THE EFFECT OF VINE SPACING AND TRELLISING ON YIELD AND FRUIT QUALITY OF SHIRAZ GRAPEVINES

Peter R. Hedberg and Joy Raison

Respectively Senior Research Horticulturist, New South Wales Department of Agriculture, Viticultural Research Station, Griffith, N.S.W., 2680, Australia; and Biometrician, New South Wales Department of Agriculture, Sydney, Australia.

The authors thank R. Giason for his help in the field. Dr. R. Smart and Mr. J. Peterson managed this trial in its early years. B. Cullis and J. Evans helped with analyzing the data.

Manuscript submitted 12 August 1981.

Revised manuscript received 9 November 1981.

Accepted for publication 17 November 1981.

ABSTRACT

The inter-relationship between vine spacing (1.5 to 4.55 m row and 1.5 to 3.05 m vine spacing) and trellis width (up to 2.25 m T trellis) was examined using vigorous Shiraz grapevines. This experiment showed that vine spacing and trellis can be manipulated to produce similar vineyard yields. The question arises whether vineyard yield is best achieved by greater numbers of less productive shoots at high vine densities or by fewer, more productive shoots at lower densities.

High density plantings produced the greatest yield per hectare in the early years; however, within six years vines grown in wide rows with wide trellises were producing more yield per hectare. After six cropping years, there was only a 20% and 7% difference in cumulative yield between row width — trellis and vine spacing treatments respectively. Wider spaced vines required larger trellises for their increased capacity to be expressed.

Close, evenly spaced vine canopies (1.5 to 2.25 m apart) produced the best yields per hectare. Reduced canopy congestion improved vine bud burst and yield per shoot. Vineyard systems to improve productivity are discussed.

Vine spacing and trellis type are major aspects of vineyard design. Both are closely related as vine spacing affects vine growth, and the trellis helps this growth to be expressed in grape yield. In the past, these two aspects have been studied separately. This paper reports on the relationship between vine spacing and trellis utilization at Griffith, Australia.

In vineyards, increased yield per hectare is mainly due to an increase in the number of fruiting shoots per hectare (14), assuming growing conditions remain constant. This is most simply accomplished by leaving more nodes per vine (1, 10). However, yield is not directly proportional to number of nodes as a smaller proportion of fruitful buds burst on lightly pruned vines and produce smaller clusters (22).

Decreasing row or vine spacing can increase the number of fruitful shoots per hectare if a similar trellis is maintained. Closer vine spacing increases vineyard yield, especially in the early years (2,13,19,20,21), but this advantage diminishes with time (2). Greater yields per hectare are achieved when vines are arranged in a square rather than rectangular pattern, so as to minimize competition (2) and canopy shading (14). Vineyard yield is directly correlated with the soil surface covered by vine foliage despite yield per vine being vastly different at different vine spacings (21).

Severe shoot crowding is detrimental to vine productivity, principally through poorer bud health whereby nodes produce fewer, less fruitful shoots (7,14,15). Modifications to the canopy of Concord vines (*Vitis labrusca*) (14) and Sultana vines (*Vitis vinifera,* syn Thompson Seedless) (15) to reduce canopy shading have produced large yield increases. Similarly, widening the vine trellis has improved vine yields in the *Vitis vinifera* cultivars Shiraz and Semillon (11), Crouchen (10), and Muscat Gordo Blanco (19). Bud fruitfulness can be reduced by low light (4,9) and water stress (6) during bud differentiation.

This experiment compares a range of vine spacing and trellising treatments which provide a series of related canopy shapes and arrangements.

MATERIALS AND METHODS

This experiment was conducted at Griffith, N.S.W., Australia, using vigorous ungrafted *Vitis vinifera* cultivar Shiraz (syn Syrah) grapevines. Griffith has a temperate climate with an average annual rainfall of 409 mm. Vines were grown in Banna Sand (3), typified by a shallow sandy loam topsoil overlying clay and flood irrigated every 15 days during the growing season (adding about 500 mm of water per year).

Planted in 1969, this split-plot experiment (Fig. 1) compared six row width - trellis treatments (main plots) and three intra-row vine spacings (sub-plots). Four replications of buffered six-vine plots were used. Vine density ranged from 717 to 4304 vines per hectare. Permanent spur-pruned bilateral cordons were established 1.5 m above the ground. These treatments produced a range of related canopy shapes and densities using either more vines or split canopies. Canopies spaced 1.5 m apart were developed with treatments 1 and 5 (Fig. 1), while they were 2.25 m apart for treatments 2 and 6. Treatments 3 and 4 were trained on a 0.9 m T trellis, the most productive of those used in commercial vineyards.

To ensure a balance between vine capacity and yield, node number left at pruning (N) was determined by winter pruning weight in kilograms (P). Vines were pruned to two-node spurs using the formula N=20+20P in 1973; N=30+20P in 1974 and 1975; and N=50P in 1976. In 1974, for example, a vine with 2 kg of prunings would be pruned to 70 nodes. The formula N=50P was found to produce near maximum yields (maximum N=75P) for Shiraz vines in this environment (C. R. Turkington, personal communication, 1976).

At each harvest (1972-1977), yield and number of clusters per vine was recorded. Prior to harvest, each treatment plot was sampled by gathering 100 randomly selected berries. These were weighed and crushed. The juice was tested for total soluble solids (T.S.S. — °Brix) using a refractometer, titratable acid (expressed as g tartaric acid/L) as titrated with 0.1N NaOH, and juice pH. Shoot numbers and pruning weight were measured each winter. Butt circumference (cm) was measured in 1976 at a point 15 cm below the vine crotch.

During 1975-1977 environmental factors affecting growth and productivity were monitored. Diffused and reflected illuminance (lux/m^2) was measured at noon on three cloudless days during bud differentiation (Nov-Dec) by placing the selenium cell of a Light-master photometer at the cordon centre of six vines of each treatment (1.5 m vine spacing). The meter was angled southwards along the cordon so as to eliminate sunfleck interference (8) when measuring diffused light, and towards the ground to measure reflected light. The temperature in the centre of the cordon was measured with an infra-red thermometer at the same time. Soil temperature, 20 and 40 cm below the vines of two replicates (1.5 m vine spacing), was measured weekly by thermistors during two summer seasons. Leaf water potential (bars) of six exterior leaves per row width - trellis and vine spacing treatment was measured in two

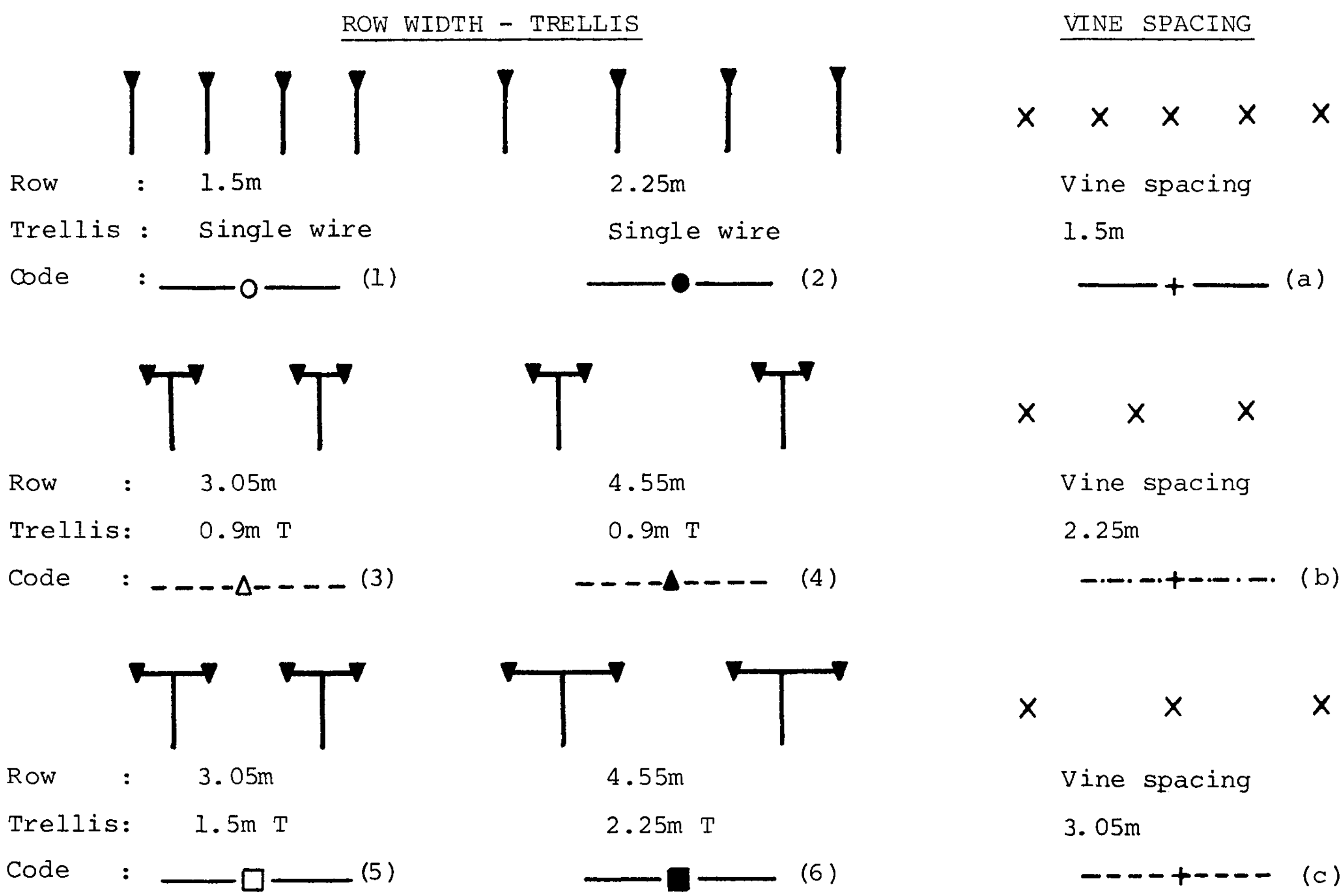

Fig. 1. Diagramatic representation of the 6 row width-trellis and 3 intra-row vine spacing treatments used in this experiment (Symbols: ▼ - spur pruned cordon as viewed down the row; and X - vine spacing. Line codes for successive figures are shown below each treatment diagram).

replicates on February 1, 1977 by a Scholander pressure chamber (12) the day prior to an irrigation. Soil water tension was measured by tensiometers and gypsum blocks placed at 20 and 40 cm below vines and one third the way across rows.

Data were assessed by analysis of variance. Least significant differences (5% level) are represented by vertical bars in figures, and significance levels are recorded as ns (non-significant); *(0.01<P<0.05); **(0.001<P<0.01); and ***(P<0.001). Treatment line codes for all figures are shown in Fig. 1.

RESULTS

There were very few significant interactions between row width - trellis and vine spacing treatments; hence, these results are presented separately.

Yield per vine: Annual yield per vine increased with decreasing vine density as shown by wider row spacing (Fig. 2A) or wider vine spacing (Fig. 2B). In most cases yield per vine was increased when similarly spaced vines were grown on wider trellises (treatments 3 v 5 and 4 v 6).

Vines in closely spaced rows (treatments 1 and 2) produced the highest yields per hectare in the early years (Fig. 3). With time, however, vines grown in wider rows and on wider trellises produced slightly more yield than the more closely spaced vines. Despite this change, closely planted vines (treatment 1) maintained a higher cumulative yield than wider spaced or trellised vines. Considering the range of treatments, it was interesting to note that after six crops there was only a 20% difference in cumulative yield between the six row width - trellis treatments (descending order: treatment 1, 3, 2, 6, 5 and 4).

Close intra-row spacing produced more yield per hectare in the early years but lost this advantage in later years (Fig. 3) in all except the wide row treatments (treatments 4 and 6). After six crop years there was only a 7% difference in cumulative yield between intra-row vine spacings.

Clusters per vine: As the pruning level was based on pruning weight, the larger more widely spaced vines carried more nodes and hence clusters per vine (Fig. 4). Although the number of shoots per vine was the main factor influencing the number of clusters per vine, there was usually a decrease in clusters per shoot in vines planted in very close rows (treatment 1) (Fig. 5A) and closer in the row (Fig. 5B).

Cluster weight: Closer vine spacing decreased cluster weight (Fig. 6). Different trellis widths at similar row spacings did not affect cluster weight.

The components of cluster weight are number of berries and berry weight. Closely planted vines had slightly fewer berries per cluster than wider spaced vines. In the last four years vines spaced at 2.25 m and 3.0 m in the row had 12% and 15% more berries

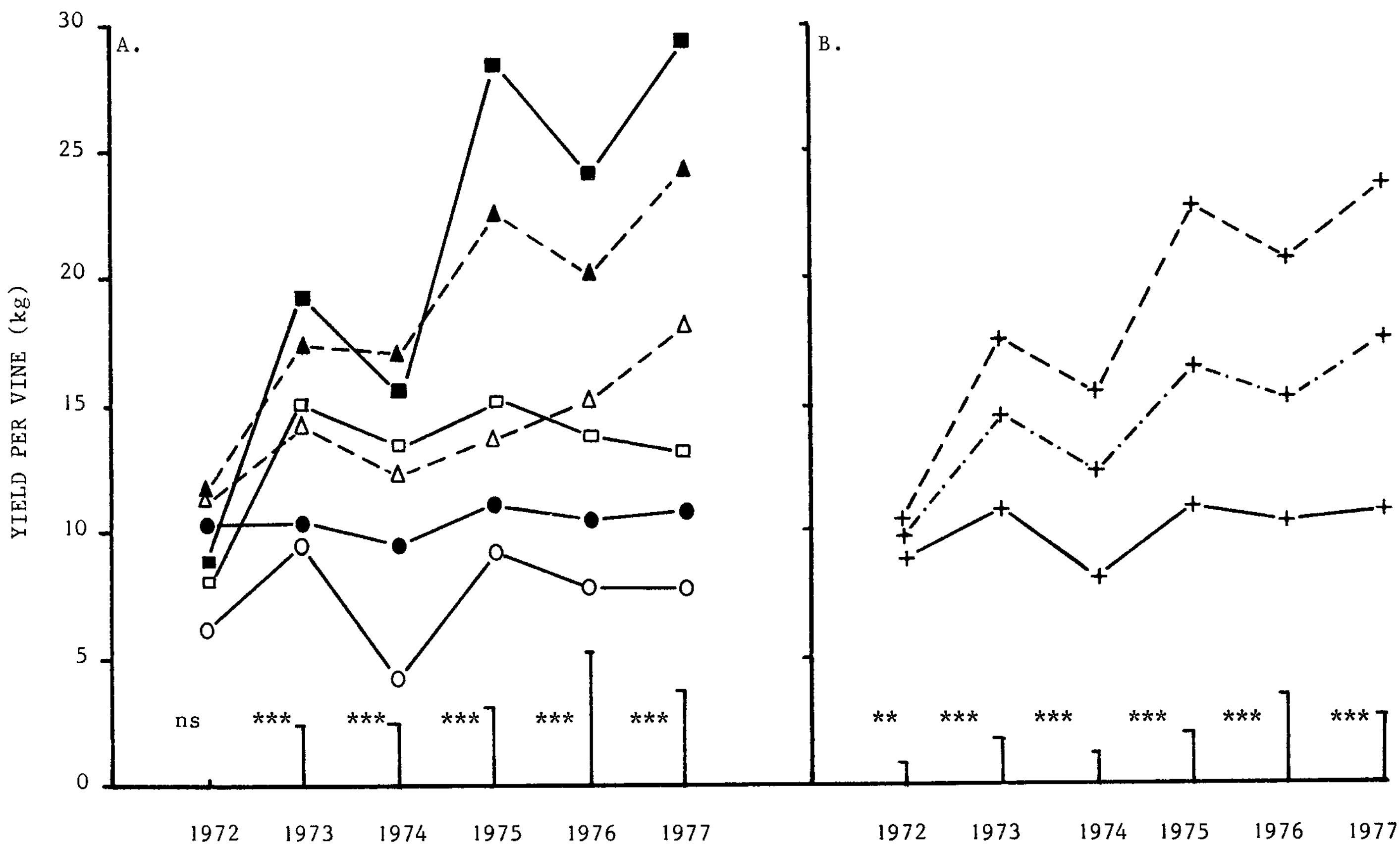

Fig. 2. Yield per vine when grown in different row width-trellis (A) and vine spacing treatments (B).

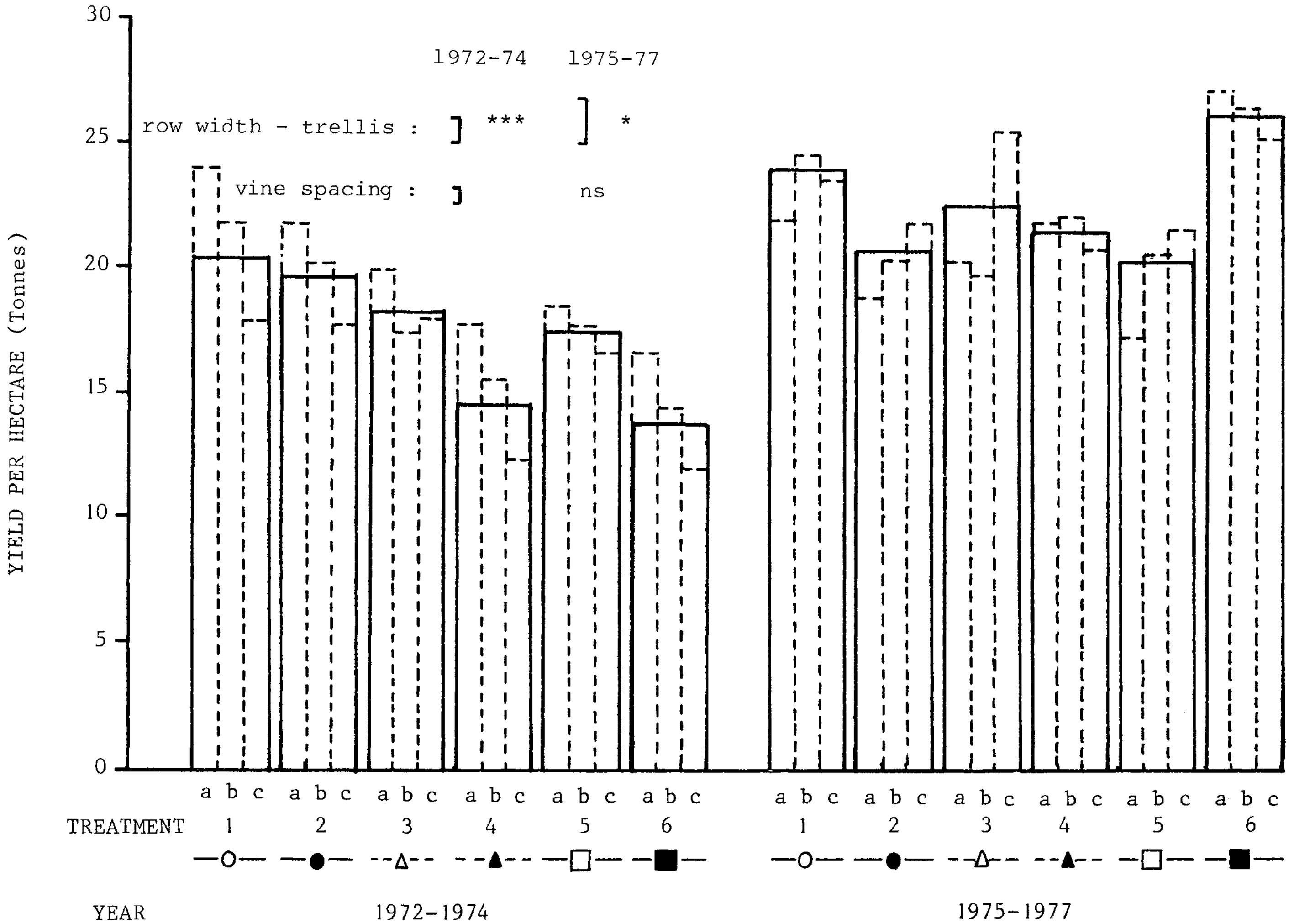

Fig. 3. Mean yield per hectare of row width-trellis and vine spacing treatments in the formative years (1972-1974) and at maturity (1975-1977).

respectively than vines at 1.5 m spacings. There were no consistent differences in berry weight between row-trellis or vine spacing treatments.

Yield per shoot: Widening vine rows increased the yield per shoot (Fig. 7A) as did widening intra-row vine spacing (Fig. 7B). Increasing trellis width for vines grown at similar row spacings had no real effect.

Yield per node left: Yield per node left at pruning increased as rows were widened (Fig. 8A) and as intra-row vine spacing was widened (Fig. 8B). Yield per node left between vines on different trellises, but similar row spacings, was not significantly different (Fig. 8A), except for 1975. As well as improved yield per shoot, wider spaced vines produced more shoots per node left than those planted more closely (treatments 1 and 2) (Fig. 9). Lighter pruning in the later years reduced yield per node left and shoot numbers per node left.

Shoots per hectare: Total vineyard yield is dependent upon the number of shoots per hectare. Table 1 shows that, despite vines being pruned to a node number as related to pruning weight, the closely planted vines have a greater pruning weight and hence number of shoots per hectare than wider spaced vines.

Vine growth: Vine growth as expressed by weight of winter prunings per vine (Fig. 10) increased as vine spacing was increased. Wider spaced vines also had a significantly greater butt circumference than closer planted vines (Table 1).

Grape quality: Grape maturity (°Brix) was different in three of the six years, wherein there was a trend for vines in close rows to be less mature at harvest (Table 2) than vines in wider rows. In the later and more settled years vines planted wider in the row were less mature at harvest than those closely planted. Juice pH was significantly lower for vines in the widest rows (Table 2) in three of the four years than those vines in closer rows. Wider intra-row vine spacing caused a reduction in juice pH in two of the four years recorded. Juice titratable acid (g/L tartaric acid) was not different between treatments, except that vines planted widely in rows had non-significant but consistently higher levels than narrower spaced vines.

Vine micro-climate: *Light:* Diffuse and reflected illuminance measured at the cordon (Table 3) showed that vines planted in close rows (treatments 1 and 2) or in wide rows with a 0.9 m wide T trellis (treatment 4)

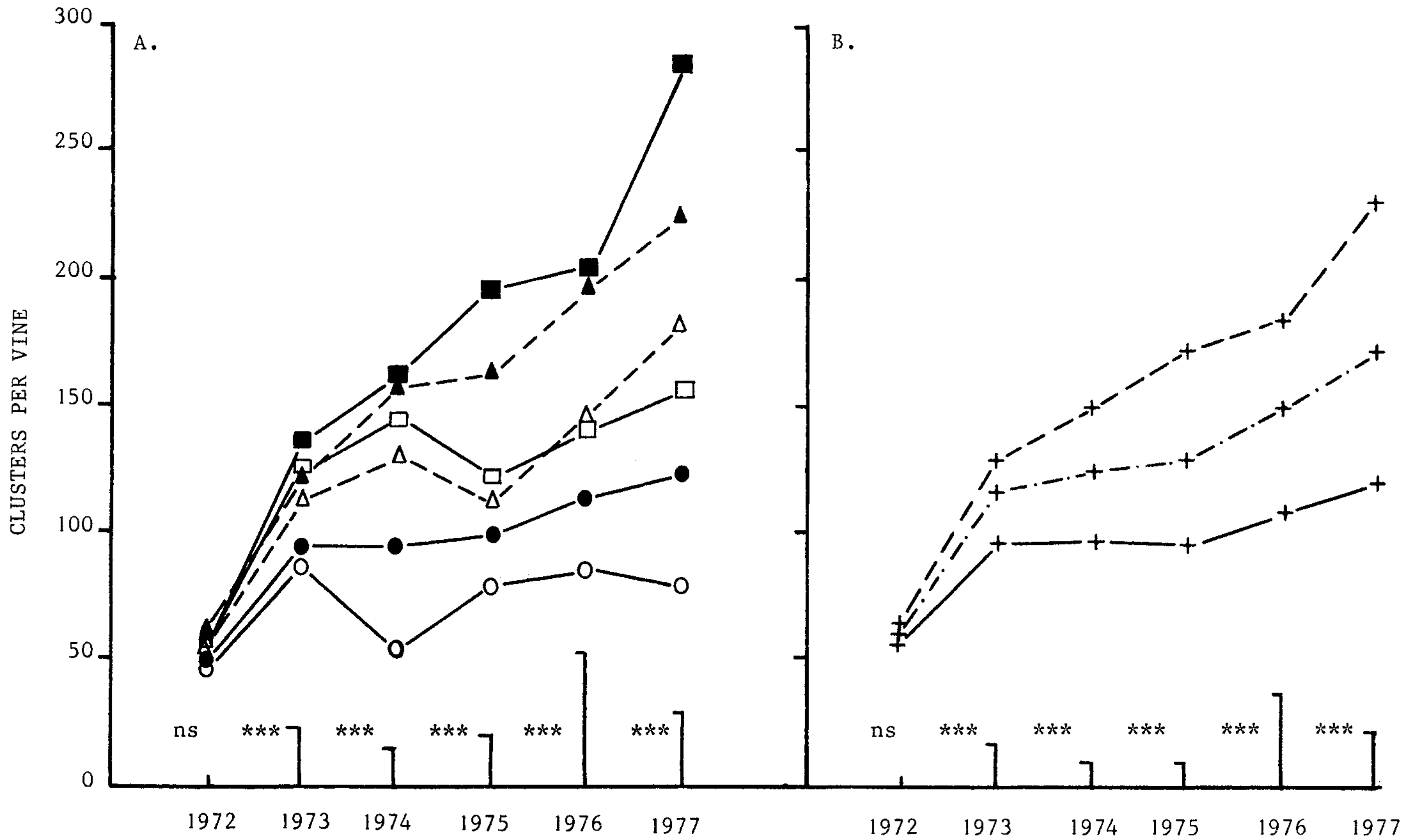

Fig. 4. Clusters produced per vine when grown in different row width-trellis (A) and vine spacing treatments (B).

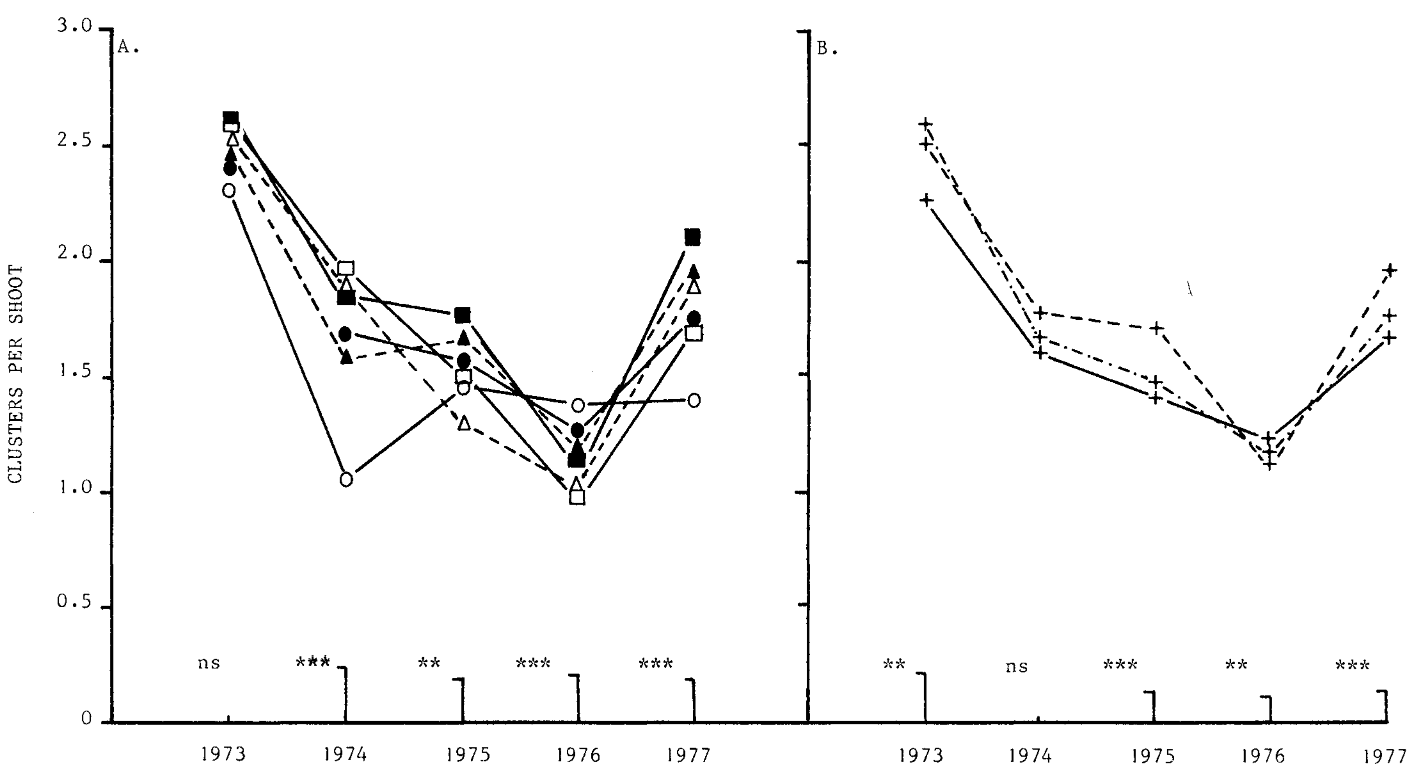

Fig. 5. Clusters produced per shoot on vines grown in different row width-trellis (A) and vine spacing treatments (B).

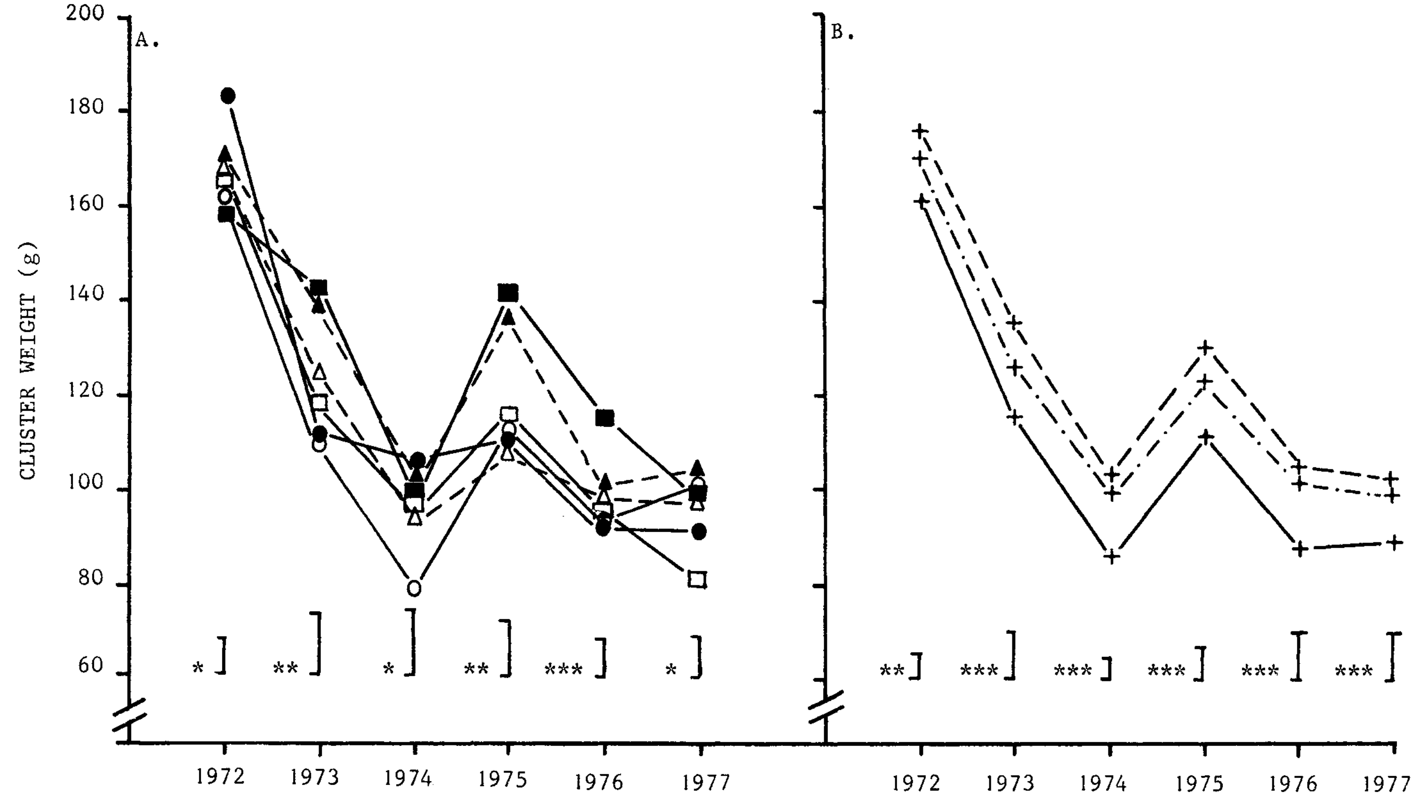

Fig. 6. Cluster weight of vines grown in different row width-trellis (A) and vine spacing treatments (B).

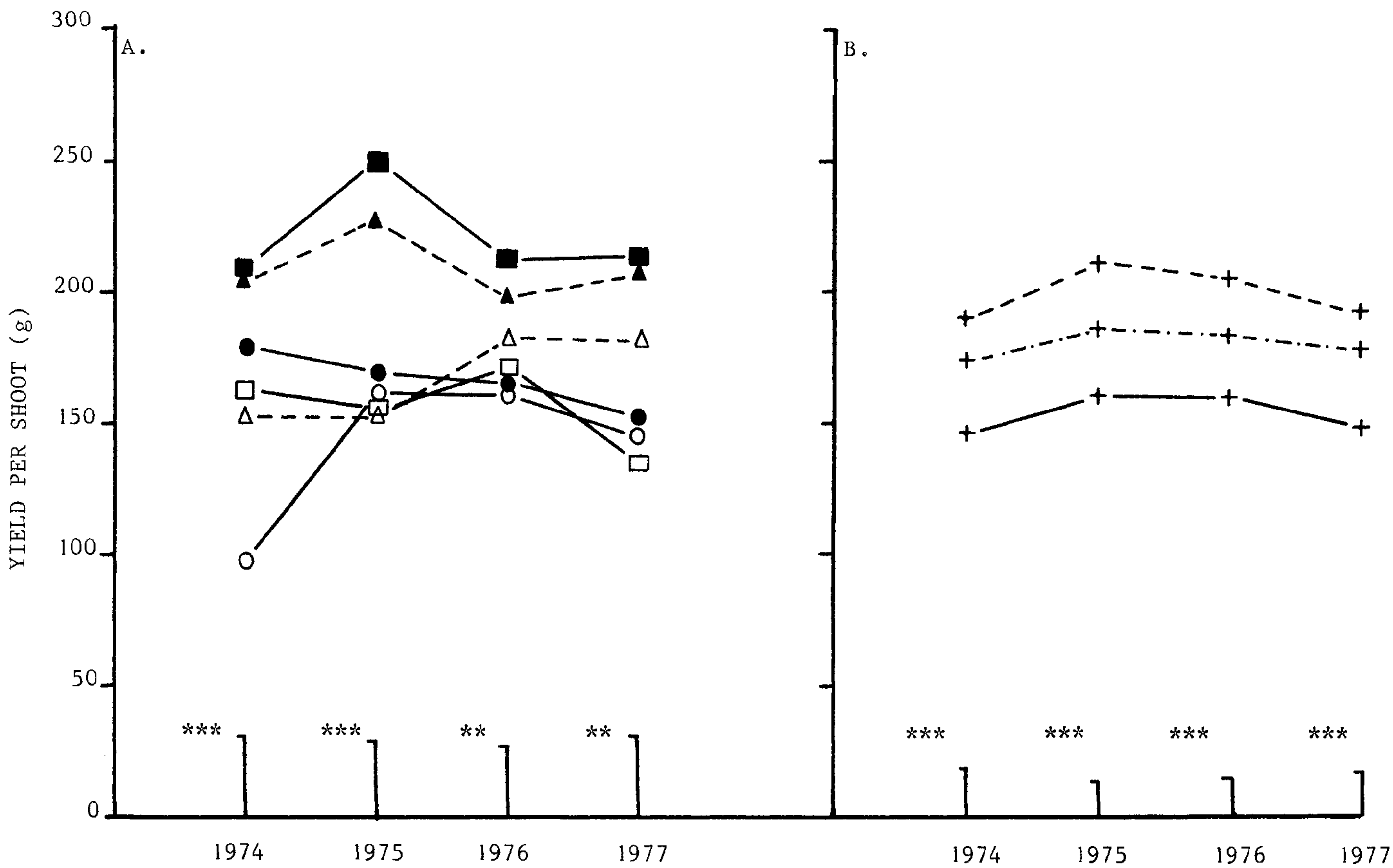

Fig. 7. Yield per shoot of vines grown in different row width-trellis (A) and vine spacing treatments (B).

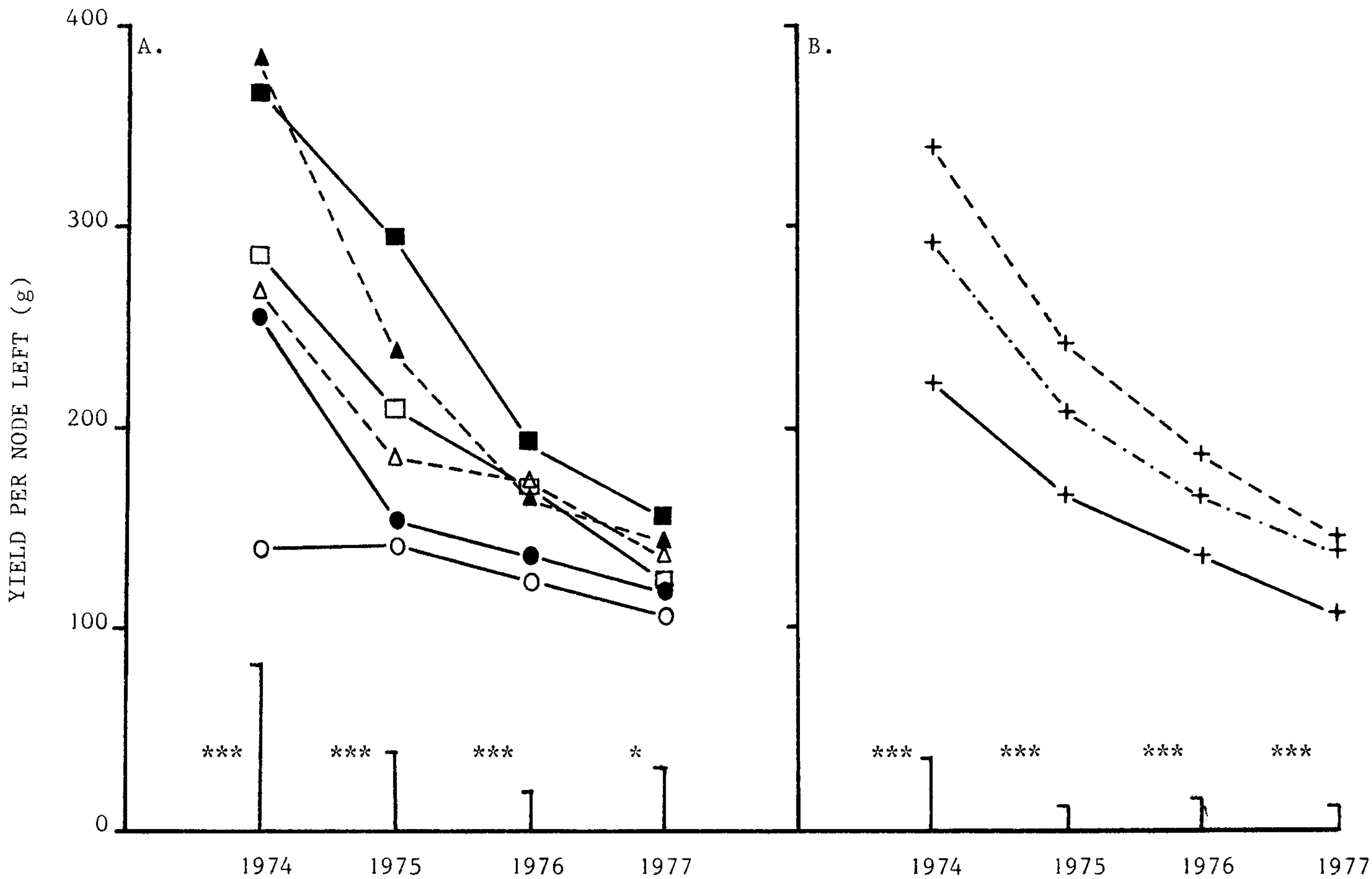

Fig. 8. Yield per node left at pruning for vines grown in different row width-trellis (A) and vine spacing treatments (B).

had less cordon light than the other treatments.

Temperature: Cordon temperature was not significantly different between row width - trellis treatments. Mean soil temperatures (Fig. 11) decreased with those row width - trellis treatments that increased ground shading (treatments 1, 2, 4 and 6).

Moisture: Leaf water potential data (Fig. 12) show that (apart from treatment 2) larger, wider spaced vines, particularly when trained on a larger trellis (treatments 4, 5 and 6) are under more water stress than smaller densely planted vines (treatment 1). Although leaf water potentials were not significantly different between vine spacings, there was a trend for wider spaced vines to have more negative water potentials. Soil water levels were not found to be consistently different between treatments, and differences were more related to soil variation throughout the trial.

DISCUSSION

Assuming adequate vigor, the adverse effect of wide spacing can be countered by increasing trellis size. The question posed by these data is whether productivity is best achieved by greater numbers of less productive shoots at high vine densities or by fewer, more productive shoots at lower vine densities.

Increasing vine density decreases vine size and capacity as shown by annual pruning weights (Fig. 10) and butt circumference measurements (Table 1). As found by others (2, 13, 20, 21), closely planted vines are quicker to attain full production than those planted at wider spacings. Close intra-row vine spacing was very beneficial in the early years (Fig. 3) but lost this advantage in time in all but those treatments with wide rows. As suggested by Bioletti and Winkler (2), a square planting arrangement was most beneficial in all but the wide (4.55 m) rows.

Winkler (21) showed that when nodes retained were proportional to canopy surface area, vineyard yield could be maintained, although he suggests that larger trellises could be necessary for the wider spaced vines. Our data agree in that, when vines are balanced pruned, similar yields per hectare can be achieved with mature close or widely spaced vines. However, in this environment as rows become wider, larger trellises are necessary to maintain vineyard yield. The larger trellises allow the increased vine vigor and capacity, as encouraged by reduced vine density, to be expressed.

Shaulis (14) greatly improved the yield of Concord vines (at the same spacing) by dividing vine canopies into two separate pendulous curtains of foliage (Geneva Double Curtain — G.D.C.). In contrast, Shiraz vines have strong, erect shoots and are not easily shoot posi-

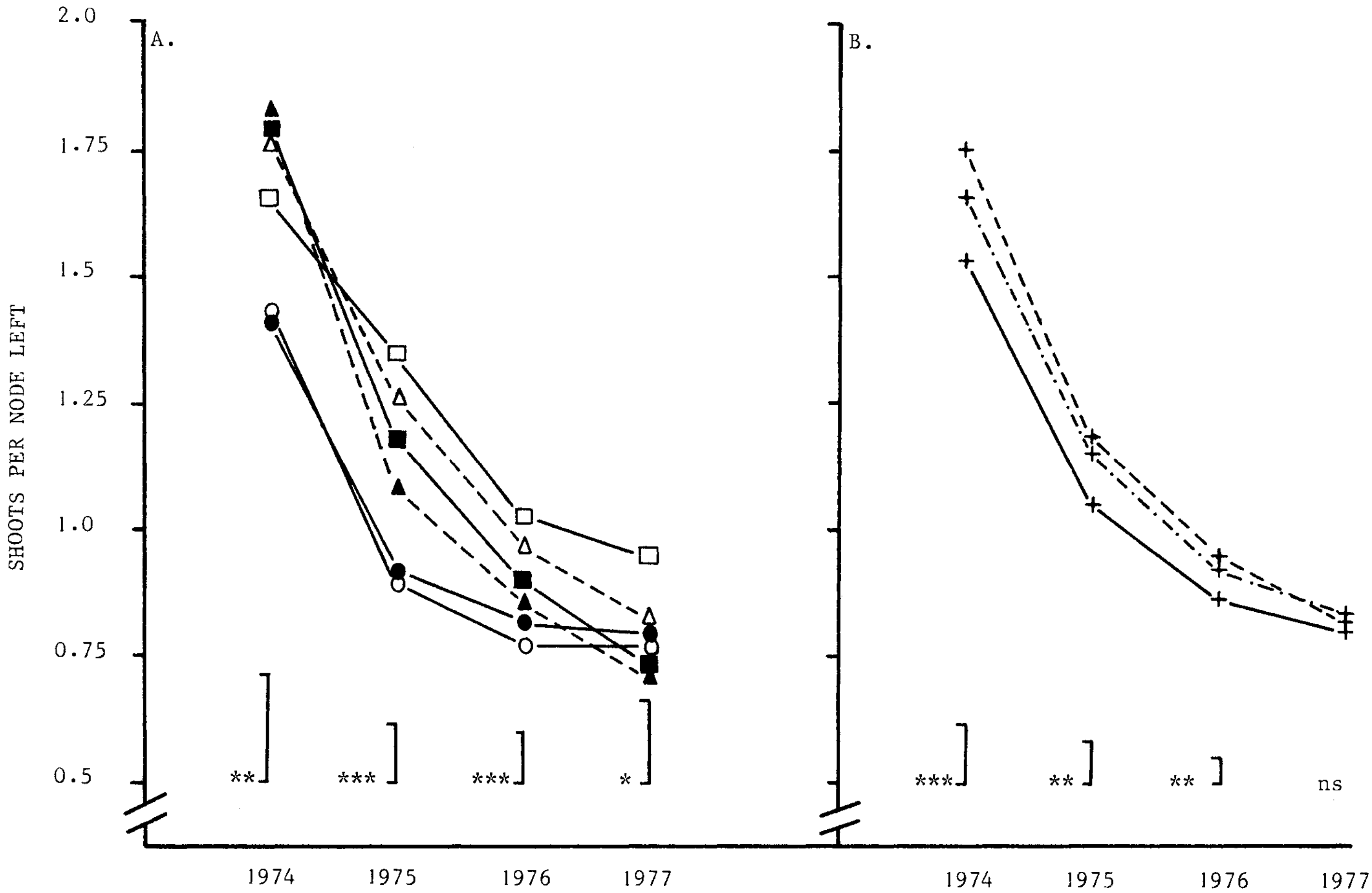

Fig. 9. Number of shoots developed per node left at pruning for vines grown in different row width-trellis (A) and vine spacing treatments (B).

Table 1. Butt circumference per vine (1976); mean pruning weight and shoot number per hectare (1975-1977) of vines grown in different row width-trellis and vine spacing treatments.

Row width (m) (2.25 m vine spacing)	Trellis	Vines/ha	Butt circumference (cm)	Pruning weight/ha (tonnes)	Shoots/ha
1.5	single wire	2868	13.1	4.36	163 055
2.25	single wire	1911	13.4	3.56	142 199
3.05	0.9 m T	1434	15.5	2.88	153 508
4.55	0.9 m T	956	17.0	3.07	120 392
3.05	1.5 m T	1434	14.1	2.58	154 131
4.55	2.25 m T	956	17.1	3.42	134 159
significance			***		
lsd (0.05)			1.9		
Vine spacing (m)					
1.5	(all row	2392	13.7	4.07	179 639
2.25	width-trellis	1594	15.4	3.70	165 085
3.05	treatments)	1196	16.6	3.55	153 367
significance			***		
lsd (0.05)			1.3		

tioned. In this experiment, vine canopies were not shoot positioned or controlled by trimming.

Widening the trellis at a set row spacing usually increases vine yield (10,11,19). In this study vines in 3.05 m rows were no more productive when the trellis was widened from 0.9 m to 1.5 m, whereas a 16% increase in yield resulted when vines in 4.55 m rows had their trellis widened from 0.9 m to 2.25 m. Lower vine capacity, as shown by the lower pruning weights (Fig. 10) and smaller butt circumference measurements (Table 1), caused the former negative resonse to wider trellising. This situation demonstrates that adequate vine capacity is required to fully utilize large trellises. Narrowing rows from 2.25 m to 1.5 m increased single wire trellised vine yield by only 11% despite a 50% increase in vine numbers. Lack of canopy separation, shoot bridging, and lower light levels (Table 3) were major factors in the reduced performance of vines in 1.5 m rows.

Increased vine yield by vines at lower densities

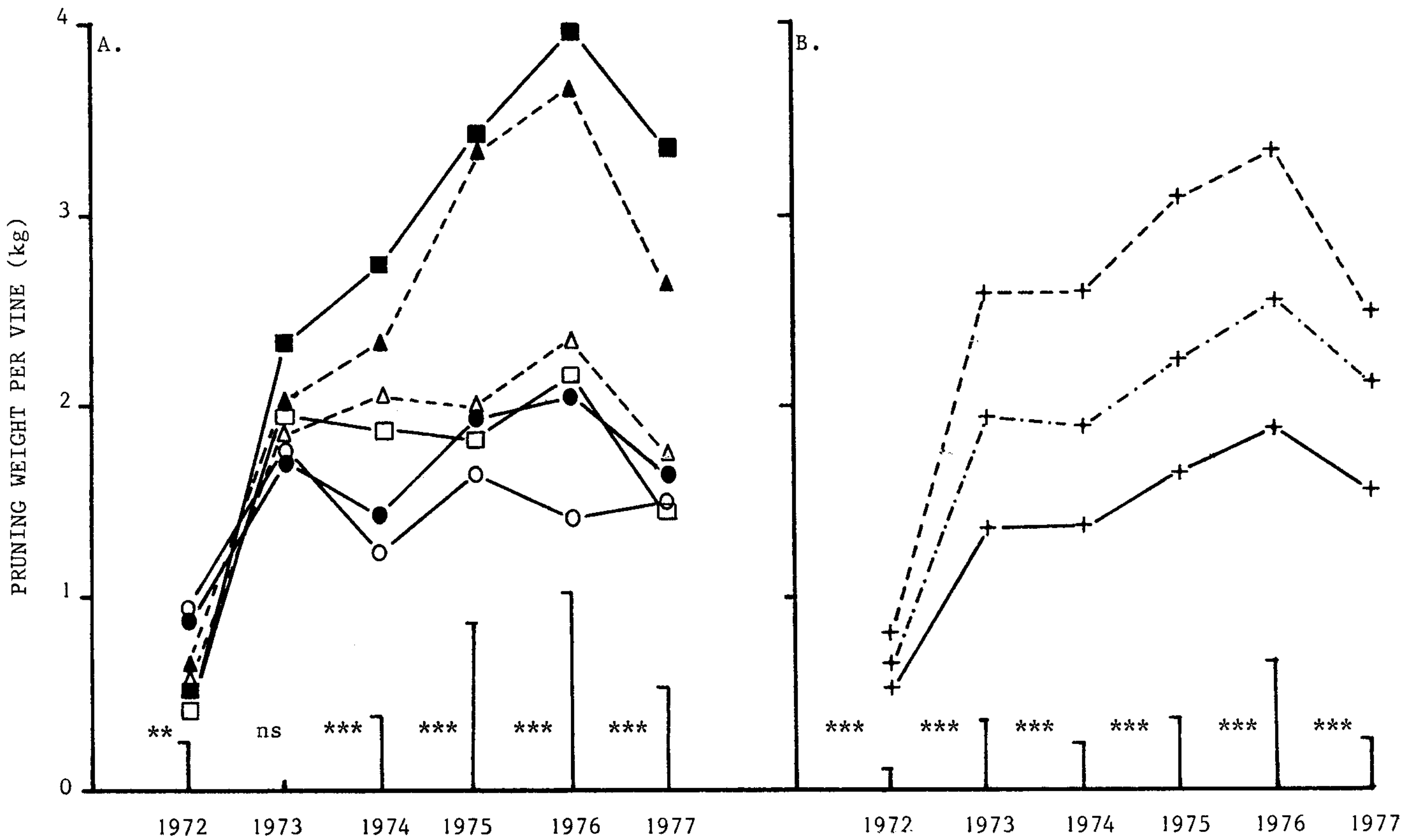

Fig. 10. Pruning weight per vine when grown in different row width-trellis (A) and vine spacing treatments (B).

Table 2. Total soluble solids (°Brix) and juice pH (in brackets) of grapes grown in different row width-trellis and vine spacing treatments.

Row width-trellis treatment	Year					
	1972	1973	1974	1975	1976	1977
1	19.5	20.1	24.6(3.73)	19.3(3.61)	18.7(3.98)	20.8(3.83)
2	19.3	21.3	24.1(3.63)	20.9(3.58)	18.9(3.93)	20.7(3.79)
3	20.8	21.0	23.6(3.48)	21.4(3.61)	18.7(3.84)	20.0(3.72)
4	21.7	21.6	24.2(3.54)	20.8(3.48)	19.6(3.86)	20.8(3.63)
5	22.3	21.0	24.5(3.62)	21.1(3.61)	18.4(3.87)	20.7(3.76)
6	22.2	22.1	23.8(3.49)	19.8(3.41)	18.8(3.87)	20.6(3.61)
Significance	***	*	ns (**)	**(***)	ns (ns)	ns (***)
lsd (0.05)	0.9	0.9	(0.12)	0.9(0.08)		(.06)
Vine spacing (m)						
1.5	20.3	21.1	24.5(3.60)	21.0(3.58)	19.4(3.90)	20.7(3.79)
2.25	20.9	21.0	23.8(3.57)	20.5(3.55)	18.9(3.90)	20.5(3.72)
3.05	21.7	21.5	24.1(3.58)	20.1(3.52)	18.4(3.87)	20.6(3.70)
Significance	***	*	ns (ns)	* (*)	*** (ns)	ns (**)
lsd (0.05)	0.6	0.6		0.6(0.04)	0.5	(0.03)

Table 3. Diffuse and reflected illuminance (lux/m²) as measured at the cordon centre over three days and during bud differentiation (24/11/75, 27/11/75 and 10/12/75).

Treatment	Row (m)	Trellis	Diffuse light	Reflected light
1	1.5	single wire	25.5	152.8
2	2.25	single wire	53.2	256.9
3	3.05	0.9 m T	78.7	289.4
4	4.55	0.9 m T	48.6	266.2
5	3.05	1.5 m T	81.0	388.9
6	4.55	2.25 m T	55.6	259.3
	significance		* *	* * *
	lsd (0.05)		27.8	69.4

resulted from increased cluster numbers per vine (Fig. 4) which in turn reflects mainly the increased number of shoots per vine. As found by May et al (10) and Peterson et al (11) increased numbers of shoots per vine were largely due to more nodes being left on larger vines. However, bud health, as reflected by shoots per node left (Fig. 9), was also improved when vine spacing was widened and is no doubt related to the more open canopy (10,13,14,15). As a result, yield per node left (Fig. 8) was increased for wider spaced vines and some wider trellises (treatment 4 v 6) with some additional support

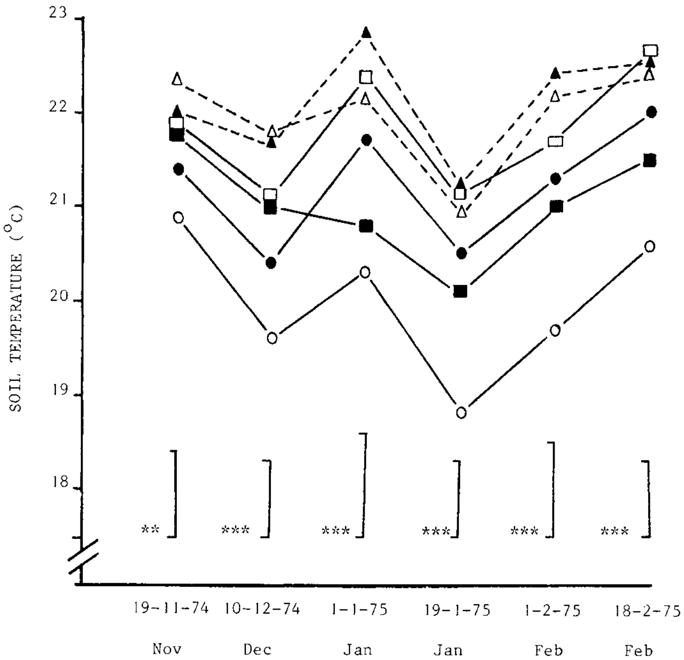

Fig. 11. Mean soil temperature under vines grown in different row width-trellis treatments. Measurements were made across the row, 20 and 40 cm deep, and with vines spaced at 1.5 m.

from increased bud fruitfulness as expressed by clusters per shoot (Fig. 5).

Shoot yield was improved when vines were planted at lower densities (Fig. 7). The relatively inconsistent improvement in bud fruitfulness (cluster per shoot) in wider spaced or wide trellis treatments agrees with others (10,14,15) and suggests that sunlight levels during bud differentiation are adequate (4, 5) in this region. As found by Winkler (21), cluster weight (Fig. 6) was increased with wider spaced vines, mainly as a result of increased number of berries rather than berry weight. Widening trellises resulted in a similar but slight increase in cluster weight and so supports the result of Shaulis and May (15).

These vine spacing and trellising treatments did not dramatically affect grape maturity as also found in similar experiments (13,18,21). Vines spaced widely in the row had mostly lower total soluble solids, lower pH, and a tendency for higher titratable acid levels than narrowly spaced vines and no doubt reflect the slower maturation of higher yielding vines (Table 2). The tendency for vines in close rows to have lower total soluble solids than wider spaced and trellised vines is most likely related to the shaded (Table 3) horizontal canopies that developed.

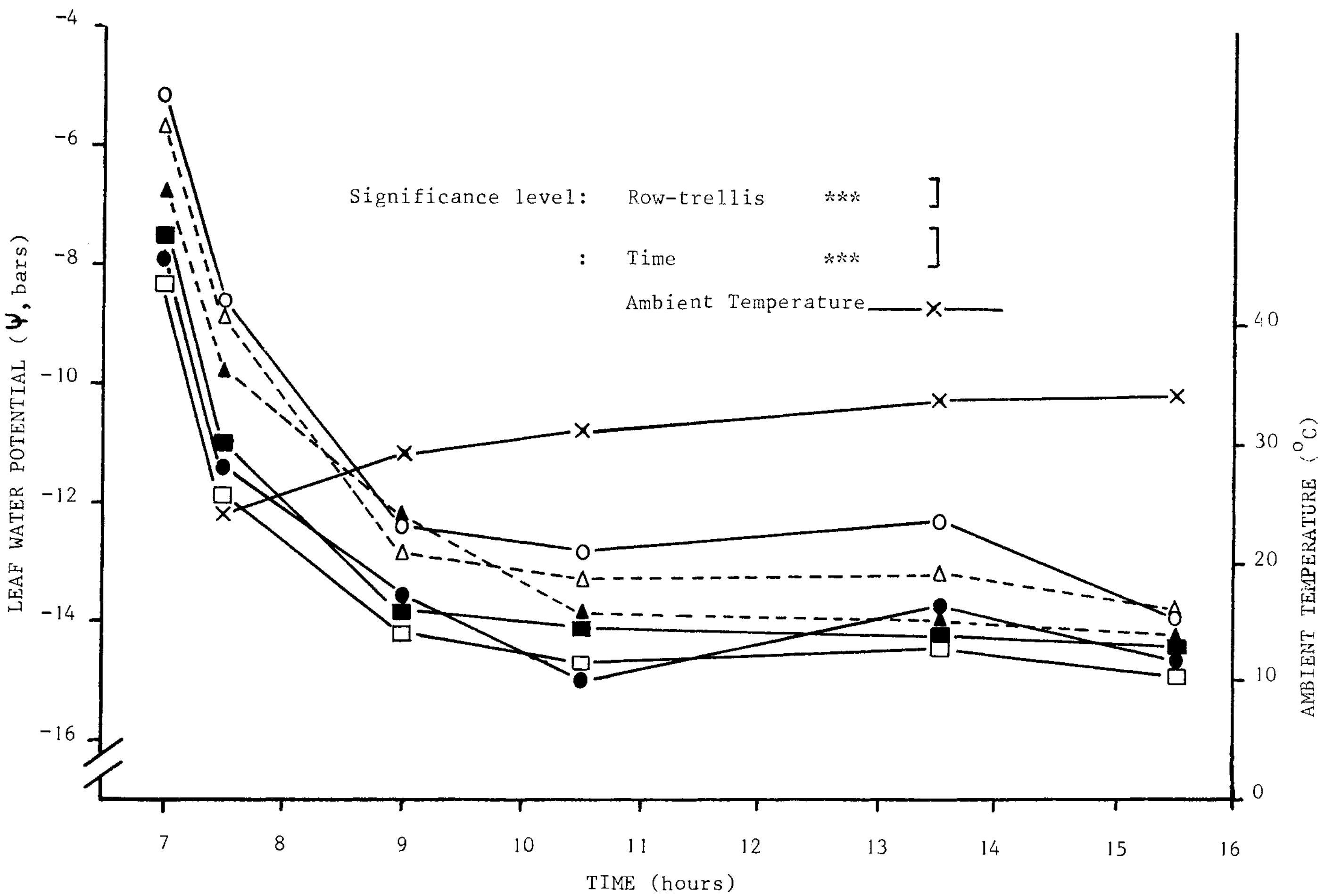

Fig. 12. Diurnal changes in leaf water potential ( ) of vines grown in different row width-trellis treatments as related to ambient temperature and time of day (2.25 m vine spacing; February 1, 1977).

Vine productivity between treatments did not seem to be affected greatly by plant and soil water (6), except for treatment five which suffered from poorer soil conditions. Consistent differences in soil water content between treatments were not obvious and probably reflect irrigation regularity and measurement techniques. As often occurs in this region, leaf water potentials (Fig. 12) of all treatments usually reach the critical value of −13 bars by 10.00 am (17). Indeed, any increased water stress as found in the wide spaced, widely trellised vines did not cause any reduction in cluster weight (Fig. 6) or berry weight. Root distribution studies showed that roots of all vines penetrated into the center of the row or beyond and that density of roots did not vary greatly between treatments.

Shiraz vines have a high light requirement for adequate bud differentiation (5). Our illuminance measurements (Table 3) support the finding of others (9, 10, 14, 15) that node yield is reduced by canopy shading. As found by Shaulis et al (14), increased bud burst (shoots/node left, Fig. 9) rather than increased bud fruitfulness (Fig. 5) was the principal reason for increased node productivity in vine canopies that were less congested. This phenomenon was seen with wider vine spacing but not to a great extent in wider trellised vines.

This experiment showed that close (1.5 or 2.25 m), evenly spaced canopies (treatments 1, 2 and 6) tend to be more productive than widely spaced narrow canopies (treatment 4). With local costs the most profitable system was growing canopies 2.25 m apart as either narrow rows (treatment 2) or wide rows with a wide trellis (treatment 6) with some benefit from using closer intrarow vine spacing. As rows are widened, sufficiently wide trellises are required to reduce canopy bridging, shoot crowding and bud shading. Indeed, it was apparent that canopy separation only occurred with the 2.25 m spaced canopies (treatments 2 and 6). If narrow vine rows were to be used, a vertical canopy arrangement, as suggested by Smart (16), would allow greater light interception than a high horizontal canopy that developed in this trial. Such methods would improve node and shoot productivity while maintaining high shoot numbers per hectare. Vineyard systems which increase canopy surface areas and light penetration are desirable. Whether this is best achieved by narrow vertical walls of foliage grown upwards or pendulous walls of foliage (14) grown downwards (G.D.C.) is to be further investigated.

LITERATURE CITED

1. Antcliff, A. J. A comparison of cropping levels in the Sultana. Vitis. 5:1-9 (1965).

2. Bioletti, F. T., and A. J. Winkler. Density and arrangement of vines. Hilgardia 8:179-95 (1934).

3. Butler, B. E. A soil survey of the horticultural soils in the Murrumbidgee Irrigation Areas, N.S.W., C.S.I.R.O. Bulletin No. 289 (1979). Revised from J. K. Taylor and P. D. Hooper.

4. Buttrose, M. S. Fruitfulness in grapevines: The response of different cultivars to light, temperature and daylength. Vitis 9:121-5 (1970).

5. Buttrose, M. S. Climatic factors and fruitfulness in grapevines. Hort. Abstr. 44:319-26 (1974).

6. Buttrose, M. S. Fruitfulness in grapevines. Effects of water stress. Vitis. 12:299-305 (1974).

7. Hopping, M. E. Effect of light intensity during cane development on subsequent bud break and yield of "Palomino" grapevines. N.Z. J. Exp. Agric. 5:287-90 (1977).

8. Kriedemann, P. E., E. Törökfalvy, and R. E. Smart. Natural occurrence and photosynthetic utilisation of sunflecks by grapevine leaves. Photosynthetica 7:18-27 (1973).

9. May, P. Reducing inflorescence formation by shading individual Sultana buds. Aust. J. Biol. Sci. 18:463-73 (1965).

10. May, P., P. R. Clingeleffer, and P. B. Scholefield. The response of the grape cultivar Crouchen (Australia syn. Clare Riesling) to various trellis and pruning treatments. Aust. J. Agric. Res. 27:845-56 (1976).

11. Peterson, J. R., C. R. Turkington, and J. C. Evans. Pruning and trellising trials with the *Vitis vinifera* cultivars Shiraz and Semillon under irrigated conditions. Aust. J. Exp. Agric. and An. Husb. 14:418-24 (1974).

12. Scholander, P. F., H. T. Hammel, E. D. Bradstreet, and E. A. Hemmingsen. Sap pressure in vascular plants. Science 148:339-46 (1965).

13. Shaulis, N., and K. Kimball. Effect of plant spacing on growth and yield of Concord grapes. Proc. Amer. Soc. Hort. Sci. 66:192-200 (1955).

14. Shaulis, N. J., H. Amberg, and D. Crowe. Response of Concord grapes to light, exposure and Geneva Double Curtain training. Proc. Amer. Soc. Hort. Sci. 89:268-80 (1966).

15. Shaulis, N. J., and P. May. Response of 'Sultana' vines to training on a divided canopy and to shoot crowding. Am. J. Enol. Vitic. 22:215-22 (1971).

16. Smart, R. E. Sunlight interception by vineyards. Am. J. Enol. Vitic. 24:141-7 (1973).

17. Smart, R. E. Aspects of water relations of the grapevine *(Vitis vinifera)*. Am. J. Enol. Vitic. 25:84-91 (1974).

18. Sparks, D., and R. P. Larsen. Effects of shading and leaf area on fruit soluble solids on the Concord grape, *Vitis labrusca*. L. Amer. Soc. Hort. Sci. 89:259-67 (1966).

19. Turkington, C. R., J. R. Peterson, and J. C. Evans. A spacing, trellising and pruning experiment with Muscat Gordo Blanco grapevines. Am. J. Enol. Vitic. 31:298-302 (1980).

20. Wiebe, J., and O. A. Bradt. Fruit yields and quality in the early years of a grape-spacing trial. Can. J. Plant Sci. 53:153-6 (1973).

21. Winkler, A. J. Effect of vine spacing in an unirrigated vineyard on vine physiology, production and wine quality. Am. J. Enol. Vitic. 20:7-15 (1969).

22. Winkler, A. J., J. A. Cook, W. M. Kliewer, and L. A. Lider. General Viticulture. Univ. of Calif. Press (1974).