The Effect of Trellis Systems on the Performance of *Vitis vinifera* L. cvs. Sultanina and Chenel in the Lower Orange River Region

J.J. Swanepoel[1], J.J. Hunter[1] and E. Archer[2]

1) Viticultural and Oenological Research Institute (VORI), Private Bag X5026, 7600 Stellenbosch, Republic of South Africa
2) Department of Viticulture, University of Stellenbosch, 7600 Stellenbosch, Republic of South Africa

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The effect of six trellis systems on the reproductive and vegetative performance of Sultanina and Chenel, grown in the lower Orange River region of South Africa, was investigated. Larger trellis systems significantly increased the yield of both cultivars, and the photosynthetic activities of the leaves at véraison as well as the canopy light environment tended to be higher for these systems. The higher yields recorded for Sultanina were attributed to improved budding percentages, which were caused by improved light environments at the basal buds. The improved yield obtained for Chenel however, was due to higher bunch masses, which were most likely caused by the higher photosynthetic activities of the leaves.

The trellising of grapevines, a common practice in the viticultural world, leads to alterations in growth, yield and fruit composition through *inter alia* its influence on the microclimate (Smart, 1985).

Positive effects on yield were obtained by enlarging canopy foliage (Shaulis & May, 1971; Kasimatis, Lider & Kliewer, 1975; Weaver & Kasimatis, 1975; Carbonneau, Casteran & Leclair, 1978) or increasing the general dimensions of the canopy, thereby encouraging replacement shoots to grow upwards (Shaulis & May, 1971; Weaver & Kasimatis, 1975). Thin canopies improved sunlight exposure and photosynthetic capacity. Since direct sunlight in combination with the leaf area index contributes the most to total photosynthesis of the canopy (Carbonneau, 1987), a canopy of three leaf layers (two exterior and one interior) is near the optimum as regards photosynthesis (Smart, 1974, 1985; Fernandez, Balkar & Meyer, 1987). The rate of photosynthesis, is, however, affected not only by light intensity but also by intermittent light and light quality, temperature, relative humidity, CO_2 and O_2 concentrations, leaf age, moisture supply, seasonal patterns and crop load (Hunter & Visser, 1988 and the references therein).

An increase in yield per vine was found to be the result of an increase in cluster weight (May, Sauer & Scholefield, 1973), the number of berries (Lynn, 1965), berry mass (Carbonneau *et al.*, 1978), bud burst (Shaulis, Amberg & Crowe, 1966; Shaulis & May, 1971; Clingeleffer & May, 1981), fruitfulness (May *et al.*, 1973; Carbonneau *et al.*, 1978; Clingeleffer & May, 1981) and the number of nodes left per vine after pruning (Kasimatis *et al.*, 1975; May, Clingeleffer & Brien, 1976; Weaver *et al.*, 1984), or combinations of these factors.

Sultanina comprises about 70% (17 500 ha) of the total vineyard area in the lower Orange River region of South Africa and is used for drying (115 200 t dried grapes), vinification (43 150 t) and table grapes (3 500 t). Grapes other than Sultanina, such as Chenel (Chenin blanc x Trebbiano), Chenin blanc and Colombar, which are grown for vinification, are cultivated on 2 600 ha and contribute 60 000 t (Anon., 1987).

More than 90% of Sultanina is currently trained on a T-trellis, but a variety of trellis systems are used for other wine grapes. According to Le Roux (1973), the harvesting and pruning of vines trained on the T-trellis is difficult, and rows have to be wide to accommodate the system and allow for cultivation practices. The appropriate trellis system for wine grapes is still not known.

The aim of this investigation was to compare the performance of Sultanina grapevines trained onto the T-trellis with those trained on other systems, and also to determine the most suitable system for Chenel in this region.

MATERIALS AND METHODS

Experimental vineyard: A trellising trial with *V. vinifera* cv. Sultanina, ungrafted, as was the general practice in that area at that stage, and cv. Chenel, grafted to 99 Richter (cl Ry 13), was established in 1979 at the Upington Agricultural Research Station (28° 25S; 21° 16E) in the lower Orange River region (climatic region V) (Saayman, 1981). The soil was classified as a Dundee series according to the system of MacVicar *et al.* (1977) and is representative of the alluvial soils along the Orange River. To ascertain the effect of trellis systems, the planting width was 3,0 x 1,5 m, and clean cultivation and full surface-flood irrigation were applied.

Sultanina was trained to a decentralised crown-development as described by Zeeman & Archer (1981), resulting in one crown per vine for the smaller systems and two crowns per vine for the T, slanting, swing-arm and factory systems. Chenel was trained to a bilateral cordon on the lengthened Perold, USA hedge, 1,5 m slanting and T-trellis and to parallel

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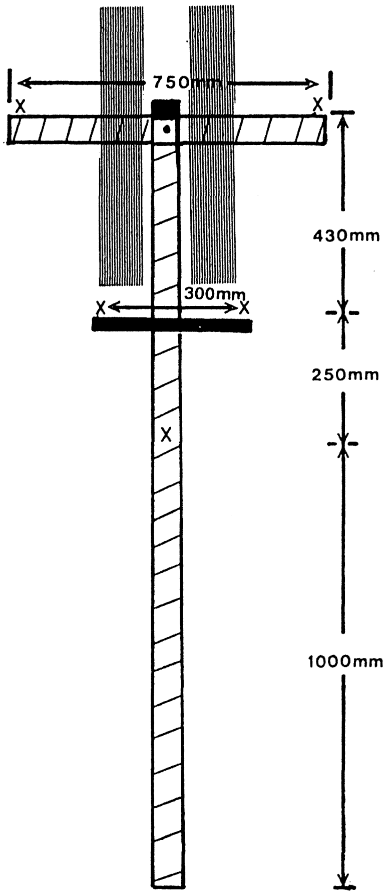

FIGURE 1a
Diagrammatic representation of the USA hedge trellis. (x=wire positions).

bilateral cordons on the factory system and Geneva Double Curtain. According to general practice, vines of all the training systems were topped twice but no attempt was made to position the shoots.

Vines were pruned according to the Guyot (Sultanina) and spur (Chenel) pruning systems, respectively, with an initial bud load of 24 (Sultanina) and 16 (Chenel) buds per kg shoot mass. Adjustments during the trial led to a pruning norm of 8 to 10 canes for sultanina (12 to 15 buds per cane) and 20 buds per kg shoot mass for Chenel.

Experimental design: The trial was laid out as a randomised block design with six treatments and four replicates for each cultivar. Each plot consisted of 14 trial vines per replicate and border effects were eliminated using border vines and rows. Treatments (trellis systems) for both Sultanina and Chenel were : a lengthened Perold, 1,5 m slanting trellis, 0,9 m T-trellis, factory system as described by Zeeman (1981) as well as a USA hedge (Steinhauer & Bowers, 1979) (Fig. 1a). Furthermore, for Sultanina, the swing-arm trellis suggested by Clingeleffer & May (1981), which was originally designed to improve mechanical harvesting and to allow the partial mechanisation of pruning, was also used. This trellis was modified (Fig. 1b) to allow the independent movement of both arms. The adaptation was made in order to adjust the trellis to a horisontal system during flowering to obtain better light penetration in the cluster zone of the unfruitful Sultanina. To obtain a longer cordon length per vine, comparable to that of the factory system, a Geneva Double Curtain (Shaulis *et al.*, 1966) was used for the more fruitful Chenel.

Data collection: Data were collected during seven seasons (1983-'89). Phenological data and the appearance of the

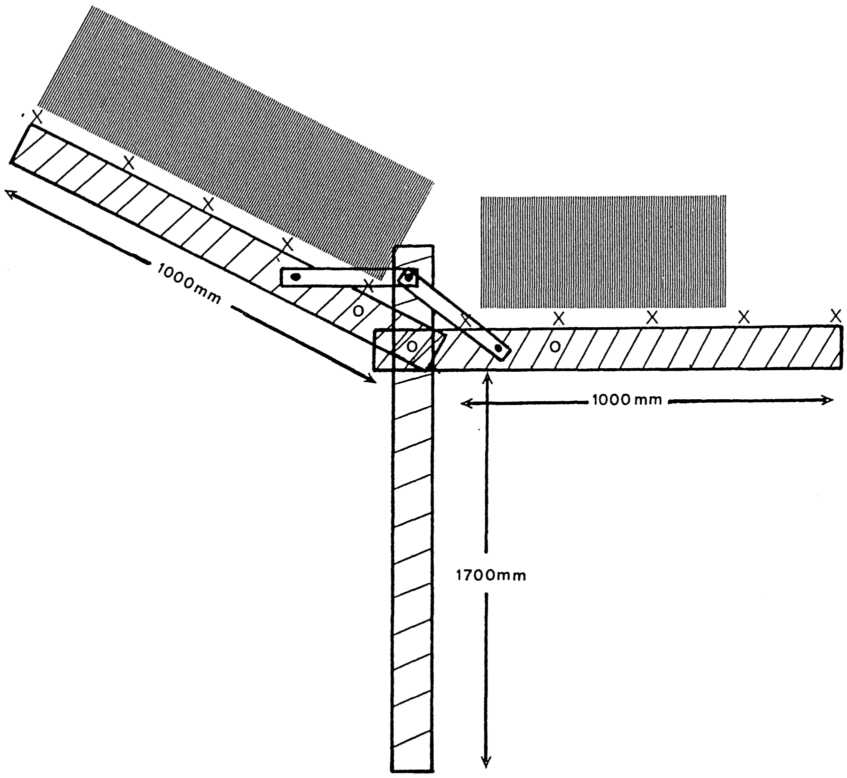

FIGURE 1b
Diagrammatic representation of the Australian swing-arm trellis. (x=wire positions).

growth-arrestment phenomenon, a common problem in this region (Saayman, 1983), were recorded through the growth season, whereas crop, cluster and berry mass were determined at harvest. Must sugar (°B) was measured using a hand refractometer, and total acidity (expressed as g/dm^3 tartaric acid) was determined by titration with 0,1N NaOH and phenolphthalein as an indicator. Fruitfulness (the number of bunches per bud allocated during pruning), the budding percentage (% allocated buds which sprouted) and pruning mass were recorded in winter.

Since inflorescence initiation occurred prior to bloom (Swanepoel & Archer, 1988), canopy density and photosynthetically active radiation (PAR) were recorded in the cluster zone at that stage. Canopy density was determined in the cluster zone (between the cordon and first wire) using the point quadrat principle of Smart *et al.* (1985), where a needle is passed through the canopy and the number of contact points and the thickness of the canopy recorded. Photosynthetically active radiation in the bunch zone as well as ambient radiation above the canopy were determined with a hand-held quantum sensor (Li-Cor).

Photosynthetic activity (mg CO_2/dm^{2}h) of the middle and basal leaves was measured at bloom and véraison during 1988 and 1989 using a portable photosynthesis meter (Analytical Development Company MK 1) and instrument parameters as described by Hunter & Visser (1988). Relative humidity (KM 8000 humidity meter), temperature and windspeed (KM 4003 thermo-anemometer) were measured in the centre of the canopy as well as ambient. These measurements were carried out between 10:00 and 14:00 on cloudless days with maximum ambient temperatures of 25,3°C (Sultanina) and the following day 34,3°C (Chenel) at bloom and 32,5°C (Sultanina) and the following day 33,1°C (Chenel) at véraison, respectively. The lengthened Perold was omitted for these measurements in Sultanina since this trellis was changed to a gable system.

Statistical analysis: The significance of differences between trellis systems for a cultivar was calculated per cultivar by means of a factorial analysis based on Tukey's formula (Snedecor & Cochran, 1974) using a standard VORI statistical software package. Furthermore, for the period 1986 to 1989, a stepwise linear regression (Draper & Smith, 1981) was employed to select those variables having a strong relationship with crop mass.

RESULTS

Phenological data: Although the effect of trellis systems on the date of bud burst (10-13 September) and full bloom (18-23 October) of Sultanina and Chenel was very small (data not shown), vines on the smaller vertical systems (lengthened Perold and USA hedge) tended to reach these stages later than those on the higher systems.

Yield: Generally, horizontal trellises (1,5 m slanting, T-system, factory and swing-arm) tended to induce higher average yields over years than the vertical trellises for Sultanina (Table 1). This confirms the results of other workers who found that larger trellises caused increased yields (Weaver & Kasimatis, 1975). Typical of Sultanina, a large variation in yield over years was observed (data not shown). Albeit not significant, berry mass tended to be the highest for the T-trellis but bunch masses showed no definite tendency.

For Chenel the factory system induced significantly higher yields than the vertical systems and the 1,5 m slanting trellis. The larger systems tended to increase bunch masses, but the specific berry mass showed no tendency.

Growth-arrestment phenomenon: This phenomenon, which causes a loss in yield (Saayman, 1983), was observed

TABLE 1
Mean performance (1983-1989) of Sultanina and Chenel trained onto different trellis systems in the lower Orange River region.

Trellis system	Crop mass (t/ha)		Bunch mass (g)		Berry mass/100 berries (g)		Budding (%)		Fruitfulness (bunches/ shoot)		Cane mass (kg/vine)		Crop:cane mass ratio	
	S	C	S	C	S	C	S	C	S	C	S	C	S	C
Lengthened Perold	18,9c	21,7b	423,1a	218,1a	159,8a	154,5a	59,2b	90,6a	0,39a	1,51b	2,4a	2,3b	3,9b	5,1b
USA hedge	21,0b	22,2b	347,1a	194,2a	150,9a	147,9a	59,3a	88,9a	0,42a	1,61ab	2,7a	2,7a	3,7b	4,5b
1,5 m Slanting	23,1ab	25,3b	407,1a	247,5a	167,1a	144,8a	66,3a	90,8a	0,45a	1,62ab	1,9b	2,4ab	5,8a	5,5ab
T-system	24,2a	27,3ab	420,4a	248,0a	169,1a	151,0a	65,0ab	90,5a	0,41a	1,77a	2,1b	2,1b	5,5a	6,8a
Factory	24,4a	30,9a	394,9a	272,5a	164,5a	148,4a	66,9a	90,2a	0,48a	1,63ab	2,4a	2,6ab	4,8ab	5,6ab
Swing-arm/GDC*	26,0a	28,3ab	384,7a	251,7a	166,9a	151,3a	65,0ab	88,6a	0,42a	1,59ab	2,2ab	2,3b	5,2a	6,3a
Mean	22,9	26,0	396,2	238,7	163,1	149,7	63,6	89,9	0,43	1,62	2,3	2,4	4,8	5,6

S = Sultanina.
C = Chenel.
* Swing-arm for Sultanina.
Geneva Double Curtain for Chenel.

Values designated by the same letter do not differ significantly ($p < 0,05$) for each parameter and cultivar.

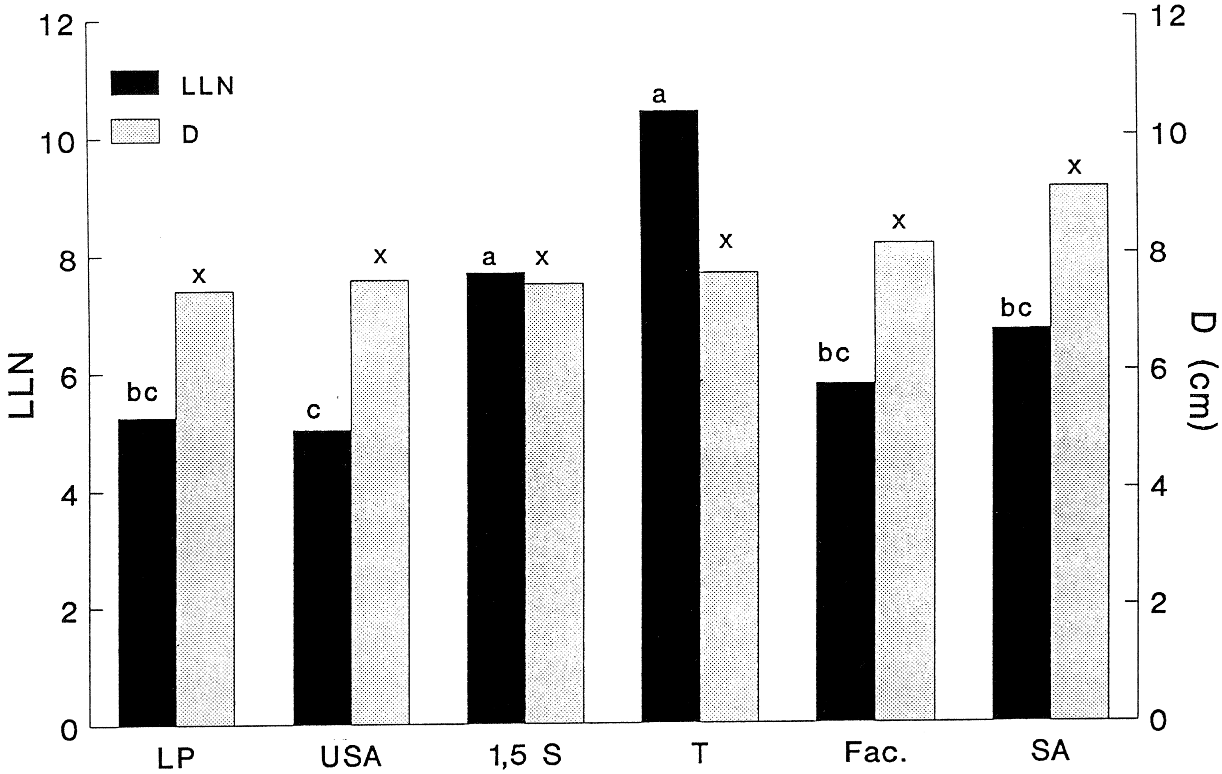

FIGURE 2a
Leaf layer numbers (LLN) and distance between contact points (D) measured in the cluster zone of Sultanina trained onto six trellis systems. Vertical bars designated by the same letter do not differ significantly ($p < 0,05$) for each parameter. [LP = lengthened Perold; USA=USA hedge; 1,5 S = 1,5 m slanting trellis; T=T-trellis; FAC=factory; SA=swing-arm].

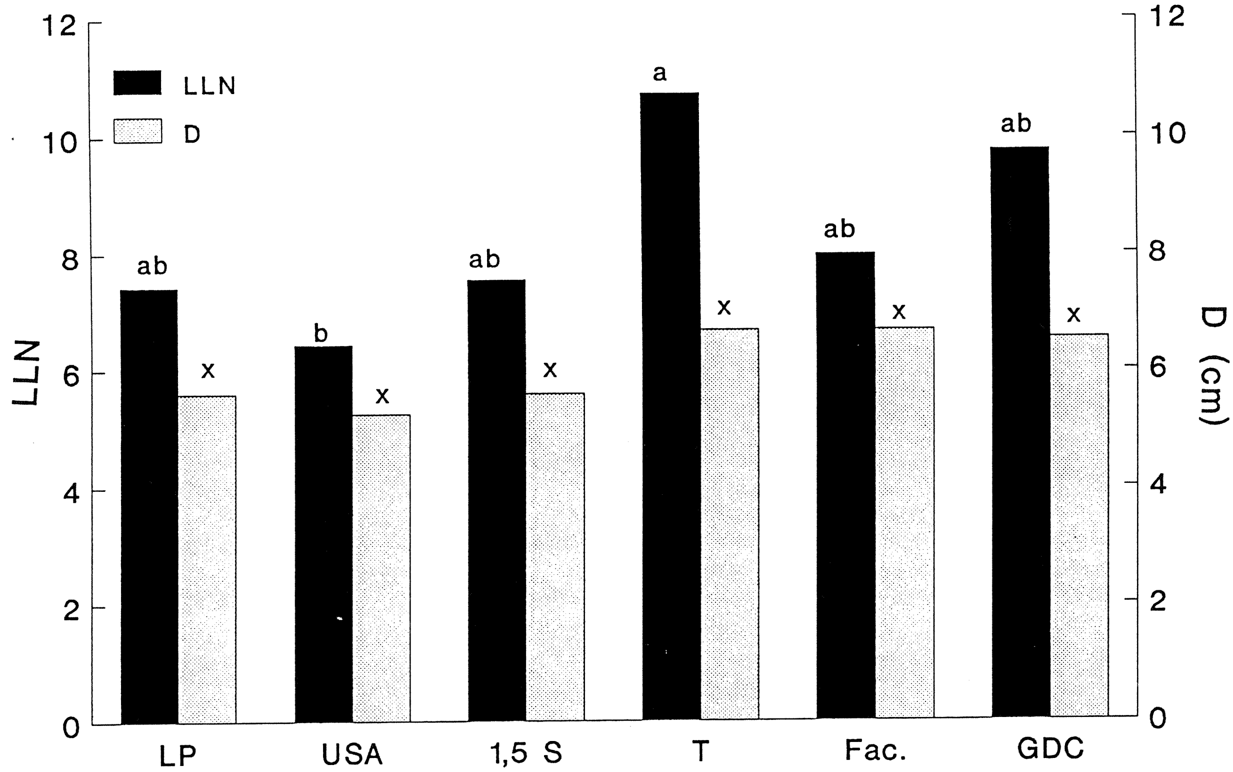

FIGURE 2b
Leaf layer numbers (LLN) and distance between contact points (D) measured in the cluster zone of Chenel trained onto six trellis systems. Vertical bars designated by the same letter do not differ significantly ($p < 0,05$) for each parameter. [LP = lengthened Perold; USA=USA hedge; 1,5 S = 1,5 m slanting trellis; T=T-trellis; FAC=factory; GDC=Geneva Double Curtain].

during two years only for Sultanina trained on the T-trellis.

Budding percentage and fruitfulness: A significantly lower budding percentage was found for Sultanina trained on the vertical systems (Table 1). Though not significant, the larger systems, e.g. the factory system, tended to induce a higher fruitfulness.

Small variations (cv = 4,3%) were observed in the budding percentage of Chenel trained on different trellis systems. The vertical lengthened Perold, however, induced significantly lower fruitfulness than the horisontal T-trellis (Table 1).

A stepwise variable selection procedure, during which all vegetative and reproductive variables were used in the regression equation in order of their importance for reduction in the total sum of squares of *Y* (crop mass), indicated that the budding percentage was the most important parameter in declaring the variation in crop mass of Sultanina (R^2=0,82). Although the fit of the equation was not significant at a 95% level, the variation in crop mass for Chenel, however, was mainly caused by differences in bunch mass (R^2=0,27).

Grape composition: Must sugar, which varied from 21,6°B to 23,2°B for Sultanina, was the highest for the factory (23,2°B) and the swing arm (23,0°B) systems, but it was the lowest for the USA hedge (21,6°B) and the T-trellis (21,9°B). Total acidity, albeit very low, was the highest for the factory system (4,9 g/dm^3). For Chenel, the factory system also induced the highest (25,5°B) and the T-trellis and the USA hedge the lowest (24,0°B) sugar concentration, whereas the highest total acidity was obtained with the 1,5 m slanting trellis (6,0 g/dm^3).

Cane mass: From Table 1 it is evident that trellis systems had a marked effect on cane mass, especially for Sultanina. For Sultanina the vertical and the factory systems induced a significantly higher cane mass, whereas for Chenel the vertical systems and the T-trellis retarded vigour since they induced significantly lower cane masses. The crop: cane mass ratios were, however, very low for the vertical systems for both cultivars. This was probably due to excessive growth which could not be accommodated by these systems, the result of which was also poorer grape development.

Canopy density: Excessive vigour and too dense canopies are also depicted in the distance between contact points (leaves, clusters, shoots) in the foliage. Although the average leaf-layer number (LLN) for Sultanina during full bloom was the lowest in the lengthened Perold (5,3) and USA hedge (5,0) and still not near the optimum of 3,0 as suggested by Smart (1985) for low-vigour vines, the distances between contact points were similar to those of the horisontal systems, suggesting canopies of comparable densities (fig. 2a). Although the canopies were denser in the case of Chenel, a similar tendency was obtained (Fig. 2b).

Canopy microclimate: Photosynthetically active radiation, measured in the cluster zone during full bloom for Sultanina, as well as that expressed as a percentage of ambient light intensity, appeared to be very low in general. Although

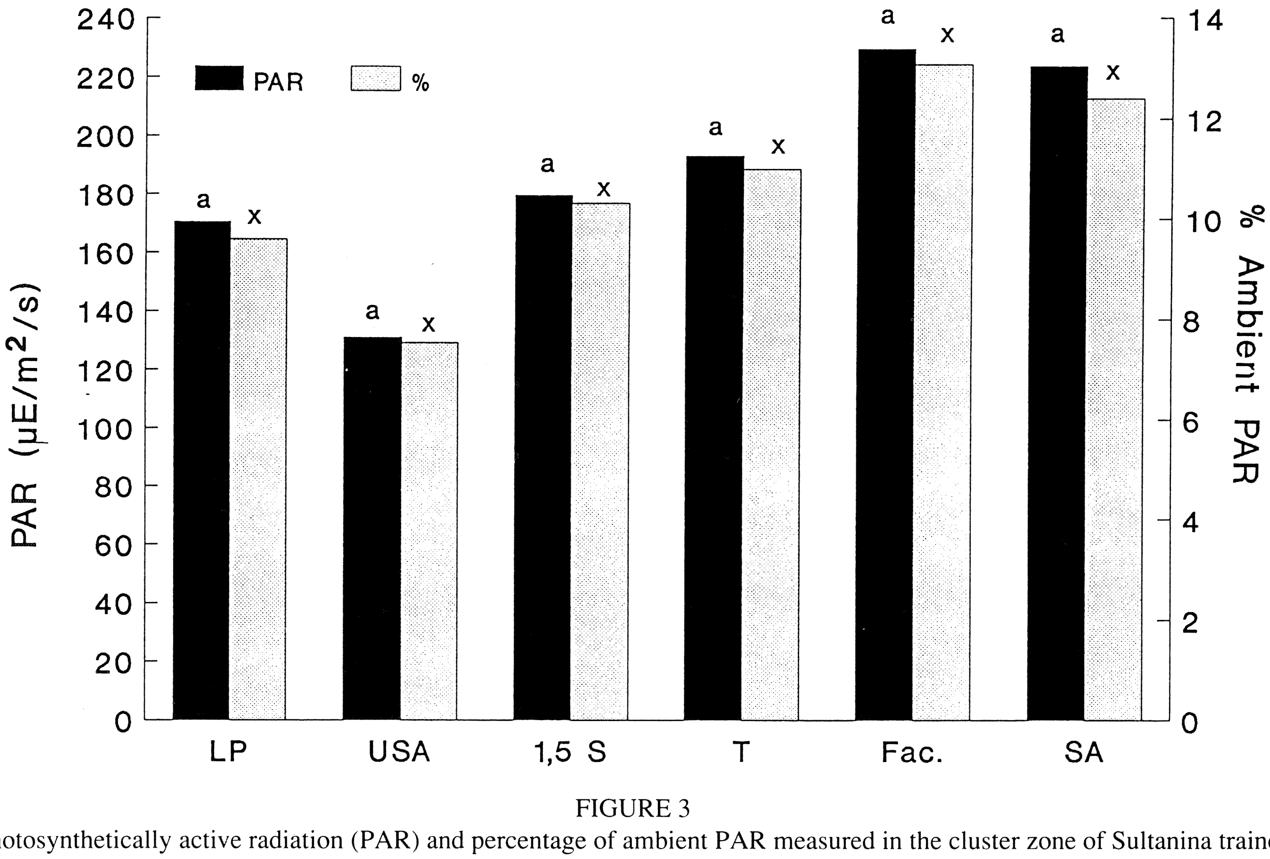

FIGURE 3
Photosynthetically active radiation (PAR) and percentage of ambient PAR measured in the cluster zone of Sultanina trained onto six trellis systems. (LP=lengthened Perold; USA=USA hedge; 1,5 S = 1,5 m slanting trellis; T-T-trellis; FAC = factory; SA = swing-arm).

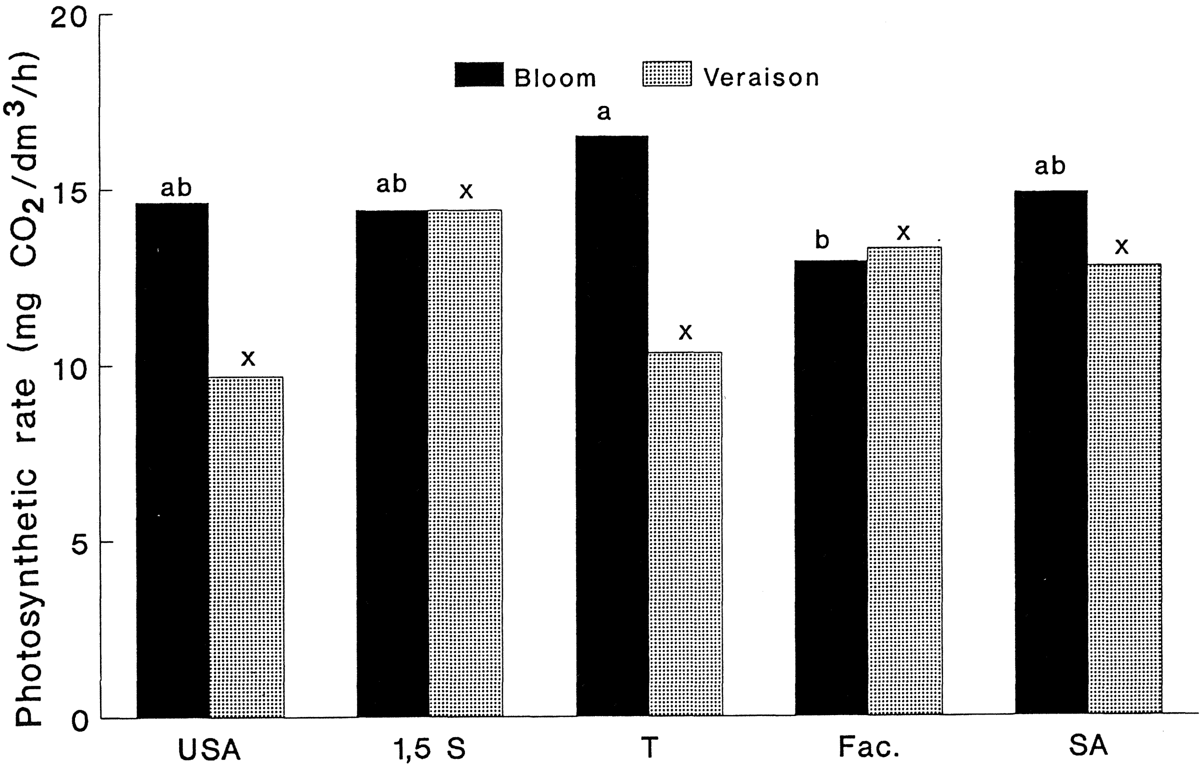

FIGURE 4a
Specific photosynthetic rate measured for the middle leaves during bloom and vêraison for Sultanina trained onto five trellis systems (lengthened Perold omitted). [USA=USA hedge; 1,5S=1,5m slanting trellis; T=T-trellis; FAC=factory; SA=swing-arm].

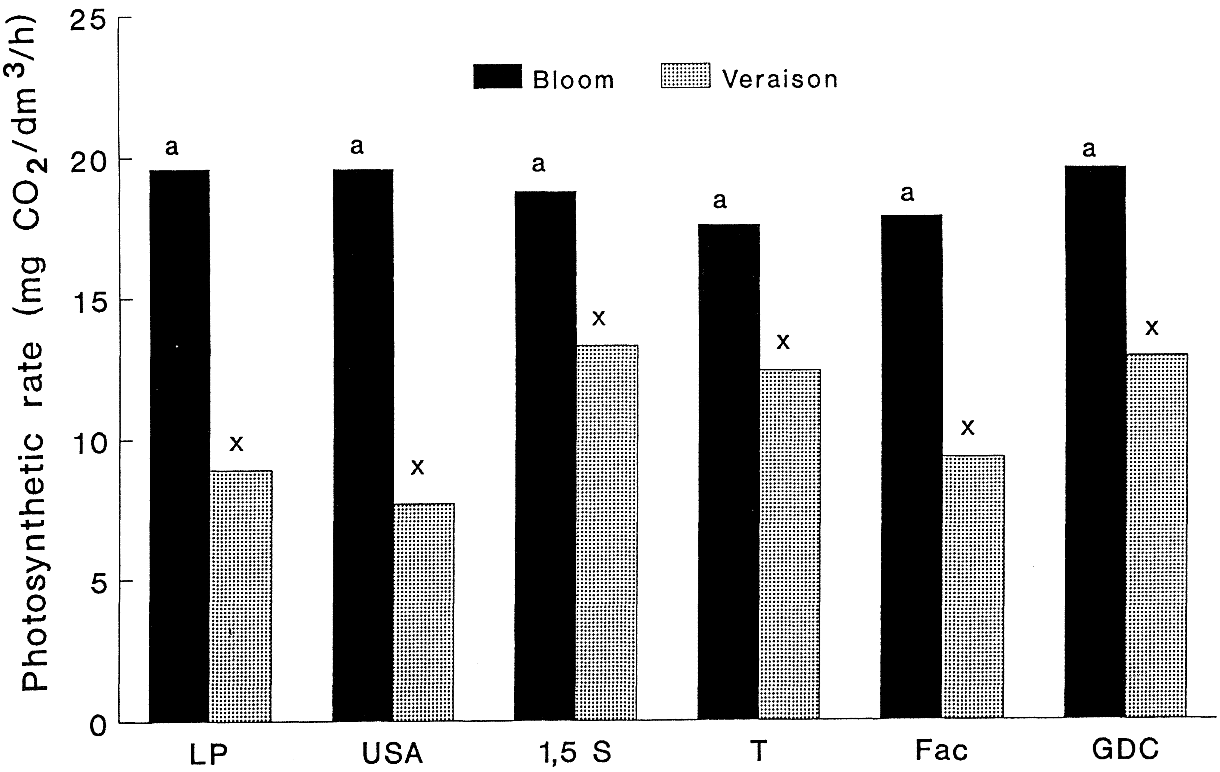

FIGURE 4b
Specific photosynthetic rate measured for the middle leaves during bloom and vêraison for Chenel trained onto six trellis systems. [LP=lengthened Perold; USA=USA hedge; 1,5S=1,5m slanting trellis; T=T-trellis; FAC=factory; GDC=Geneva Double Curtain].

not significantly, it appears to be lower in the vertical USA hedge than in the horisontal factory system (Fig. 3). This was also observed during véraison, with measurements as low as 0,8% of ambient light intensity for the USA hedge. For Chenel, the vertical systems also tended to induce the lowest PAR values (0,1%) at véraison (data not shown). Furthermore, a good relationship between PAR and the distance between contact points (canopy density) was obtained for Sultanina (r=0,79).

Although no significant differences were obtained between trellis systems concerning temperature, relative humidity and windspeed in the canopy during full bloom and at véraison (data not shown), higher canopy temperatures (25,7°C; 33,2°C) were recorded for Sultanina trained on the T-trellis than in the other systems (23,9°C; 32,5°C).

Specific photosynthetic activity: Although the specific photosynthetic activity of the middle leaves was higher than that of the basal leaves, the differences between trellis systems for such leaves were similar to that observed for the basal leaves. Therefore, only the results of the middle leaves are discussed.

The specific photosynthetic rates of the middle leaves of Sultanina during full bloom were higher for the T-trellis than for the factory and also tended to be higher than for the other systems, whereas during véraison the 1,5 m slanting and factory trellises tended to induce higher rates (Fig. 4a). In contrast to that observed for Sultanina, trellis systems had no effect on the photosynthetic rate of Chenel during full bloom (Fig. 4b). Photosynthetic rates, which tended to be the highest in the vertical systems at bloom, were the lowest in these trellises during véraison. The photosynthetic rates generally decreased from full bloom to véraison for both cultivars, confirming the results of Hunter & Visser (1988).

Stomatal resistance values for both cultivars were very low at full bloom (- 0,3 s/cm), but at véraison (between 1,11 and 5,02 s/cm) it was comparable to those found for other cultivars as quoted by Hunter & Visser (1988). In contrast to the findings of these authors, transpiration rate increased from full bloom to véraison (data not shown). This phenomenon can probably be explained by the higher ambient as well as canopy temperatures at véraison, resulting in higher transpiration.

DISCUSSION

In view of the small effect of trellis systems on the date of bud burst, higher cordon development should rather be employed to overcome the problem of late frost (up to mid-October). Since trellis systems have small effects on the dates of bloom, which occurred during the last half of October, canopy management practices such as suckering and shoot positioning should commence at this date, irrespective of trellis system and cultivar, to ensure an optimum light environment for inflorescence formation.

Higher yields of Sultanina in this study were due mainly to an improved budding percentage which confirms the results of Shaulis *et al.* (1966), Shaulis & May (1971) and Clingeleffer & May (1981). Improved budding percentages in the larger systems were primarily caused by a more efficient accommodation of vegetative growth resulting in an improved light environment in the canopy, although that improvement was very small. A higher budding percentage was also obtained by Hunter & Visser (1990) after partial defoliation (improved light environment) of Cabernet Sauvignon. If approximately 1,0 kg (canes per vine retained during pruning) was added to the average cane mass, the even lower crop: cane mass ratios indicated a serious misbalance between yield and growth. Mass per cane as well as shoot length could have been a more accurate indication of the vigour. Photosynthetically active radiation levels of about 180 mE/m^2/s were well below the minimum of 360 mE/m^2/s required for inflorescence formation (Buttrose, 1969) and were caused not only by a denser canopy but probably also by larger leaves.

The apparently higher bunch masses found for Chenel when trained on larger trellises resulted in higher yields compared to those of the small vertical trellises. This confirms the findings of other researchers who reported an increase in yield by enlarging the canopy foliage, either by widening the trellis (Shaulis & May, 1971; May *et al.*, 1973) or by increasing the height of the canopy (Scholefield, May & Neales, 1977). The former caused an increase in the amount of direct solar radiation intercepted by the foliage, as found by Carbonneau *et al.* (1978) and Kliewer (1982) and, therefore, would result in a higher photosynthetic capacity of the canopy (Smart, 1974, 1985). Although no differences could be found in the budding percentage of Chenel trained to different trellis systems, the larger canopies increased bud fruitfulness. This can be ascribed to less dense canopies, resulting in an improved light environment in the cluster zone. The fruitfulness values obtained for both cultivars, however, clearly showed that Chenel is still relatively fruitful at radiation levels where Sultanina is unfruitful.

In general, the lower vertical trellis systems, i.e. the lengthened Perold and USA hedge, resulted in high photosynthetic activities of the leaves at full bloom compared to those of the larger systems. This was probably due to less leaves exposed to direct sunlight in the former systems, causing the leaves to compensate, and therefore higher specific photosynthetic activities were recorded. This was also found by Hunter & Visser (1988). This confirms the general conception among viticulturists that canopy management practices such as suckering, shoot positioning, tipping, topping and leaf removal are necessary to achieve the optimum potential of a trellis system for a given in-row spacing. The lower photosynthetic activities during véraison in the vertical trellises probably resulted from the higher densities of the canopies at that stage and, therefore, resulting in decreased yields.

The high sugar content of 23°B of Sultanina found for the factory and swing-arm trellises, together with the higher yields in comparison with the vertical systems, may result in more raisins of better quality. The higher levels were probably caused by better canopy exposure and the improved light environments created by these canopies. From the sugar and acid analyses as well as small differences in the canopy microclimate of Chenel, very little differences in the wine qualities of grapes harvested from different trellis systems are expected.

CONCLUSIONS

By influencing the microclimate, especially the light environment, trellis systems exerted an important influence on the reproductive and vegetative performance of both Sultanina and Chenel.

An improvement over the reproductive performance of vines on the T-system (a trellis commonly used in the lower Orange River region for the cultivation of Sultanina) was obtained with the factory and swing-arm trellises, whereas the vertical trellises (lengthened Perold and USA hedge) performed poorly. This improved performance of the two larger systems for Sultanina could have been more pronounced had the soil volume (larger in-row spacing) been enlarged and the available canopy volume utilised. Furthermore, a system such as the lyre trellis as proposed by Carbonneau & Casteran (1986) in combination with leaf removal may overcome the problems of too much vigour.

The improvement in yield was due mainly to less dense canopies causing a better light environment, which resulted in higher budding percentages, especially in the case of Sultanina. Furthermore, the higher specific photosynthetic activities and, therefore, probably also the total photosynthetic activities found for the larger canopies during véraison, could be responsible for the higher bunch masses obtained for Chenel with a concomitant increase in yield. Since all the canopies for both cultivars were generally too dense and not near the optimum density of three, the differences in yield, budding percentage, fruitfulness, PAR and photosynthetic activities could have been more pronounced had the canopies been managed correctly.

Since canopies were denser and radiation levels lower for the more fruitful Chenel, it is evident that Sultanina needs higher levels of radiation to improve fruitfulness in this cultivar. Furthermore, although Chenel was still relatively fruitful under poor light conditions, its fruitfulness was influenced to a larger extent by a poor light environment than that of the unfruitful Sultanina. This aspect needs to be investigated further.

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