner *et al.*, 1985). A cessation in shoot growth was observed in field-grown Cabernet franc when midday LWP was about -1,0 MPa (Matthews *et al.*, 1987), -1,25 MPa for field-grown Thompson Seedless (Peacock *et al.*, 1987), and when pre-dawn LWP was -1,2 MPa (Schultz & Matthews, 1988) in greenhouse-grown White Riesling.

Shoot elongation could therefore theoretically serve as an indicator for irrigation control. However, since continued vegetative growth during fruit ripening is not recommended and shoot growth is affected by crop load (Winkler *et al.*, 1974), it is impractical to use shoot elongation as a criterion for post-véraison irrigation control.

The relationship between irrigation and fruit quality has been reviewed by Smart and Coombe (1983) and by Bravdo and Hepner (1987). Irrigation has been shown to have both positive (Vaadia & Kasimatis, 1961; Freeman *et al.*, 1980) and negative (Bravdo *et al.*, 1985) effects on wine quality. This discrepancy may be attributed to the interaction with crop-load effects. Intensive irrigation may increase canopy density and consequently shading, thereby reducing fruit quality (Kriedemann, 1977; Neja *et al.*, 1977; Smart & Coombe, 1983). Although the accumulation of total soluble solids per berry increases following excessive irrigation, Brix levels may be reduced due to either dilution (Van Zyl, 1984; Bravdo *et al.*, 1985) or competing vegetative sinks (Winkler *et al.*, 1974; Bravdo *et al.*, 1985 Bravdo & Hepner, 1987). Total titratable acid increases and total soluble solids content decreases with excessive irrigation, resulting in delayed maturation (Vaadia & Kasimatis, 1961; Freeman *et al.*, 1980; Bravdo *et al.*, 1985; Hepner *et al.*, 1985; McCarthy & Coombe, 1985).

The objective of this project was to study the effect of irrigation regime from véraison to harvest on Sauvignon blanc yield, fruit quality and water relations using pan evaporation coefficients and plant water-stress indicators.

MATERIALS AND METHODS

Experimental vineyard: A drip irrigation experiment was conducted in a 5-year-old Sauvignon blanc vineyard on 110R rootstock (3,5 m x 1,5 m spacing) grown in shallow, stony, basaltic soil (39% clay, 47% silt, 14% fine sand) in the Golan Heights, Israel. The experimental vineyard is located in a semi-arid zone, about 50 km east of the Mediterranean Sea and 800 m above sea level. There are generally no summer rains and the skies are cloudless throughout most of the summer. The long-term average midday temperature, relative humidity and wind speed are 29 °C, 35% and 3,5 m/h, respectively. Vines were trained to a bilateral cordon with 14 two-bud spurs per vine on a one-wire trellis plus two additional parallel wires for upright positioning of the green shoots. The vineyard was irrigated from budbreak to leaf drop.

Experimental plots: The experimental plots were replicated four times using a randomized block design with three rows of 20 vines each. Measurements were taken on 10 vines in the central row of each replicate and the same vines were used each season. Irrigation was applied daily to avoid flooding and runoff due to the low saturated hydraulic conductivity of 1,0 mm/h (Shani *et al.,* 1987). The irrigation system consisted of a single lateral per row with 2 L/h drippers spaced 1 m apart. The vineyard was fertilized continuously from budbreak to véraison. A {7,5% (N): 3,5% (P_2O_5): 6,5% (K_2O)} solution, diluted 1:1000, was applied via the irrigation system using an injector pump (T.M.B., Israel). This amounted to approximately 90 kg N, 36 kg P and 84 kg K per hectare per year. Irrigation and fertilization were controlled with an irrigation computer (GAL-II, Israel).

Treatments: Irrigation was identical for all treatments from budbreak to véraison (mid-July). The average daily amount of water , about 0,5 mm/day, applied from budbreak, was mainly for fertilizer application. Irrigation, based on daily Class A pan evaporation readings taken on-site using appropriate coefficients, was increased gradually towards véraison (Table 1). Irrigation level at véraison was 2 mm/day in 1987 (according to the commercial practices in the region). This level was increased to 3,5 mm/day in 1988, 1989 and 1990 to improve the poor vegetative growth observed in 1987. Daily irrigation in 1987 from véraison to harvest was 0,5 mm, 1,0 mm and 1,5 mm for the low (L), medium (M) and high (H) irrigation treatments, respectively. In 1988, 1989 and 1990 maximum irrigation was not reduced after véraison in the H treatment. Water was applied at rates of 1, 2 and 3,5 mm/day in the L, M and H treatments, respectively.

Measurements: Soil matrix potential was measured in each plot using mercury tensiometers at 200 and 400 mm depths and 100 mm horizontal distance from a dripper. At the beginning of the season four shoots per plot were marked. Shoot elongation was measured once a week where laterals were trimmed. LWP was measured several times throughout 1988, 1989 and 1990 using a pressure chamber (ARI-MAD, Israel). Leaves were placed in a plastic bag only during the 1990 measurements. Comparative LWP measurements in the range of -0,9 to -2,0 MPa showed significant differences between bagged and non-bagged leaves of a little under 0,1 MPa ($\alpha=0,05$) for LWP values below -1,1 MPa. The maximum difference between bagged and non-bagged leaves was -0,16 MPa at a LWP of -0,9 MPa. During 1989 leaf temperature was measured several times on the upper side of a leaf facing the sun, using a surface thermocouple probe. Stomatal resistances were measured with a portable gas analyser (LI-6000, Li-COR, USA). These measurements were always taken after 09:00 to ensure light saturation (above 1800 $\mu Em^{-2}s^{-1}$). Leaf water potential, leaf temperature and R_s were measured in one replicate only. Yield was harvested from 10 vines per plot. Juice was extracted from a 25 kg sample using a hydraulic press (pressure 4,5 MPa) and Brix, total titratable acids and soluble potassium were measured. Berry mass was determined on a sample of 100 berries per plot. The berries were randomly collected from different clusters (three berries per plot). Pruning mass was measured from 10 vines per plot in 1989 and 1990.

Statistical analysis: Statistical analysis of variance was performed, followed by Duncan's Multiple Range Test using the GLM procedure (SAS, Sas Institute Inc., USA).

RESULTS AND DISCUSSION

The pan evaporation coefficients (Table 1) used during June and July 1987 resulted in poor vegetative growth prior to véraison. Increased irrigation levels in 1988, 1989 and 1990 improved vigour prior to véraison. The lower pan evaporation coefficients used in 1987 resulted in a lower amount of total irrigation (Table 2). This in turn may partly explain the lower yield for that year (Table 3). Accordingly the increased amounts of water applied during the following years may have been positively responsible for the higher yields. Yields in 1988 and 1990 were significantly higher in the H treatment compared to those in the L treatment. In 1990 the average crop load, defined as yield mass/pruning mass by Bravdo *et al.* (1985), of 10,9

TABLE 1
Pan evaporation coefficients for the high, medium and low irrigation level treatments.

	1987			1988			1989			1990		
Month	L	M	H	L	M	H	L	M	H	L	M	H
May	0,18	0,18	0,18	0,15	0,15	0,15	0,17	0,17	0,18	0,13	0,14	0,13
June	0,22	0,22	0,22	0,28	0,28	0,28	0,28	0,28	0,28	0,27	0,27	0,27
July	0,21	0,21	0,21	0,20	0,27	0,36	0,24	0,28	0,38	0,31	0,36	0,41
August	0,12	0,15	0,20	0,12	0,27	0,45	0,11	0,19	0,42	0,12	0,28	0,39

was much higher than that in 1989 (3,9). However, no significant differences in crop load between treatments were found in either year. The higher crop load in 1990 might explain the lower Brix in all treatments compared to that in 1989. The fresh berry masses on 1988-09-05 were 1,47, 1,65 and 2,01 g/berry for the L, M and H treatments, respectively. Berry mass in the H treatment was significantly higher than those in the L and M treatments. The increase in yield was greater relative to the increase in berry mass, indicating either a higher number of clusters per vine or of berries per cluster in the H treatment. Juice production per unit mass of grapes (Table 3) tended to be higher in the H treatment than in the L treatment (significant in 1988), probably due to better water status and larger berries. The Brix level was higher in the H than in the L treatment, whereas the amount of titratable acid did not vary significantly (except in 1989).

Shoot elongation ceased at véraison in all three treatments (Fig. 1). Annual shoot elongation was similar for the three treatments in 1988 and 1989. This is probably due to the identical water regimes up to véraison, *i.e.* during the main shoot growth period. It should be noted that in well-irrigated treatments in other regions, shoot growth continues throughout almost the entire season (Christensen, 1975).

Near véraison soil water matrix potential exceeded -65 kPa (the minimum tensiometer reading) at depths of 200 and 400 mm in all three treatments (data not shown). This may be attributed to the shallow wetting zone resulting from daily irrigation intervals and low water infiltration rates. However, due to the stony nature of the soil, roots may have penetrated into the deeper layers to extract additional water.

In addition to the fact that tensiometers normally do not function well in stony soils, the abovementioned conditions created an irregular wetting zone, further complicating the selection of representative locations for the tensiometers. Vines are known for their ability to penetrate

TABLE 2
Average pan evaporation rates, total irrigation from budbreak to harvest and harvest date.

	Pan Evaporation ($mm.day^{-1}$)				Irrigation (mm)			Harvest date
	May	June	July	Aug.	L	M	H	
1987	7,0	7,6	8,8	9,0	177	187	205	2 Sept.
1988	8,0	8,0	8,5	7,7	181	238	311	8 Aug.
1989	9,3	8,5	8,6	9,2	228	255	312	15 Aug.
1990	7,6	8,1	9,0	8,5	204	273	325	15 Sept.

TABLE 3
Parameters used for grape yield and fruit maturation.

	Yield ($t.ha^{-1}$)				Sugar (°B)				pH			
	87	88	89	90	87	88	89	90	87	88	89	90
L	15	27a	18	27	18,6	16,5b	20,4b	17,5b	3,44	3,33	3,37	3,09b
M	13	30ab	17	30	18,8	18,6a	21,1ab	18,4ab	3,40	3,36	3,35	3,16a
H	13	32b	19	35	19,7	19,6a	21,4a	18,9a	3,46	3,32	3,31	3,16a

	Total acid (titratable) ($g.1^{-1}$)				Potassium ($mg.1^{-1}$)			Juice fraction ($ml.kg^{-1}$)		
	87	88	89	90	87	88	89	87	88	89
L	7,2	6,6	8,8a	7,5	1414	1625	1486	650	650a	650
M	7,8	6,0	9,3b	7,6	1266	1595	1497	690	730b	650
H	7,2	6,8	9,6a	7,8	1428	1630	1545	700	730b	730

a,b: Groups of means in columns followed by the same symbol do not differ significantly at 95% confidence level.

deep soil layers. Controlling and/or identifying the complete root zone and selecting a representative location for tensiometers might also not be possible for some vineyards planted in deep stone-free soils. The advantage of using physiological and meteorological criteria for irrigation control under such conditions is obvious.

Midday LWP in the H treatment tended to be higher than in the L treatment in 1988, 1989 and 1990 (Fig. 2). Values for the M treatment were intermediate but tended to be closer to those of the L treatment. During 1988 and 1990 differences in midday LWP between the H and the L treatments tended to increase from véraison, reaching a maximum 20 days later, with the exception of one measurement on day 237 of 1988.

The LWP values recorded in this experiment were much lower than those reported by Smart (1974), Kliewer *et al.*, (1983), Matthews *et al.*, (1987), Peacock *et al.*, (1987) and Grimes and Williams (1990), but similar to those found by Giulivo and Ramina (1981), During and Loveys (1982) and Dundon and Smart (1984). The lower midday LWP values may be attributed to the relatively high average midday vapour pressure deficit of 3,5 kPa and midday wind speed of 3,5 m.s^{-1}, enhanced by high levels of irradiation. In general, variations in LWP which are not a result of changes in soil water availability are attributable to temporal variations in meteorological parameters. These temporal changes in evaporative demand are mainly caused by the vapour-pressure deficit. A better understanding of the ralationships between LWP and meteoro-

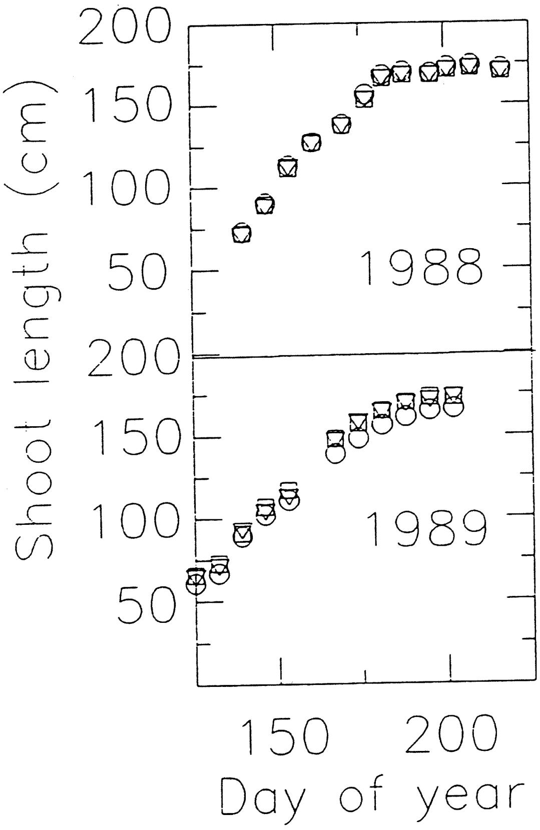

FIGURE 1

Seasonal changes in shoot length in 1988 and 1989 for the H (circles), M (triangles) and L (squares) treatments.

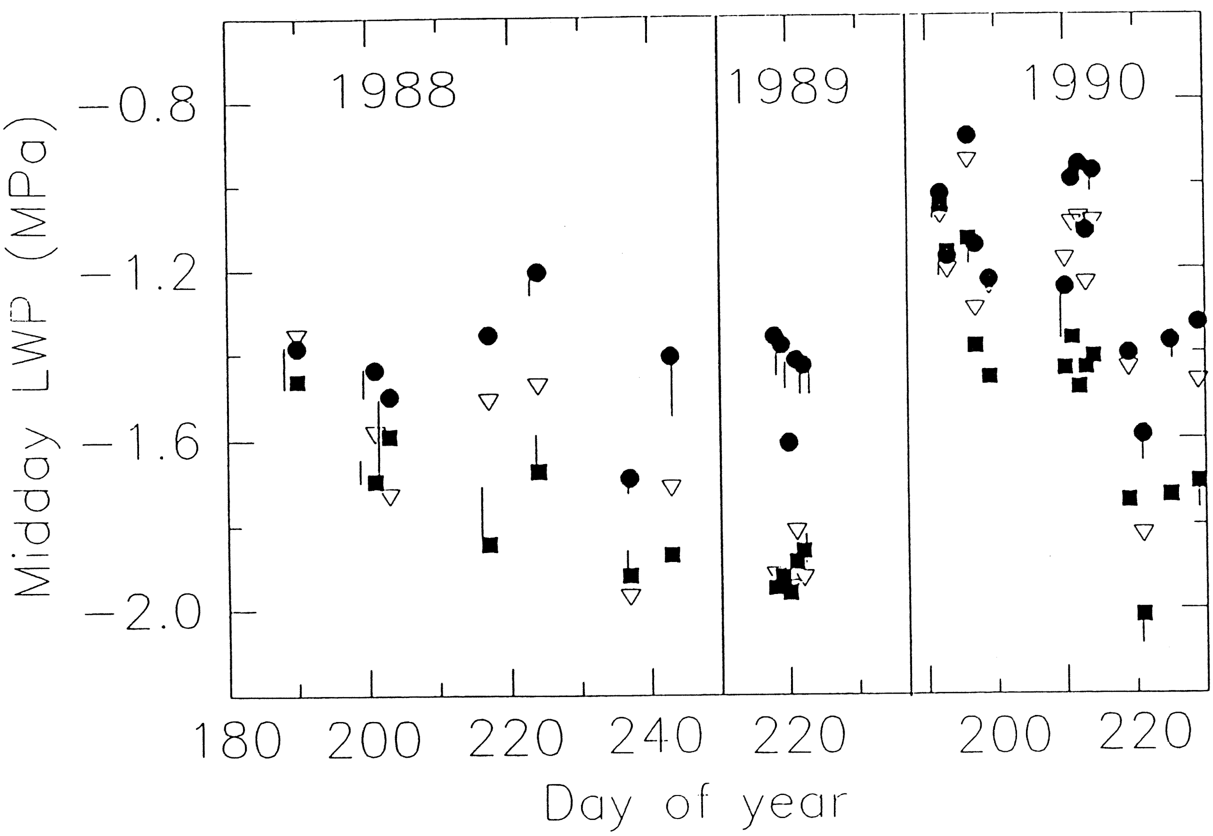

FIGURE 2

Midday leaf water potential (LWP) on selected days (presented as day of year) in 1988, 1989 and 1990 for the H (circles), M (triangles) and L (squares) treatments. Bars denote standard error for H and L treatments when larger than symbol size.

logical parameters such as vapour-pressure deficit and net radiation could improve the utilization of LWP as a criterion for irrigation control.

The variation in LWP on selected days during 1988 is presented in Fig. 4. For the L treatment minimum LWP (-1,9 MPa) was generally reached early in the morning and did not increase at least before 14:00. This lower limit may be associated with the higher R_S found at LWPs lower than -1,3 MPa (Kriedemann & Smart, 1971; Liu *et al.*, 1978). At a LWP of -1,9 MPa the stomata seem to be nearly closed. Stomatal resistance from 08:00 to midday increased in all three treatments (Fig. 4) Values of R_S tended to be consistently lower in the H treatment than in the M and L treatments. Simultaneous measurements of LWP and R_S (Fig. 5) showed a negative correlation between the two for LWPs lower than -1,2 MPa. However, data were insufficient to evaluate this relationship quantitatively at LWP above -1,2 MPa. This finding is in agreement with data reported by Kriedemann and Smart (1971) and Liu *et al.* (1978). Transpiration rate is directly affected by R_S for a given set of climatic conditions and is expected to be sensitive to changes in LWP in the range of -1,3 MPa for highly irrigated vines to -1,9 MPa for less irrigated vines. It therefore seems that LWP and R_S could serve as indicators for irrigation control, at least in warm regions where low midday LWPs occur. However, stomatal resistance measurements are expensive and impractical. An indirect evaluation of R_S using a heat balance approach should therefore be considered, provided that satisfactory methodologies for the estimation of boundary-layer resistance and net radiation in vineyards are developed.

Leaf temperature fluctuations from 12:00 to 14:00 in the L and M treatments showed a similar pattern and were probably due to small fluctuations in meteorological parameters (Fig. 6). The much smaller fluctuations in the H treatment were probably due to the plant's improved water status (Fig. 2). The tendency to lower midday leaf temperatures in the H treatment measured on selected

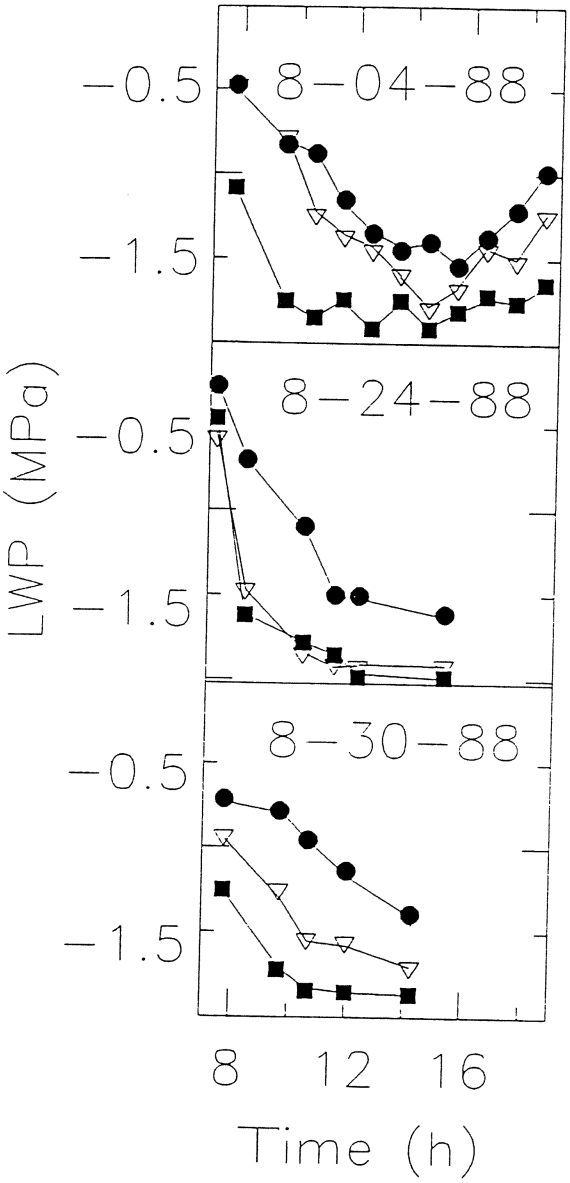

FIGURE 3

Diurnal pattern of leaf water potential (LWP) on selected days in 1988 for the H (circles), M (triangles) and L (squares) treatments.

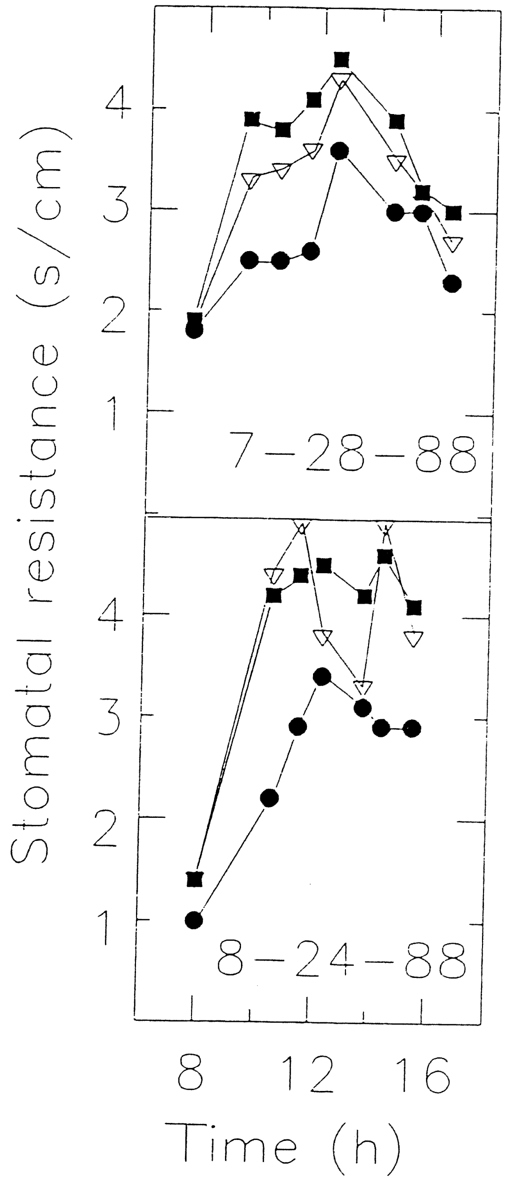

FIGURE 4

Diurnal pattern of stomatal resistance on selected days in 1988 for the H (circles), M (triangles) and L (squares) treatments.

days during August 1989 (Fig. 7) support this interpretation.

Assuming an average LWP of -1,2 MPa for zero growth (Matthews *et al.*, 1987; Peacock *et al.*, 1987; Schultz & Matthews, 1988) raises the question as to whether midday LWPs in the H treatment were too low. It should be noted that zero turgor may be changed differentially by active osmotic adjustment throughout the season (During, 1984), for different cultivars and under different climatic conditions (During & Loveys, 1982) or for water stress (Grimes & Williams, 1990). Variations in the LWP at which shoot growth ceases are therefore expected.

CONCLUSIONS

Our results support previous findings that the major effects of irrigation on yield and quality are indirect and are more related to alterations in vegetative growth and crop load than to a direct effect of water on fruit components. A cutback in post-véraison irrigation produced inferior results in the experiment reported here. Vegetative shoot growth is greatly affected by crop level as well so irrigation could very well be increased even further to improve fruit quality. While this assumption needs to be tested, the results of this study clearly show the negative effect of excessive water stress on Brix levels. This contradicts a common belief among growers that irrigation affects fruit and wine quality negatively. Midday LWP may serve as an irrigation control criterion. However, the effects of climatic conditions, plant variety and trellis systems on optimal LWP level need to be taken into account.

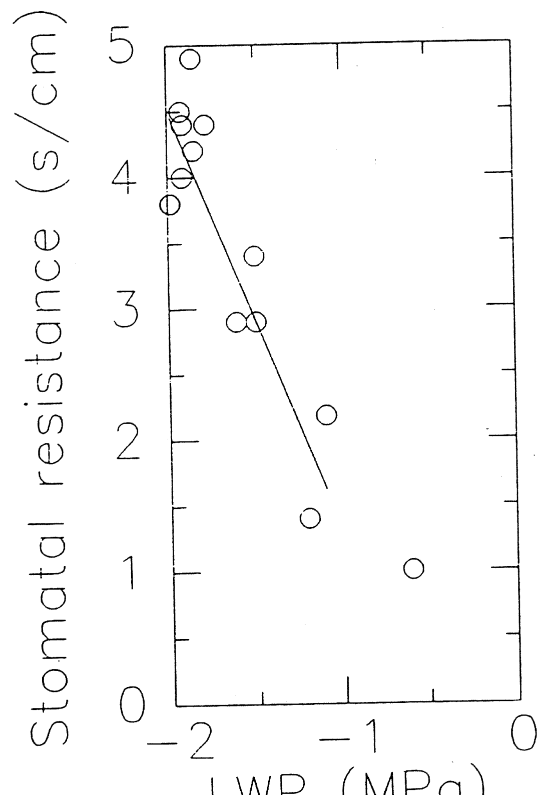

FIGURE 5

Stomatal resistance as a function of leaf water potential (LWP) 24 August 1988. The line represents linear regression of data values lower than -1,0 MPa (r^2=0,79).

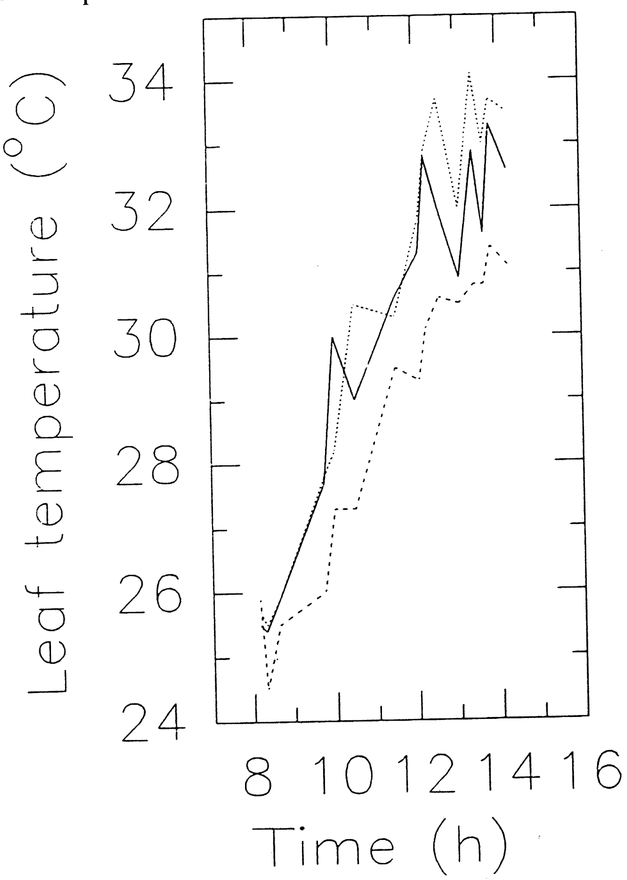

FIGURE 6

Variation in leaf temperature on 6 August 1989 for the H (dashed line), M (solid line) and L (dotted line) treatments.

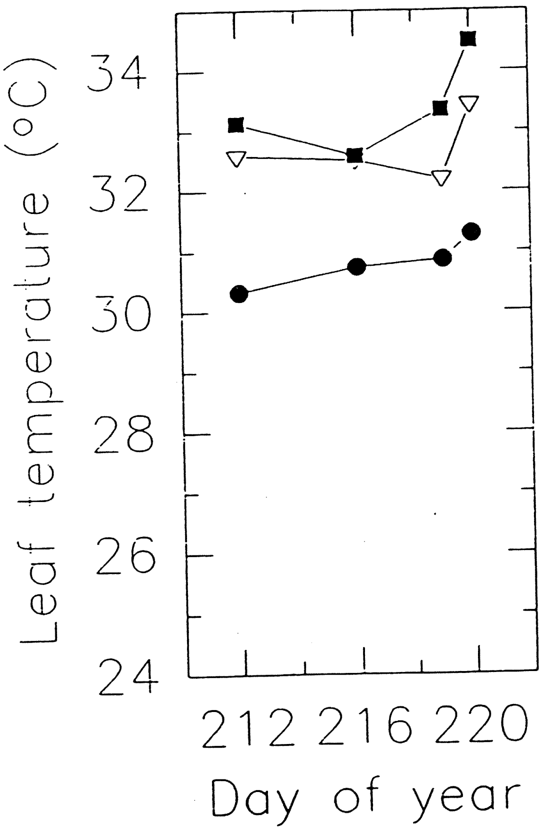

FIGURE 7

Midday leaf temperature on selected days in 1989 for the H (circles), M (triangles) and L (squares) treatments.

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