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BARD

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Integrated Canopy Management Practices for Optimizing Vine Microclimate, Crop Yield, and Quality of Table and Wine Grapes

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Appendix VI

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Title

Integrated canopy management practices for optimizing vine microclimate, crop yield and quality of table and wine grapes.

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ABSTRACT

Five grapevine field experiments with cultivars 'Cabernet Sauvignon,' 'Chardonnay,' 'Sauvignon blanc,' and 'Chenin blanc' were conducted at Oakville and Davis, California between 1986 and 1990 using various combinations of trellis-training systems (GDC, 'U', Vertical), shoot positioning, leaf removal in the fruiting zone, pruning level, and row spacing as treatment variables. Canopy microclimate, crop yield, vine growth, fruit composition, and wine quality of each experiment were evaluated. Leaf removal in the fruiting zone, vertical shoot positioning, and dividing canopies into two separate curtains, or walls of foliage, were highly effective in increasing photosynthetic photon fluence rate (PPFR), sunflecks, red/far red (R:FR) light ratio, and evaporative potential. Each of these canopy management practices generally increased vine productivity, reduced Botrytis bunch rot, and in mature fruits, increased the level of sugar, anthocyanin (red varieties), total phenols, and reduced pH, titratable acidity (TA), malate and potassium. All treatments that improved exposure of fruits to PPFR generally increased wine quality. Shoots trained to grow downward grew at a slower rate, developed smaller and fewer primary and lateral leaves, and had lower cane dry weight density than shoot trained to grow upward or horizontally. Canopies with evaporative potential (as measured with atmometers) in the fruiting zone of 60% of ambient or greater, generally did not develop any bunch rot. Cabernet Sauvignon vines planted at 2 x 2.4 m vine x row spacing, pruned to 60 nodes/vine and trained on a GDC trellis averaged 32.9 tons/hc compared to control vines (2 x 3.6 m vine spacing, 24 nodes/vine, and 2-wire vertical trellis) that averaged 12.2 tons/hc over a period of four years with no significant differences in wine quality. In a glasshouse experiment, exposure of naturally shaded Cabernet franc fruit to red light advanced the beginning of ripening, increased the level of sugars and anthocyanin in fruits, and enhanced the activity of phenylalanine ammonia lyase, of five invertase and nitrate reductase enzymes compared to fruits receiving no supplemental red light.

D. OBJECTIVES OF THE RESEARCH

The objectives are as follows: 1) To determine the effects of different trellis-training systems, either alone or in various combinations with pruning method and level, shoot positioning, and vine spacing on vine growth, crop yield, components of crop yield, and on composition of fruit and wine in both cool and warm climatic regions. 2) To determine how trellis-training systems and combinations of these systems with other cultural practices influence canopy microclimate. 3) To correlate canopy microclimate (air, leaf and fruit temperatures, and photon fluence rate and light intensities) with fruit bud differentiation, vine growth, crop yield, and composition of fruit and wines. 4) To use Sequential Yield Component Analysis (SYCA) to identify important yield components at several experimental sites and to describe the mode of action of treatments, such as trellising, vine density, training, and pruning upon growth and yield relations. 5) To determine the effects of mechanical pruning compared to various levels of hand pruning of vines trained on different types of trellis systems and grown under a range of vine densities. 6) To determine the optimum vine form and canopy architecture for production of table grapes in hot regions under "normal" field conditions. 7) To determine the optimum vine form, density and training system for maximal production of high quality table grapes in greenhouses, PVC plastic tunnels and for small, highly intensified plots under outdoor conditions.

C. **BODY OF REPORT**

I. Scientific Published Papers:

Three scientific reviewed papers have been published and are included in this Final Report. The three published reports are as follows:

1. Kliewer, W. M., J. J. Marois, A. M. Bledsoe, S. P. Smit, M. J. Benz, and O. Silvestroni. Relative effectiveness of leaf removal, shoot positioning, and trellising for improving winegrape composition. In, Proceedings Second International Cool Climate Viticulture and Oenology Symposium. R. E. Smart, R. J. Thornton, S. B. Rodriguez, and J. E. Young (Eds), January 11-15, 1988, Auckland, New Zealand, pp. 123-126 (1988).

2. Kliewer, W. M., P. Bowen, and M. Benz. Influence of shoot orientation on growth and yield development in Cabernet Sauvignon. American Journal of Enology and Viticulture 40:259-264 (1989).

3. Kliewer, W. M. and R. E. Smart. Canopy manipulation for optimizing vine microclimate, crop yield, and composition of grapes. In, Manipulation of Fruiting. C. J. Wright (Ed.), Butterworths, London, pp. 275-291 (1989).

In addition to the three published reports listed above, three other major field experiments were completed between 1987 and 1990 in California, and titled as follows:

1. Trellising, row spacing, and pruning level effects on the performance of Cabernet Sauvignon grapevines at Oakville, California.

2. Trellising and shoot positioning/hedging effects on performance of Chardonnay, Sauvignon blanc, and Cabernet Sauvignon at Oakville, California.

3. Effects of trellising, shoot positioning and leaf removal on canopy characteristics, microclimate, yield, and fruit composition of Chenin blanc grapevines grown at Davis, California.

The findings of each of these three experiments will be reported individually. Unless otherwise stated, all data from each of the three experiments are the mean of four years, 1987 to 1990.

II. TRELLISING, ROW SPACING AND PRUNING EFFECTS ON THE PERFORMANCE OF CABERNET SAUVIGNON GRAPEVINES AT OAKVILLE, CALIFORNIA

1. Materials and Methods

In 1981, 3024 Cabernet Sauvignon vines grafted onto AXR#1 were planted at the South Oakville Experimental Vineyard on Bale gravelly dry loam soil in a double split plot design (72 rows with 42 vines per row, each vine planted seven feet apart within the row) with the main treatment row spacing (8, 10, and 12 feet) and these in turn split for trellis system (two-wire Vertical and two-wire Geneva Double Curtain with the wires located 72 inches from the ground on a crossarm 48 inches apart) and these in turn split again for pruning level (24, 36, 48, and 60 buds per vine). All vines were cordon trained and spur pruned to two node spurs. The row spacing was laid out in groups of four rows with the two center rows used for data collection. Each treatment was replicated six times with six data vines per replicate. The vines were drip irrigated as needed. An example of the field plot layout is shown in Figure 1. Crop yields, yield components, fruit composition, vine growth, and canopy microclimate of all treatments were evaluated as described previously (Kliewer). Wines of several treatments were made by the Department of Viticulture and Enology, at the U. C. Davis experimental winery and evaluated by the Department's taste panel using a 20 point scoring system and duo-trio taste comparisons.

2. <u>Results</u>

The effects of three row spacings (2.4, 3.0, and 3.6 m) in combination with two trellis systems [Single Canopy Bilateral Cordon (BC) and Divided Canopy Quadrilateral Cordon (QC)] on shoot growth, crop yield and composition of Cabernet Sauvignon grown at Oakville, CA., was studied over a period of four years (1987 - 1990). QC vines averaged 22.0 mt/ha compared to 18.9 for BC vines; the increase in yield was due to greater number of shoots and clusters per vine (Tables 1 and 4). At harvest (22.5°Brix) QC fruits had lower pH and higher anthocyanin than BC fruits (Table 1 and Figure 1). TA, malic acid and K did not differ significantly between trellis systems. QC vines had less pruning weight and higher yield/pruning weight ratio than BC vines (Tables 1 and 2). Reducing row spacing from 3.6 m to 2.4 m increased crop yield by 33% and 6 mt/ha, but reduced pruning weight per vine from 3.4 to 2.6 kg (Tables 3 and 5). Row spacing had no significant effect on fruit composition except TA was slightly lower at 2.4 m spacing than at the two wider spacings (Table 3). QC vines had more shoots, but of small length and less leaf area per shoot than BC vines (Table 2). The canopy density of QC trellised vines was significantly less than BC trellised vines. QC vines had significantly less pruning weight per vine and per cane, shorter shoots, fewer leaves per shoot and less primary and lateral leaf area per shoot (Table 2). Row width was directly related to shoot number per vine and inversely related to weight per shoot (Table 5).

Increasing the pruning level from 24 to 60 buds per vine increased crop yield from 6.6 tons/acre to 11.0 tons/acre (Table 6). Increasing the number of buds per vine from 24 or 36 to 60 resulted in a seven to ten day delay in ripening to reach the same level of °Brix (22.5). At harvest, fruits from vines pruned to 48 and 60 buds/vine had <u>lower</u> pH, TA, malic acid and potassium and <u>higher</u> anthocyanin than vines pruned to 24 and 36 buds per vine (Table 6). Dividing the canopy into two curtains of foliage, reducing the distance between rows from 12 feet to 8 feet and increasing the number of buds per vine from 24 to 60 all reduced average shoot length, shoot weight, pruning weight per vine and the primary and lateral leaf area per vine (Tables 2, 5, and 7). Each of these practices increased the cropping efficiency or the amount of fruit produced per unit weight of pruning (Tables 1, 3, and 6).

Sensory analysis revealed QC wines could be distinguished from BC wines (Table 8). Sensory analysis was not able to distinguish between low crop (pruned to 24 buds/vine) and high crop (pruned to 60 buds/vine) [Table 8].

3. <u>Conclusions</u>

The main conclusions from a four-year study of trellising, row spacing and pruning level of Cabernet Sauvignon at the Oakville Experimental Vineyard are as follows:

1. Reducing row spacing from 12 feet to 8 feet increased crop yield by 35% or 2.8 tons/acre with little or no significant difference in fruit composition.

2. At each of the three row spacings, QC trellised vines produced approximately two tons/acre higher yield than BC trellised vines averaged over a period of four years.

3. At the same level of °Brix at harvest, QC fruit had lower pH and higher levels of anthocyanins than BC fruit.

4. The higher level of anthocyanins in QC fruits than BC fruits were correlated to greater amount of photosynthetic active radiation in the fruiting region of the former treatment.

5. Increasing the pruning level from 24 to 60 buds/vine increased crop yield from 6.6 tons/acre to 11.0 tons/acre.

6. With increase in the number of buds per vine from 36 to 60 there was an average of seven to ten days delay in ripening.

7. At harvest, fruits from vines pruned to 48 and 60 buds/vine had <u>lower</u> pH, TA, malic acid and K and <u>higher</u> anthocyanin than vines pruned to 24 and 36 buds/vine.

8. Dividing the canopy, reducing distance between rows, and increasing the number of buds per vine all <u>reduced</u> shoot length, shoot weight, pruning weight per vine, and primary and lateral leaf area per shoot and <u>increased</u> the cropping efficiency.

9. The canopy density of QC trellised vines was significantly less than BC trellised vines.

10. Sensory analysis showed that BC wines could be distinguished from QC wines.

11. Sensory analysis could not distinguish between low crop wines (24 buds/vine) and high crop wines (60 buds/vine).

III. TRELLISING AND SHOOT POSITIONING/HEDGING EFFECTS ON PERFORMANCE OF CHARDONNAY, SAUVIGNON BLANC, AND CABERNET SAUVIGNON AT OAKVILLE, CALIFORNIA.

1. <u>Materials and Methods</u>

In 1982, a trellising-shoot positioning experiment with Cabernet Sauvignon, Chardonnay and Sauvignon blanc was planted at the Oakville North Vineyard on AXR#1 rootstock. For each cultivar there were five trellis systems with the horizontal distance between cordon branches the main variable. A bilateral two-wire vertical cordon trellis served as the control and was compared with four quadrilateral cordon trellis systems in which the distance between cordon branches was one, two, three, or four feet. The fruiting wire of each five trellis systems was 42 inches from the ground. Each of the four quadrilateral trellis systems were with or without two pairs of movable foliage catch wires to facilitate vertical shoot positioning, making a total of ten treatments, each treatment replicated six times with four vines per treatment in a randomized complete block design. The vines vertically shoot positioned were also shoot trimmed to about 15 nodes; both operations were done within ten days after fruit-set. The vines of all ten treatments were spur pruned to 40 nodes per vine and all shoots on wood two years and older were removed shortly after budbreak. The parameters measured were the same as that in Experiment I. The photosynthetic photon flux density (PPFD) was measured in the fruiting region between 1100 and 1300 hours with a sunfleck ceptometer (Decagon Devices, Inc., Pullman, WA). All data are the mean of five years (1986 to 1990), unless otherwise stated.

2. Results

Tables 9 and 11 give the five-year-means (1986 to 1990) of shoot positioning effects on yield, growth and fruit composition of Chardonnay, Sauvignon blanc, and Cabernet Sauvignon grapevines grown at the Oakville Experimental Vineyard. Shoot positioning (SP) was done each year on half the vines at approximately fruit-set and consisted of positioning the shoots of BC one, two, three and four foot wide QC trained vines to grow upward between two pairs of shoot position wires located 12 to 14 inches above the fruiting wires. Shortly following fruit-set, the vines shoot positioned were trimmed (hedged) to about the 15th node.

Shoot positioned Chardonnay, Sauvignon blanc, and Cabernet Sauvignon vines averaged 0.4, 0.4 and 0.2 tons/acre higher yield than non-shoot positioned (NSP) vines over a period of five years (Tables 9 to 11). The increase in yield was mainly due to increase in number of berries set per cluster and higher berry weight. Shoot positioning/hedging significantly reduced the level of total soluble solids in Chardonnay, Sauvignon blanc and Cabernet Sauvignon fruits at harvest by 0.6, 1.3 and 0.7°Brix respectively, compared to NSP fruits (Tables 9 to 11). Shoot positioning also significantly reduced the pH and level of potassium in must at harvest of all three cultivars (Tables 9 to 11) and increased the level of malic acid and TA in Sauvignon blanc and Cabernet Sauvignon must (Tables 9 and 11). Malic acid and TA of SP and NSP Chardonnay fruits at harvest did not differ significantly.

Shoot positioning/hedging reduced the pruning weights and average weight of individual canes by about 15% of all three cultivars (Tables 9 to 11). The lower pruning weight of SP vines was proportional to the amount of growth removed by hedging. The amount of crop produced per unit of pruning weight was significantly greater in SP vines compared to NSP vines (Tables 9 to 11).

Sensory analysis of NSP versus SP Sauvignon blanc wines by duo-trio comparisons showed that SP BC and SP one and two foot wide QC wines were significantly different from NSP wines (Table 12). Shoot positioned and NSP four foot wide QC wines did not differ significantly. Shoot positioned and NSP Chardonnay wines also differed significantly at the 5% level (Table 12).

The data in Tables 13 to 15 show the effects of trellis width or distance between cordon branches on crop yield, yield components and fruit composition of Chardonnay, Sauvignon blanc and Cabernet Sauvignon fruit at harvest averaged over a period of five years.

Chardonnay and Cabernet Sauvignon vines trained to QC trellis systems had significantly higher yield than BC vines, the higher yield being mainly due to increase in the number of clusters per vine (Tables 13 and 15), whereas the yield of Sauvignon blanc vines did not differ significantly between trellis-training systems (Table 14). Vines of all treatments were pruned to 40 nodes and shoot thinned to allow only the shoots from count nodes to grow. The quadrilateral trained vines generally produced more shoots per node, which mainly accounted for the higher number of clusters per vine. The two and three foot wide quadrilateral trained vines generally produced the highest yield at the site this study was conducted at (Figure 3). Cluster weight, berry weight and number of berries set per cluster tended to be less on the quadrilateral systems than on bilateral and one-foot wide QC trained vines.

Fruits of quadrilateral vines of all three varieties at harvest were generally higher in sugar (°Brix) and lower in TA and malic acid than fruit from BC vines (Tables 13 to 15 and Figures 4 and 5). The level of pH and potassium in fruits generally did not differ significantly between trellis width treatments. The pruning weight of BC vines was generally greater than quadrilateral vines, whereas the yield/pruning weight ratio showed the opposite relationship (Tables 13 to 15). This indicates that the QC trained vines were more efficient in producing fruit per unit weight of vegetative growth than BC vines.

The PPFD across the canopy width in the fruiting region of bilateral and one, two, three and four foot QC Sauvignon blanc vines are presented in Figures 6 to 10. In the center of the vine row, above the vine trunk, SP vines had higher amounts of PPFD than NSP vines. There was also an increase in the amount of leaf area fully exposed to sunlight with an increase in trellis width or distance between cordon branches (Figures 6 to 10).

3. Conclusions

The main conclusions from SP are as follows (conclusions are based on five year averages):

1. Shoot positioning/hedging of Chardonnay and Sauvignon blanc increased crop yield by 4 to 5% or 0.4 tons/acre compared to NSP and hedging. Shoot positioning and hedging did not affect the crop yield of Cabernet Sauvignon.

2. Shoot positioning reduced the amount of direct light and increased the amount of indirect light (diffuse light) in the fruiting zone.

3. At harvest, on the same date, SP Chardonnay, Sauvignon blanc and Cabernet Sauvignon fruits were 0.6, 1.3 and 0.7°Brix lower than NSP fruits.

4. The pH and level of potassium of SP fruits were significantly less than NSP fruits of all three cultivars.

5. The level of malic acid and TA of SP Sauvignon blanc and Cabernet Sauvignon fruits were significantly greater than NSP fruits at harvest. Malic acid and TA of SP and NSP Chardonnay fruits at harvest did not differ significantly.

6. Shoot positioning/hedging reduced pruning weights of all cultivars by approximately 15% compared to NSP/hedging.

7. Shoot positioning/hedging significantly increased the cropping efficiency or the amount of crop produced per pound of pruning weight of all cultivars.

8. Sensory analysis of NSP versus SP Sauvignon blanc wines by duo-trio comparisons showed that SP BC and SP one and two foot wide QC wines were significantly different from NSP wines. Shoot positioned and non shoot positioned four foot wide quadrilateral cordon wines did not differ significantly. Shoot positioned and NSP Chardonnay wines were also found to differ significantly at the 5% level.

The main conclusions from the different trellis width treatments were as follows:

1. A distance of two feet or more between cordon branches was necessary to maintain two separate canopies of foliage when vines were shoot positioned.

2. Quadrilateral cordon trained vines yielded 4 to 18% more crop than bilateral trained vines when pruned to the same number of buds per vine at this site of moderate deep soil.

3. Based on crop yield, the optimum cordon width was two to three feet.

4. Quadrilateral cordon trained vines of all three cultivars had greater number of clusters per vine than BC vines pruned to the same number of buds per vine.

5. Berry weight, cluster weight and number of berries per cluster were generally less in quadrilateral vines than in bilateral vines.

6. Fruits from quadrilateral trained vines were generally higher in sugar (°Brix) and lower in TA and malic acid than fruit from bilateral trained vines. The level of pH and potassium in fruits generally did not differ significantly between trellis width treatments.

7. The pruning weight of BC vines was generally greater than quadrilateral vines, whereas the yield/pruning weight ratio showed the opposite relationship.

8. The microclimate in the fruiting region of two, three, and four foot quadrilateral trained vines was superior to bilateral and one foot quadrilateral vines as indicated by higher amounts of photosynthetic light, R:FR light ratio, and evaporative potential.

IV. EFFECTS OF TRELLISING, SHOOT POSITIONING, AND LEAF REMOVAL ON CANOPY CHARACTERISTICS, MICROCLIMATE, YIELD AND FRUIT COMPOSITION OF CHENIN BLANC GRAPEVINES GROWN AT DAVIS, CALIFORNIA.

1. Materials and Methods

A replicated split-split block field experiment was initiated in 1987 on four-year-old Chenin blanc grapevines grafted to AXR#1 rootstock at Davis, CA, with vines planted at 2.1 x

3.3 m vine x-row spacing, oriented in an east-west direction. Three trellis systems comprised the main block (Vertical, GDC, and Lyre), each block split for shoot positioning using movable wires, and these split again for leaf removal in the fruiting region (none, north side, and north and south sides of vine rows), which was done at fruit-set. Figure 11 show diagrams of the trellis-shoot positioning treatments. There were 18 treatment combinations, each treatment replicated four times with seven vines per treatment-replicate. All vines were pruned to 24, two-node spurs, or 48 nodes/vine. Canopy microclimate was evaluated with a sunfleck ceptometer, atmometers, Skye 660 (red/730 far red) light meter, and by point quadrat. Fruit composition parameters measured included °Brix, pH, TA, malic acid, total phenols, arginine and potassium. Crop yield, yield components, primary and lateral leaf area, shoot density and weight, and total pruning weight per vine were also measured. Data were collected for four years (1987 - 1990), except for bunch rot, which was evaluated in 1989 only.

2. <u>Results</u>

The two divided canopy trellis systems (GDC and Lyre), SP and leaf removal in the fruiting region all increased the PPFD, percentage sunflecks, R:FR light ratio, and evaporation potential in the fruiting zone compared to the single canopy Vertical trellis, NSP and no leaf removal (Tables 16 and 17). Crop yield of Vertical, GDC and Lyre trellis systems averaged 37, 45 and 48 mt/hc respectively, the increased yields being mainly due to greater budbreak, number of clusters/vine and larger berry size (Table 18). Shoot positioning decreased crop yield about 10% due to fewer clusters and reduced berry weight, whereas leaf removal had no effect on yield (Tables 21 and 23). Both leaf removal and SP reduced the amount of bunch rot (Table 17). Vertical and GDC trellis systems had less bunch rot than the Lyre trellis (Table 17). The °Brix, pH and K^+ of GDC and Lyre fruits were higher than Vertical trellised fruits measured on the same date, however, when compared at the same °Brix there was no difference in pH and K^+ between trellis systems (Table 19). TA and malic acid were lower in GDC and Lyre fruits than Vertical fruits at harvest (Table 19). Total phenols in skin of GDC fruits were highest, Vertical fruits lowest and Lyre fruit intermediate (Table 20). Shoot positioned fruits at harvest were lower in °Brix, pH, malate and K^+ than NSP fruits (Table 22). Leaf removal did not significantly affect composition of fruits at harvest, except for lower malate, however, there was a trend for higher total phenols and lower pH in leaf removal compared to no leaf removal fruits (Table 24). Dormant pruning weight of Vertical, GDC and Lyre trellised vines, expressed as kg/vine, were 3.4, 2.6, and 3.9 respectively, and expressed as kg/m cordon length were 1.7, 0.65 and 0.97 respectively (Table 18). Leaf removal did not affect vine pruning weights, whereas SP reduced pruning weight, but this resulted from summer pruning (Tables 21 and 23). The amount of primary and lateral shoot growth differed greatly between the three trellis systems. Lateral leaf area as a percent of total leaf area of vertical, GDC and Lyre trellis system was 43.0, 42.6 and 51.3% respectively (Table 25). GDC vines had the greatest number of shoots per vine, but had shorter shoots and smaller internode length, and less leaf area per primary leaf, shoot, and lateral compared to vertical and Lyre vines (Table 25). Total leaf area per GDC shoot was about one-third less than Vertical and Lyre shoots. Shoot density of vertical, GDC and Lyre vines were 28.3, 17.5 and 15.5 shoots/m canopy length. Gamma (leaf area/cm shoot length) of Vertical, GDC and Lyre shoots were 27.5, 18.2 and 26.1 respectively; leaf area (cm^2)/g fruit for the three trellis systems were 5.7, 3.9 and 5.3 respectively. The yield/pruning weight ratio of Vertical, GDC and Lyre trellis vines were 8.6, 13.1 and 9.2 respectively.

Shoot positioned vines had significantly fewer number of primary leaves per shoot, shorter shoot length and internode length than NSP vines (Table 26). Shoot positioned vines also had significantly less lateral leaf area and total leaf area per shoot and per vine than NSP vines. The percentage of total area comprised of lateral leaves was also significantly less in SP than NSP vines (Table 26).

Sensory analysis revealed that SP wines made from Vertical and Lyre trellis systems differed significantly from NSP wines and GDC and Lyre wines also differed from single canopy Vertical trellised wines. Shoot positioned wines were generally less vegetative and more fruity than NSP wines. The same was also true of GDC and Lyre wines compared to Vertical wines. In both cases, the more fruity less vegetative wines were associated with greater amount of light in the fruiting region.

3. Conclusions

The main conclusions drawn from the Chenin blanc SP, leaf removal and trellising trial can be enumerated as follows:

Shoot Positioning Effects:

1. Shoot positioning of Lyre and GDC trellised vines increased PPFD, sunflecks and R:FR ratio and evaporation potential in the fruiting zone, but decreased these parameters in vertical trellised vines.

2. Shoot positioning decreased the amount of Botrytis bunch rot compared to NSP.

3. Shoot positioning decreased crop yield, berry weight, number of clusters/vine and pruning weight compared to vines NSP.

4. Shoot positioning significantly decreased the level of °Brix, pH, malic acid and K^+, and slightly increased TA in fruits at harvest.

5. Shoot positioning significantly decreased average internode length, total lateral leaf area, total leaf area per shoot and per vine, and the percentage of total leaf area comprised by lateral leaves.

6. Sensory analysis revealed SP wines made from Vertical and Lyre trellis systems differed significantly from NSP wines.

Leaf Removal Effects:

1. Leaf removal in the fruiting region improved the canopy microclimate by increasing the PPFD, sunflecks, R:FR ratio, and evaporation potential compared to no leaf removal.

2. Leaf removal had no effect on crop yield, but slightly decreased berry weight when leaf removal was done on both sides of the vine compared to no leaf removal.

3. Leaf removal decreased the level of malic acid in fruit at harvest, but had no effect on °Brix, pH, TA, K^+ and arginine. Total phenols were slightly higher in leaf removed fruit.

4. Leaf removal in the fruiting region significantly reduced the leaf layer number, percentage interior leaves and clusters, and increased canopy gaps compared to no leaf removal.

5. Averaged over all three trellis systems with and without SP, the percentage clusters with bunch rot of no leaf removal, leaf removal on north side only and leaf removal on north and south sides of vines were 5.8, 3.9 and 2.8% respectively.

Trellising Effects:

1. GDC trellised vines had significantly greater PPFD, sunflecks, and R:FR ratios in the fruiting region than Lyre and Vertical trellised vines.

2. Over a period of three years, the average crop yield of Vertical, GDC, and Lyre trellised vines were 37.5, 45.1, and 48.1 mt/hc, respectively. The higher yields of the GDC and Lyre vines were mainly due to increase in the number of shoots and clusters per vine.

3. Lyre trellised fruits had higher °Brix, pH, and K^+ and lower TA and malic acid than GDC and Vertical fruits.

4. TA and malic acid of vertical fruits were significantly greater than Lyre and GDC fruits.

5. The total phenols in the berry skins of GDC fruits were significantly higher than in Vertical and Lyre fruits.

6. Lyre trellised vines had the lowest evaporation potential in the fruiting zone and the highest incidence of Botrytis bunch rot compared to GDC and Vertical trellises. The amount of bunch rot was inversely related to the evaporation potential as measured with Livingston atmometers.

7. Wines made from grapes trained to divided canopy trellis systems (GDC and Lyre) differed significantly from single canopy Vertically trellised wines.

F. DESCRIPTION OF COOPERATION

In both Israel and California, several common vineyard canopy management practices were tried to improve vine productivity, fruit composition and wine quality. These include trellis-training systems, shoot positioning, removal of leaves and laterals in the fruiting zone to improve the canopy microclimate, shoot topping or hedging, vine spacing or density and level of pruning or the number of buds retained per vine. The microclimate of the various canopy management practices were evaluated in both countries and this information was used to help interpret the results. In both countries, similar constituents in the fruits were evaluated for the various treatments imposed. Since climatic and soil conditions in Israel and California differ greatly, the use of similar canopy management practices to improve grapevine productivity, fruit composition and wine quality provides convincing evidence that the practices used in our studies have wide application for use under widely different conditions.

G. MAIN ACHIEVEMENTS OF THE RESEARCH

The effect of three row spacings (2.4, 3.0 and 3.6m) in combination with two trellis systems [Single Canopy Bilateral Cordon (BC) and Divided Canopy Quadrilateral Cordon (QC)] on shoot growth, crop yield and composition of Cabernet Sauvignon grown at Oakville, CA, was studied over a period of five years (1986 - 1990). QC vines averaged 22.0 mt/ha compared to 18.9 for BC vines; the increase in yield was due to greater number of shoots and clusters per vine. At harvest (22.5°Brix) QC fruits had lower pH and higher anthocyanin than BC fruits. Titratable acidity, malic acid and K did not differ significantly between trellis systems. QC vines had less pruning weight and higher yield/pruning weight ratio than BC vines. Reducing row spacing from 3.4 to 2.6 kg. Row spacing had no significant effect on fruit composition except TA was slightly lower to 2.4 m spacing than at the two wider spacings. QC vines had more shoots but of small length and less leaf area per shoot than BC vines. Row width was directly related to shoot number per vine and inversely related to weight per shoot.

Increasing the pruning level from 24 to 60 buds/vine increased crop yield by 67% or approximately 10 tons/ha. With an increase in bud number per vine from 24 or 36 to 60 there was an average of seven to ten days delay in ripening. At harvest, fruits from vines pruned to 48 and 60 buds/vine had lower pH, TA, malic acid, and K and higher anthocyanin than vines pruned to 24 or 36 buds/vine.

Dividing the canopy into two distinct curtains of foliage, reducing the distance between rows and increasing the number of buds per vine all <u>reduced</u> shoot length, shoot weight, pruning weight per vine, and primary and lateral leaf area per shoot and <u>increased</u> the cropping efficiency or amount of crop produced per unit of pruning weight.

Sensory analysis revealed QC wines could be distinguished from BC wines, but could not distinguish between wines made from vines pruned to different severities, i.e., 24 to 60 buds/vine.

From 1987 to 1990, a replicated field experiment was conducted with Cabernet Sauvignon at Oakville, CA, to study the effects of shoot density and crop load on fruit composition, vine growth and light microclimate of BC and QC trained vines. The treatments consisted of five shoot densities averaging from two to ten cm distance between shoots, each at 80 clusters per vine, and five crop loads ranging from 34 to 190 clusters per vine at a constant shoot density of approximately three cm/shoot. Shoot density at constant crop load had relatively little affect on fruit composition but considerably affected the partitioning of vegetative growth between primary and lateral shoot development. Low shoot density (one shoot per eight cm canopy length or less) produced proportionally much more lateral leaf area per shoot than high shoot density (one shoot per five cm or more). Variation in crop load at constant shoot density produced large effects on fruit composition. Increased crop load decreased °Brix, pH and K in fruit. There was a significant interaction between trellising and shoot density on malate concentration with malic acid inversely correlated to photosynthetic active radiation in the fruiting region. High shoot number per vine was more effective in reducing the amount of lateral shoot growth than high crop load.

A field experiment was conducted at Davis, CA, to determine the influence of orientation of shoot growth on the growth characteristics of Cabernet Sauvignon grapevines. Shoots on 14 different mature vines were trained to grow upward, horizontally and downward, beginning shortly after budbreak. The plastochron index and leaf initiation rate of each shoot were determined at four day intervals until they reached a plastochron index of 19. Vine pruning weight and time of budbreak were related to shoot growth rate and were thus used as covariates for testing the effects of growth direction. Downward trained shoots exhibited a lower leaf initiation rate and shoot extension rate, and developed smaller primary leaves, fewer lateral leaves, and a lower cane dry weight density than did upward or horizontal shoots. The period from budbreak to bloom for downward shoots averaged 2.3 days less than that for upward trained shoots. At veraison, °Brix of fruits from upward trained shoots was significantly higher than that for downward shoots. Percent fruit-set did not differ between upward and downward shoots, but was significantly lower for horizontal shoots. The number of berries per shoot, however, did not differ among growth direction treatments.

In greenhouse and field experiments with Cabernet Sauvignon grapevines, both light quality R:FR light ratio and quantity PPFR effects on fruit composition and ripening of grapes were found. Exposure of dense naturally shaded grape clusters (R:FR ratio < 0.1) to supplemental red light that increased the R:FR ratio to 0.6 to 0.7 without significantly changing the PPFR, advanced the beginning of fruit ripening by seven to ten days, markedly enhanced berry weight and levels of sugar and anthocyanin in fruits and increased the activities of PAL, invertaes and nitrate reductase enzymes. Exposure of fruits to full sunlight, high levels of PPFR ($> 300\ \mu Em^{-2}s^{-1}$) and R:FR ratio (~ 0.70) further increased sugar and anthocyanin formation and activity of the three enzymes above that of fruits exposed to low PPFR ($< 50\ \mu Em^{-2}s^{-1}$) but with R:FR ratios similar to exposed fruit. These findings indicate that both phytochrome and photosynthesis influence fruit composition and ripening of grapes.

Leaf removal in the cluster zone, as well as canopy division by trellising, greatly improved the canopy microclimate, especially the PPFR and R:FR ratio in the cluster region. Closely associated with these microclimate changes were increased levels of sugar in fruits and reduction in TA, pH, malate and potassium in berry juice, all generally considered positive for high wine quality. Trellis systems that reduced interior canopy shading also had the added advantage of increasing crop yield, mainly through increase in development of shoots from basal buds that increased the number of clusters per vine as well as greater number of berries per cluster. Canopy division by trellising was an effective means of maintaining a desirable microclimate for high shoot numbers per hectare and producing high crop yield of quality fruit.

A replicated field experiment with Chardonnay, Cabernet Sauvignon and Sauvignon blanc grapevines was conducted at Oakville, CA, from 1986 to 1990 to test the effectiveness of Vertical SP as a means of improving canopy microclimate, fruit composition and wine quality. Data obtained from 1987 to 1990 revealed that SP canopies received mainly diffused light in the fruiting region as opposed to direct sunlight in NSP vines. Light quality of SP fruits was improved due to higher R:FR light ratios compared to NSP fruits. Shoot positioned fruits of both cultivars had significantly less sunburn damage than NSP fruits. Crop yields of SP Sauvignon blanc and Chardonnay vines averaged 0.7 and 0.5 tons/acre higher, respectively, than NSP vines. Shoot positioned fruits at harvest were lower in sugar, pH and potassium and higher in TA and malate. Taste panel evaluation of wines showed that SP and NSP wines could usually be distinguished. The reduction in fruit maturity by SP was due to both crowding of shoots closer together, i.e., reduction of exposed leaf area and promotion of lateral shoot growth stimulated by topping.

A split-block field experiment at Davis, CA, using Chenin blanc grapevines was conducted from 1988 to 1990 to investigate the effects of three trellis systems [Geneva Double Curtain

(GDC), 'U', and Scott-Henry (SH)], each with or without SP, and each of these in turn with three levels of leaf removal on canopy microclimate and on the amount of bunch rot that was present at harvest. The microclimate parameters evaluated within the fruiting zone were PPFD, percentage sunflecks, R:FR light ratio, cluster temperature and evaporation potential. GDC trellised vines had significantly greater PPFD, sunflecks, and R:FR ratio than 'U' and SH trellised vines. 'U'-trellised vines had the lowest evaporative potential and the highest incidence of Botrytis bunch rot of the three trellis systems. Shoot positioning of 'U' and GDC trellised vines increased the amount of PPFD, sunflecks and R:FR ratios in the fruiting zone, but decreased these parameters in SH trellised vines. Shoot positioning generally decreased the amount of bunch rot and increased the evaporation potential in the fruiting zone compared to NSP. Leaf removal in the fruiting region also improved the canopy microclimate by increasing the PPFD, percentage sunflecks, R:FR ratios and evaporation potential and decreased the incidence of bunch rot compared to no leaf removal. The GDC and 'U'-trellised vines had 30 to 40% higher crop yield than SH trellised vines, without any reduction in the level of sugar in the fruits harvested on the same date. Leaf removal had no effect on crop yield whereas shoot positioning reduced crop yield about 11%.

H. LIST OF PUBLICATIONS

1. KLIEWER, W.M., J. J. Marois, A. M. Bledsoe, S. P. Smit, M. J. Benz and O. Silvestroni. (1988). Relative effectiveness of leaf removal, shoot positioning and trellising for improving wine grape composition. In, R. E. Smart, R. J. Thornton, S. B. Rodriguez, and J. E. Young (Eds.) Proceedings of the Second International Symposium for Cool Climate Viticulture and Oenology, 11-15 January 1988, Auckland, New Zealand, pp. 123-126.

2. TIZIO-MAYER, C. R. (1988). Effect of width of cordon separation and shoot positioning on growth, yield and fruit quality of Sauvignon blanc, Chardonnay and Cabernet Sauvignon grapevines. M.S. Thesis, University of California, Davis, 160 p.

3. JOHNSON, R. A. (1988). The effect of trellis system, pruning level, and row spacing on yield, yield components and fruit composition of Cabernet Sauvignon grapes. M.S. Thesis, University of California, Davis, 88 p.

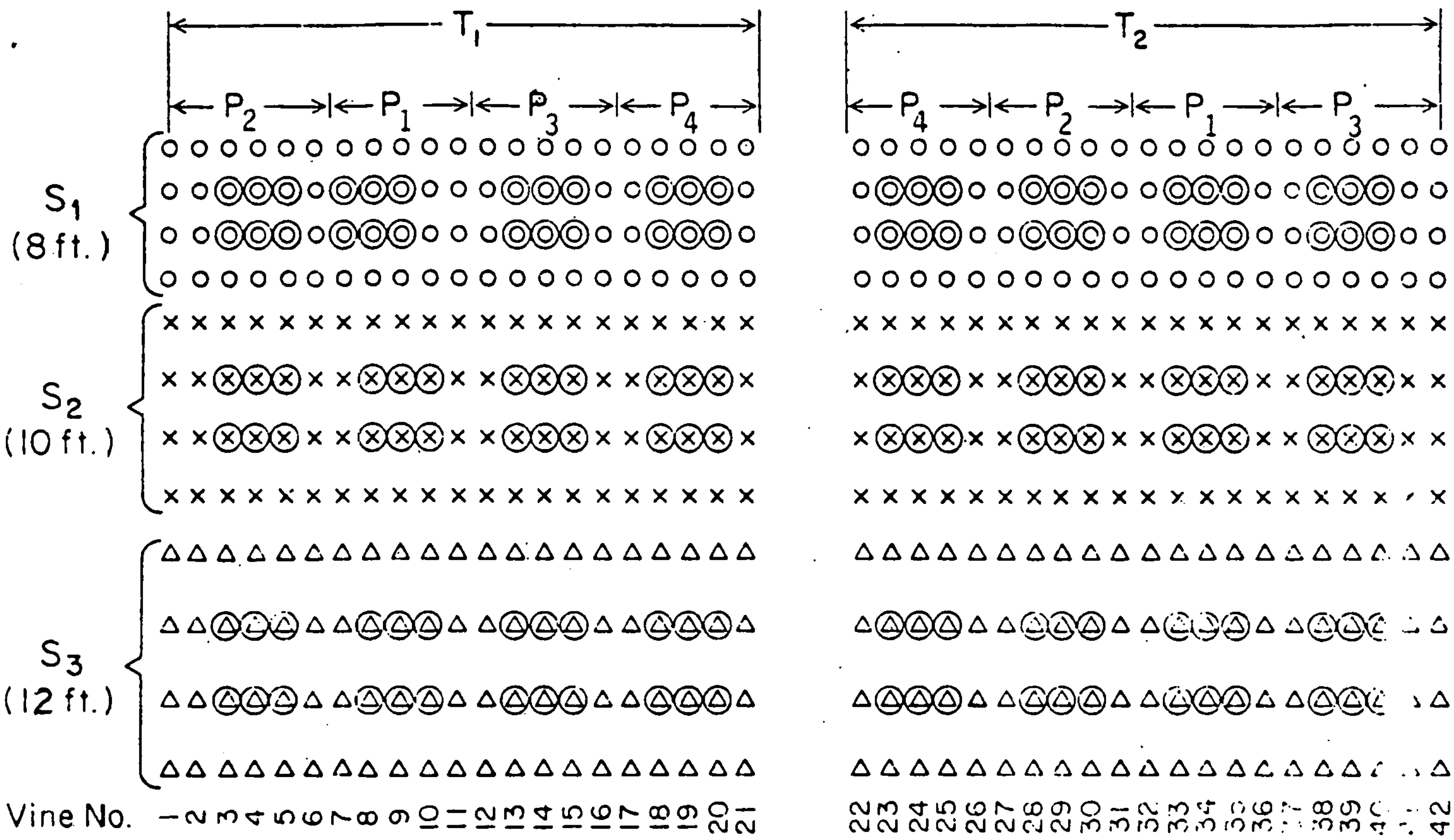
4. SMIT, S.P. (1988). The effects of leaf removal on canopy microclimate, crop yield, and composition of juice and wine of several grape cultivars. M.S. Thesis, University of California, Davis, 64 p.

5. KLIEWER, W. M., P. A. Bowen, and M. J. Benz. (1989). Influence of shoot orientation on growth and yield development in Cabernet Sauvignon. Am. J. Enol. Vitic. 40:259-264.

6. KLIEWER, W. M., and R. E. Smart. (1989). Canopy manipulation for optimizing vine microclimate, crop yield and composition of grapes. In, C. J. Wright (Ed) Manipulation of fruiting. Butterworths, London, pp. 275-291.

FIGURE 1

One of six blocks from the Oakville Cabernet Sauvignon pruning level, trellising, row spacing trial.



Treatments:

Main Plots:

Row Spacing: 8 ft. (S_1), 10 ft. (S_2), 12 ft. (S_3)

Trellising: T_1 (Single Curtain, 2-wire vertical); T_2 (Double Curtain, 2-wires 1.2 m apart)

Split Plots:

Pruning Level: P_1 (12, 2-node spurs), P_2 (24, 2-node spurs) P_3 (48, 2-node spurs), P_4 (96, 2-node spurs)

FIGURE 2

Anthocyanin versus pruning weight - 1990 Oakville Block-N Cabernet Sauvignon

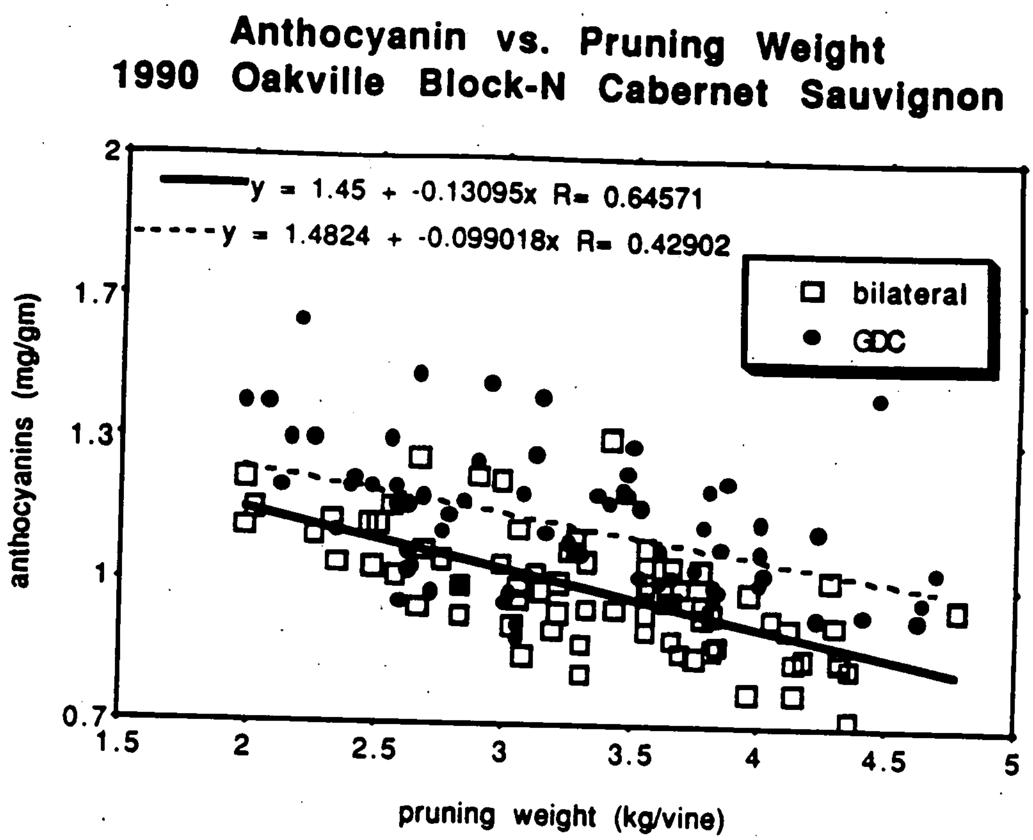
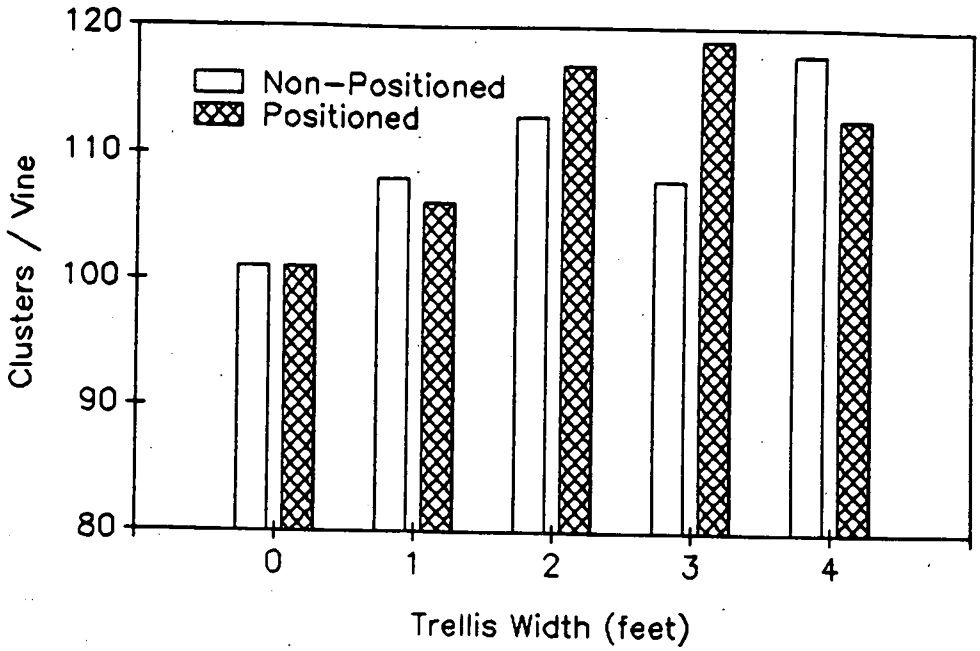


FIGURE 3

1986 - 1990 Sauvignon blanc effect of shoot positioning and trellis width (Oakville, CA)



Crop Yield

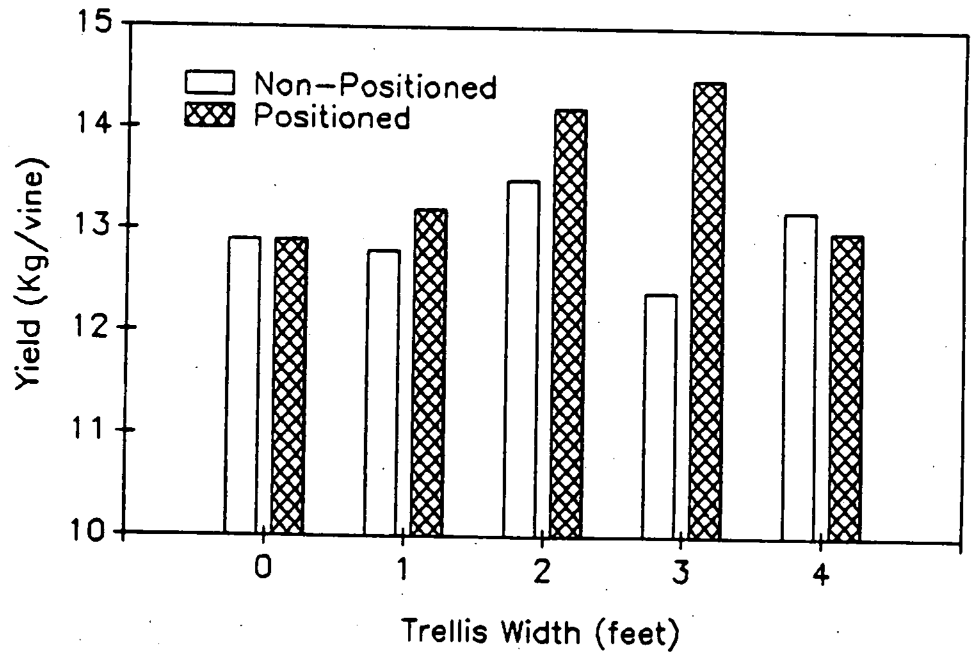
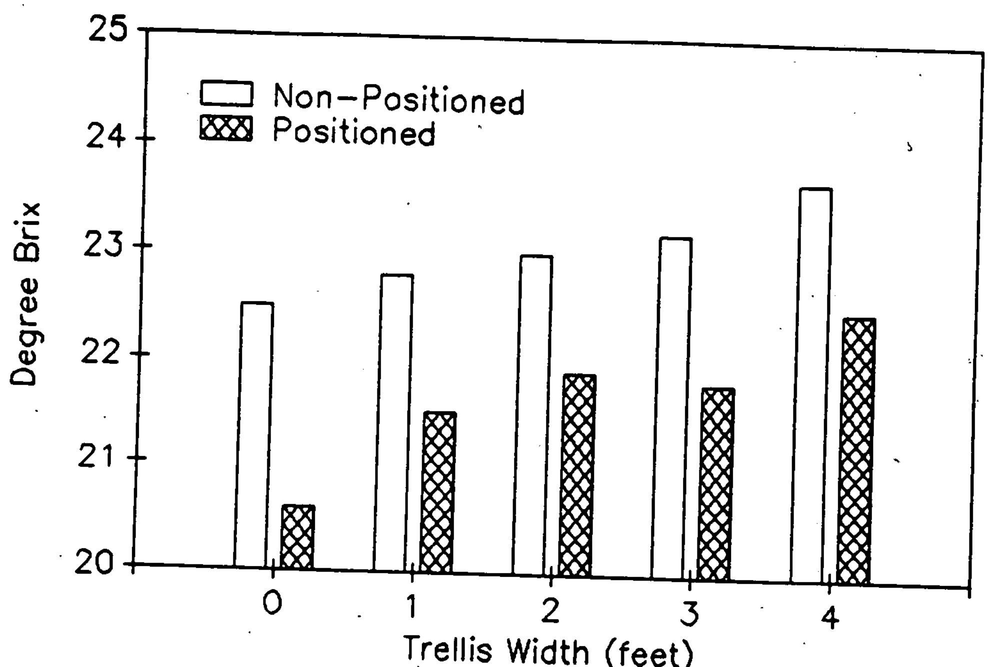


FIGURE 4

1986 - 1990 Sauvignon blanc effect of shoot positioning and trellis width (Oakville, CA)



pH at Last Intact Sample Date

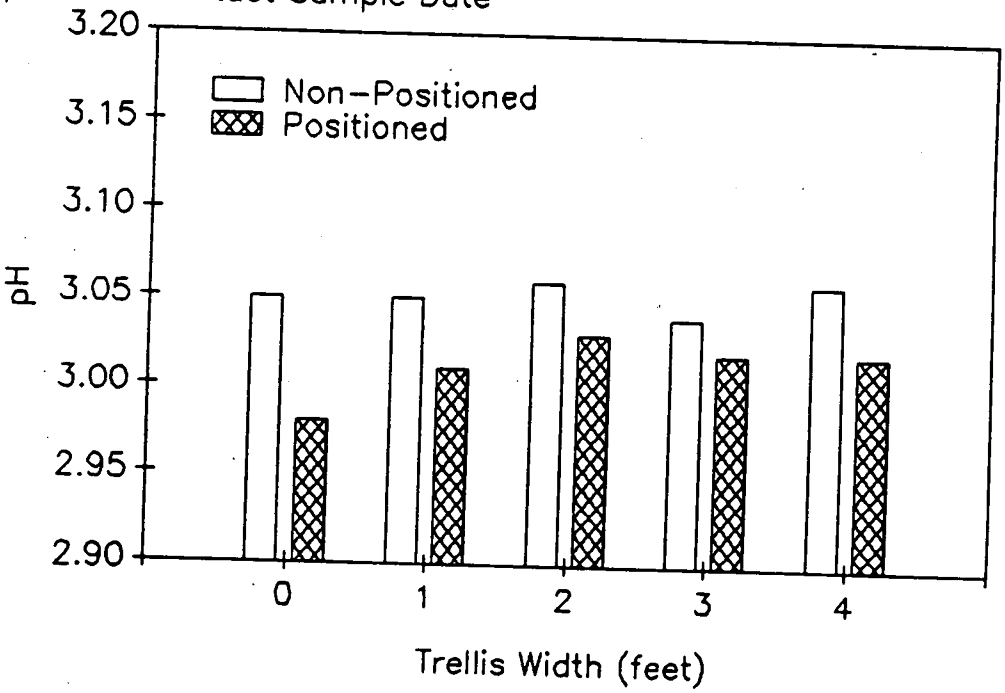


FIGURE 5

1986 - 1990 Sauvignon blanc effect of shoot positioning and trellis width (Oakville, CA)

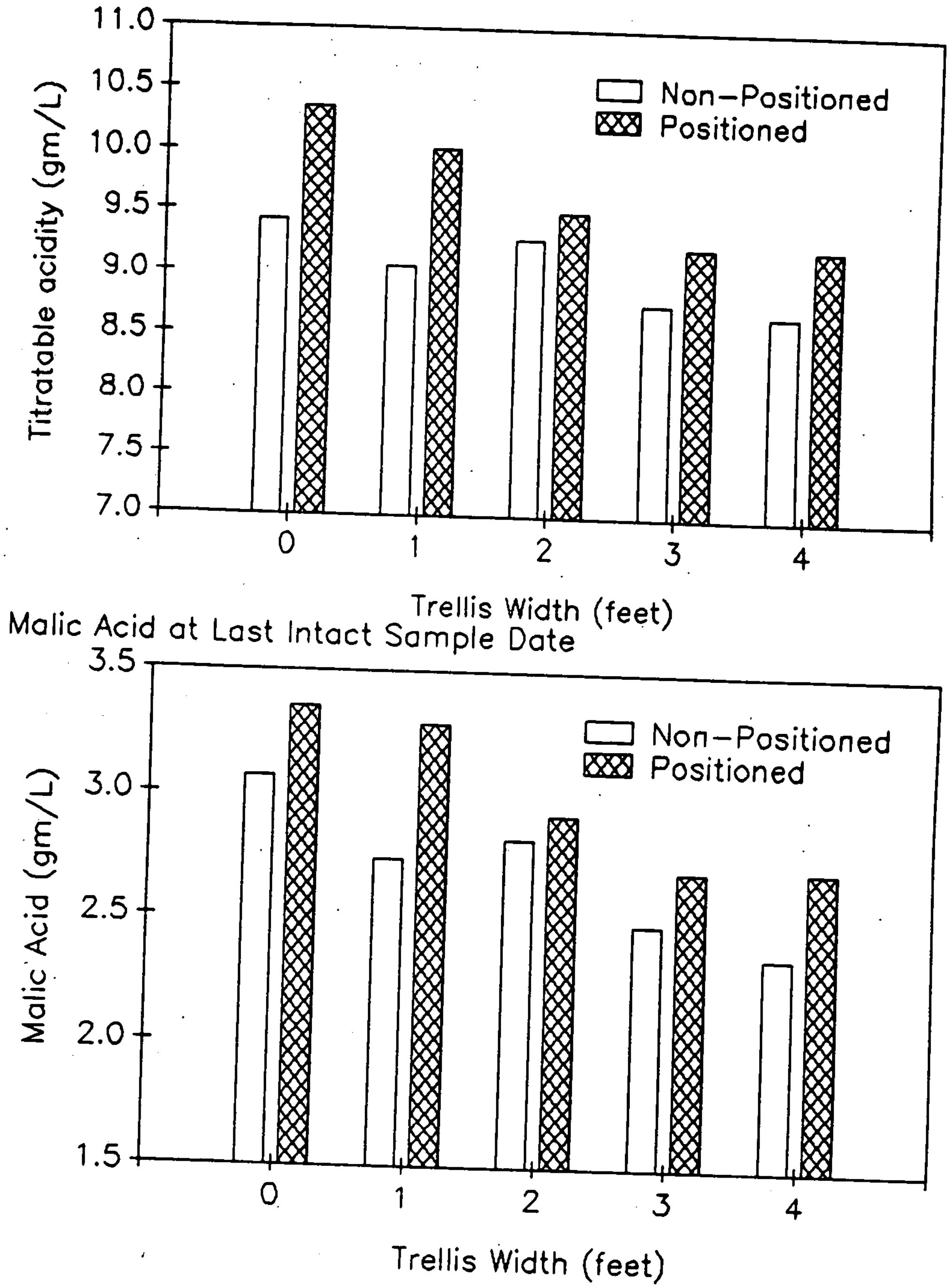


FIGURE 6

Average level of PPFD across the canopy width in the fruiting region of bilateral cordon SP and NSP Sauvignon blanc grapevines grown at Oakville, CA, and measured at the veraison stage of fruit development. Light measurements were made perpendicular to the vine row between 1100 and 1300 hours with a ceptometer. Each point is the mean of 96 light readings. Zero width indicates the center of the vine row.

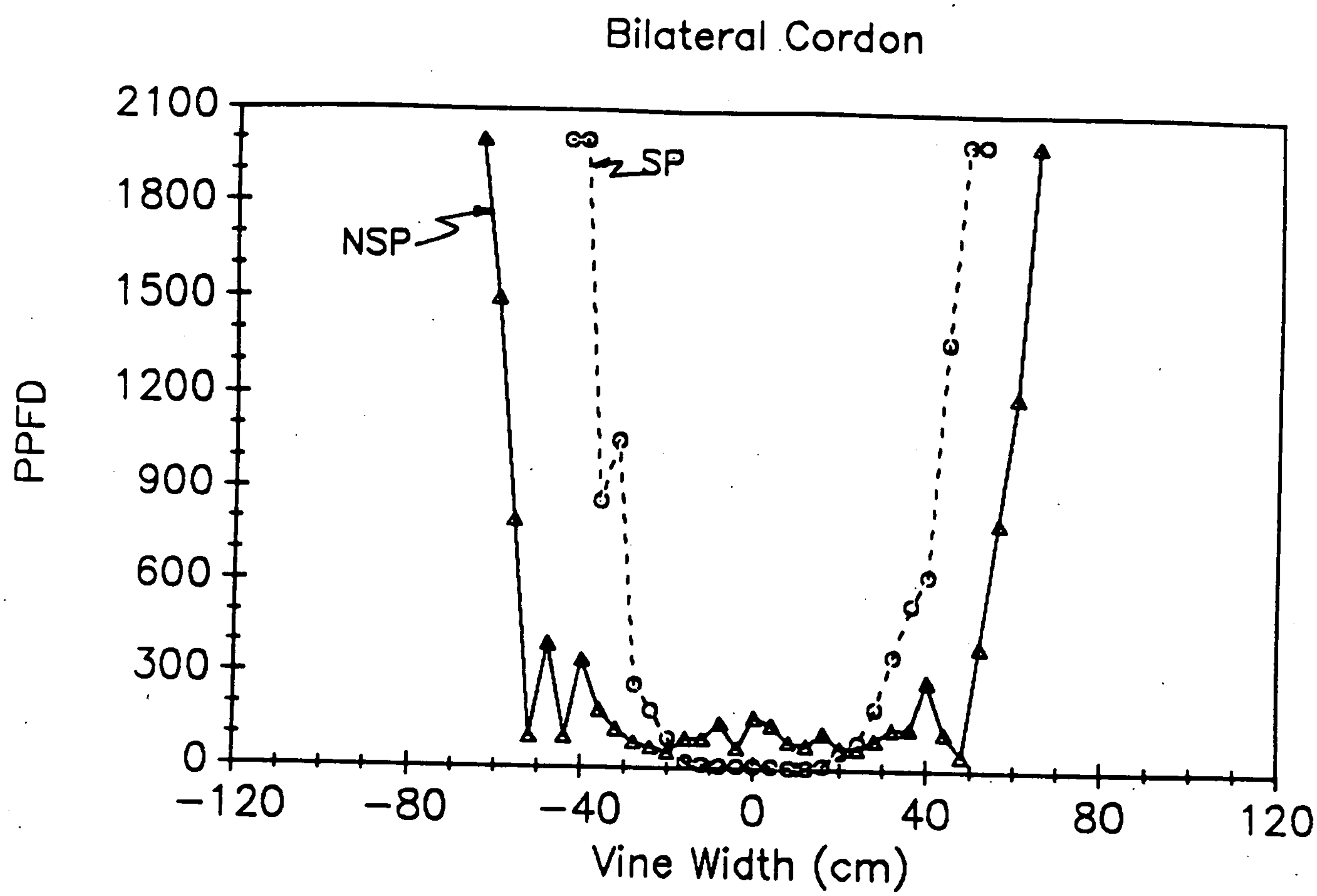


FIGURE 7

Average level of PPFD across the canopy width in the fruiting region of one foot Quadrilateral Cordon SP and NSP Sauvignon blanc grapevines grown at Oakville, CA, and measured at the veraison stage of fruit development. Light measurements were made perpendicular to the vine row between 1100 and 1300 hours with a ceptometer. Each point is the mean of 96 light readings. Zero width indicates the center of the vine row.

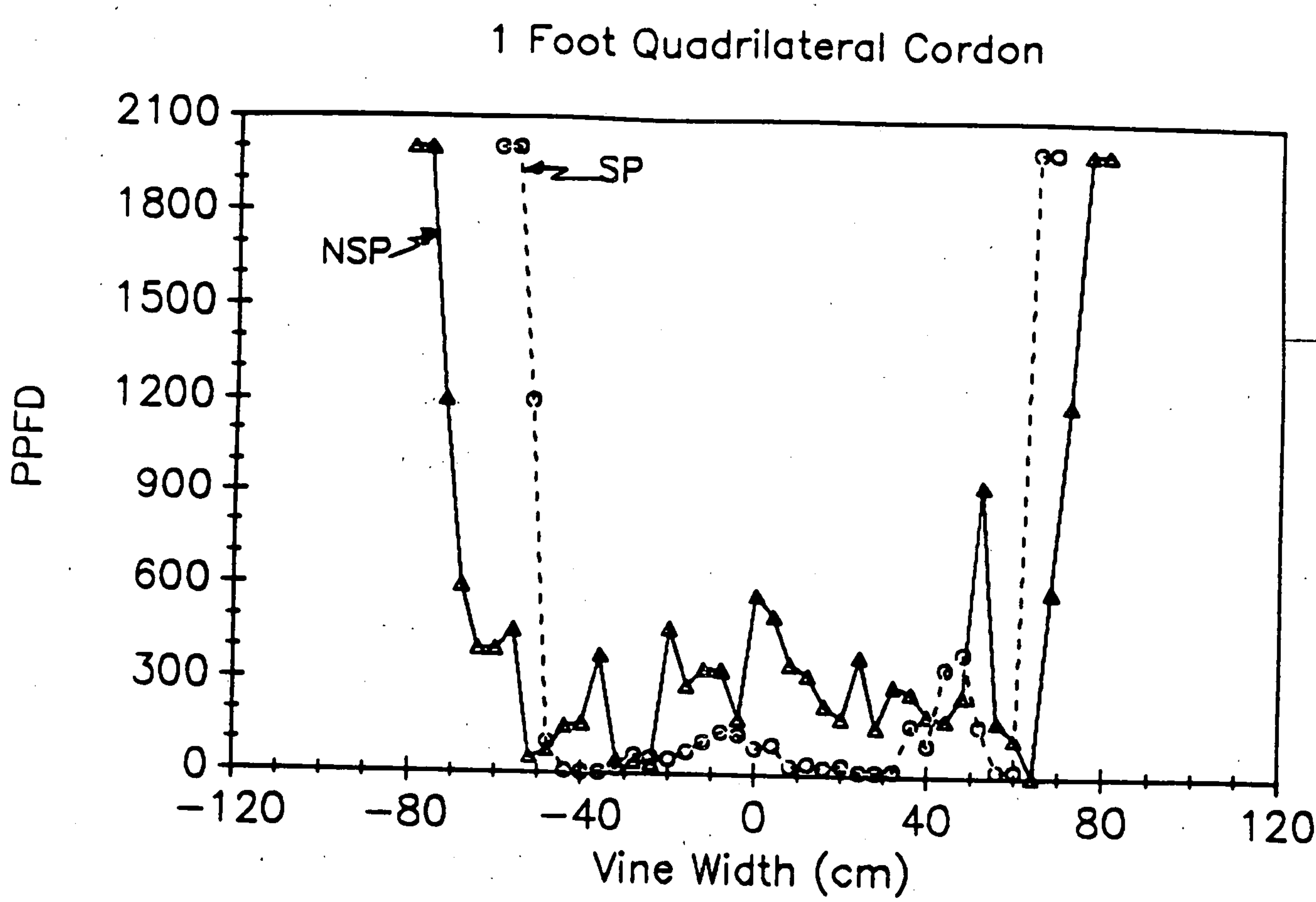


FIGURE 8

Average level of PPFD across the canopy width in the fruiting region of two foot Quadrilateral Cordon SP and NSP Sauvignon blanc grapevines grown at Oakville, CA, and measured at the veraison stage of fruit development. Light measurements were made perpendicular to the vine row between 1100 and 1300 hours with a ceptometer. Each point is the mean of 96 light readings. Zero width indicates the center of the vine row.

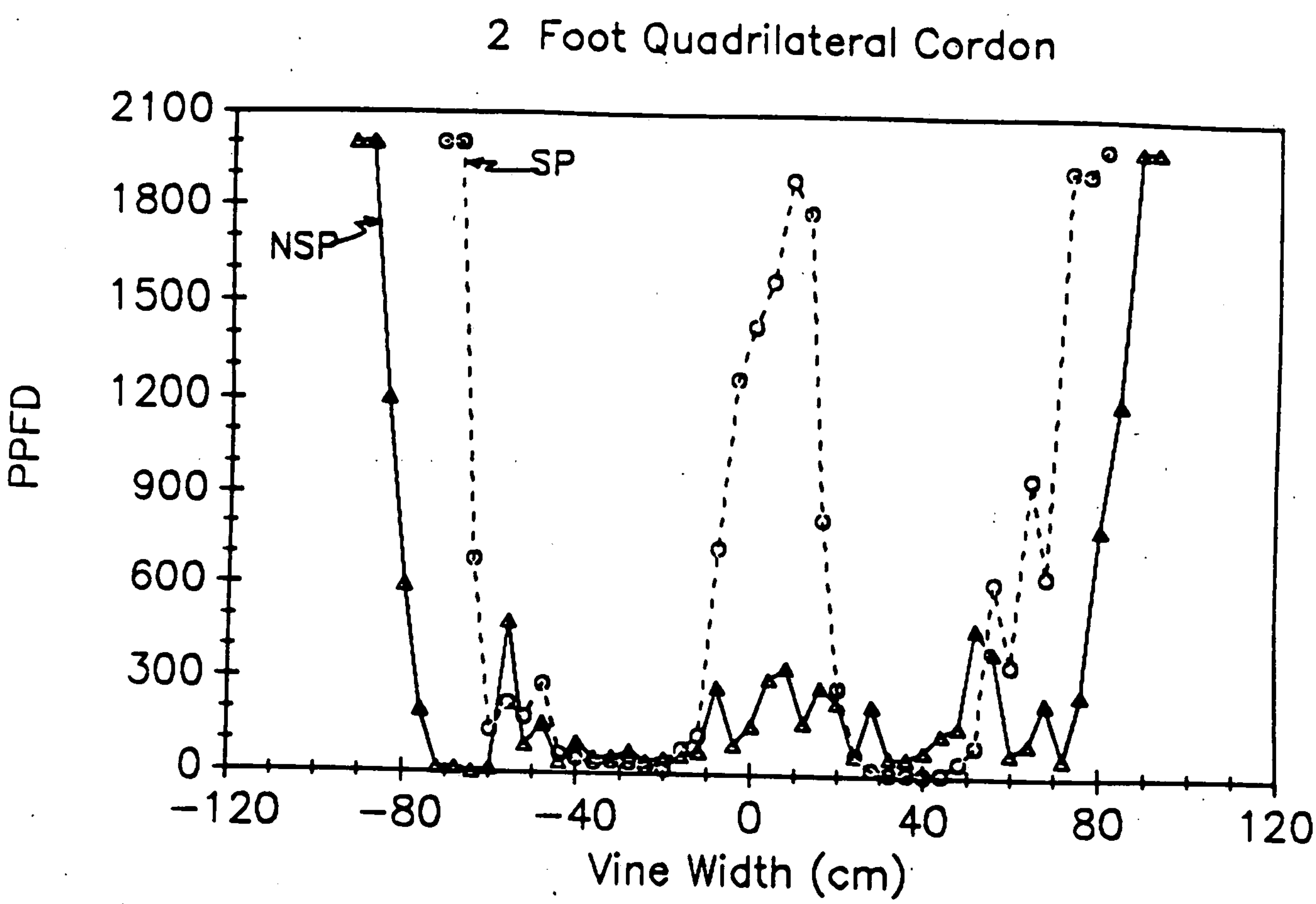


FIGURE 9

Average level of PPFD across the canopy width in the fruiting region of three foot Quadrilateral Cordon SP and NSP Sauvignon blanc grapevines grown at Oakville, CA, and measured at the veraison stage of fruit development. Light measurements were made perpendicular to the vine row between 1100 and 1300 hours with a ceptometer. Each point is the mean of 96 light readings. Zero width indicates the center of the vine row.

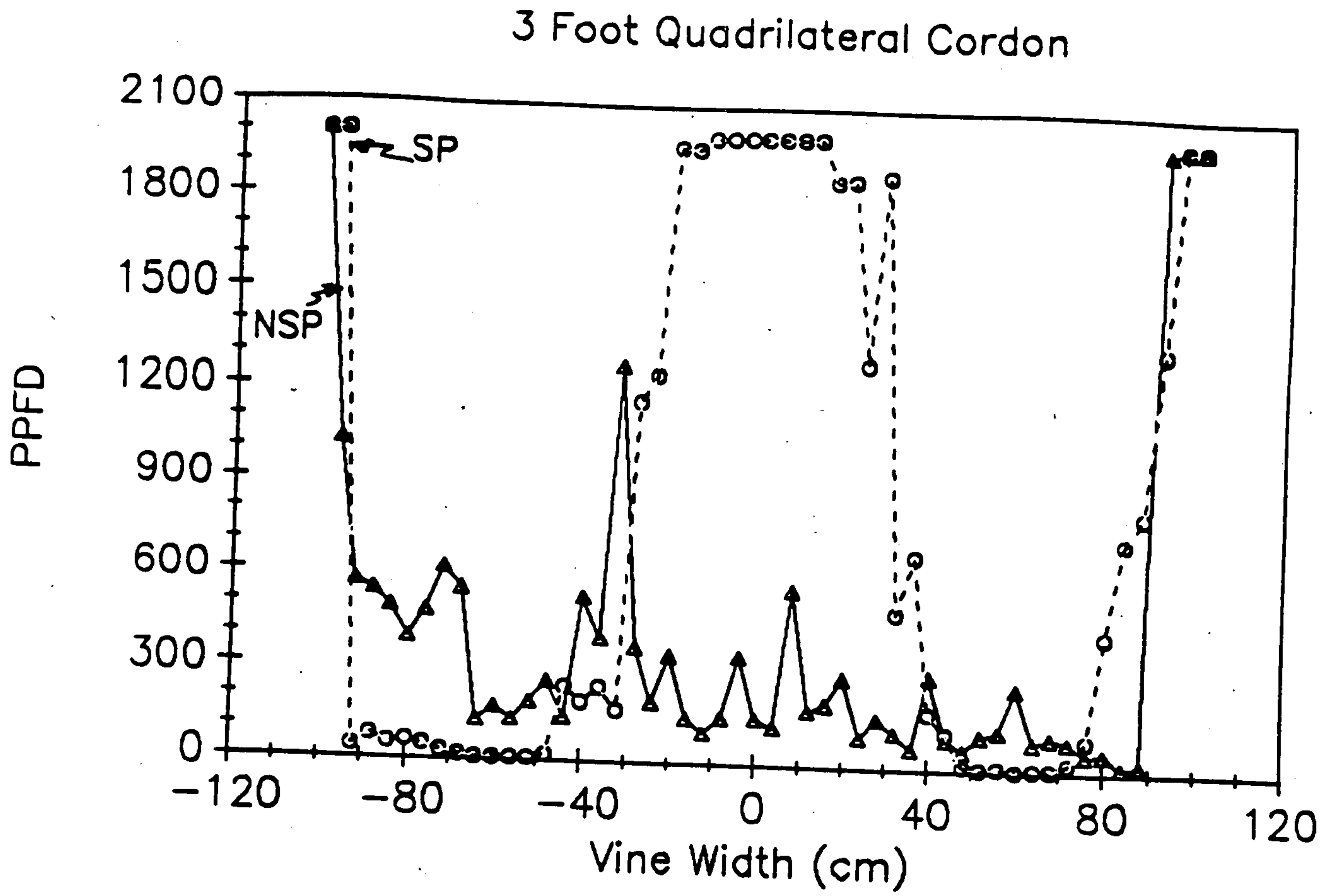


FIGURE 10

Average level of PPFD across the canopy width in the fruiting region of four foot Quadrilateral Cordon SP and NSP Sauvignon blanc grapevines grown at Oakville, CA, and measured at the veraison stage of fruit development. Light measurements were made perpendicular to the vine row between 1100 and 1300 hours with a ceptometer. Each point is the mean of 96 light readings. Zero width indicates the center of the vine row.

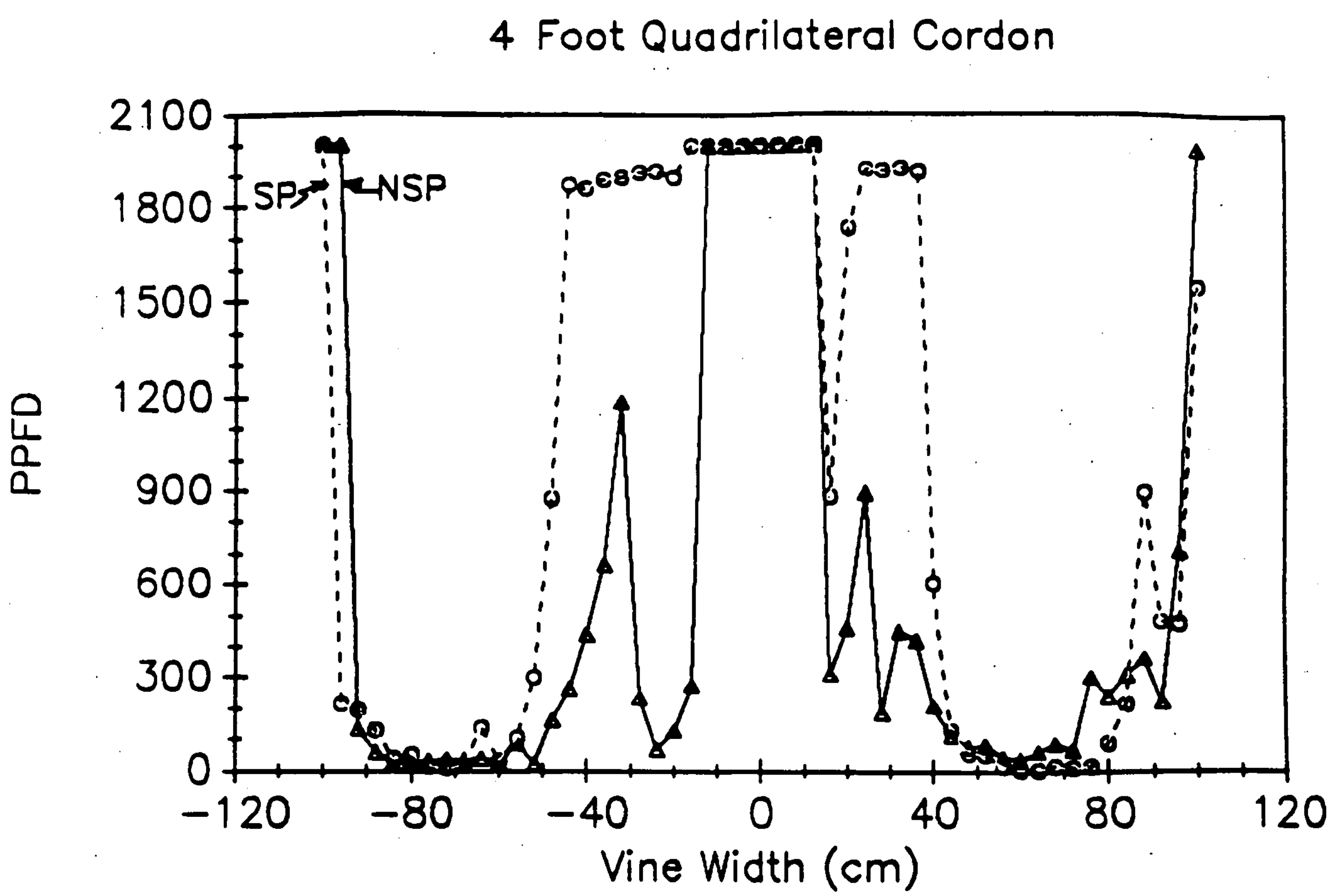


FIGURE 11

Cross-section graphs of three trellises were used in this experiment. White and dark circles represent foliage and cordon wires, respectively. Arrows indicate shoot positioning direction. Dotted lines show the canopy contour. A, B, and C are Vertical, Lyre and GDC trellises; 1 and 2 represent NSP and SP. The numbers shown within the figures are in centimeters.

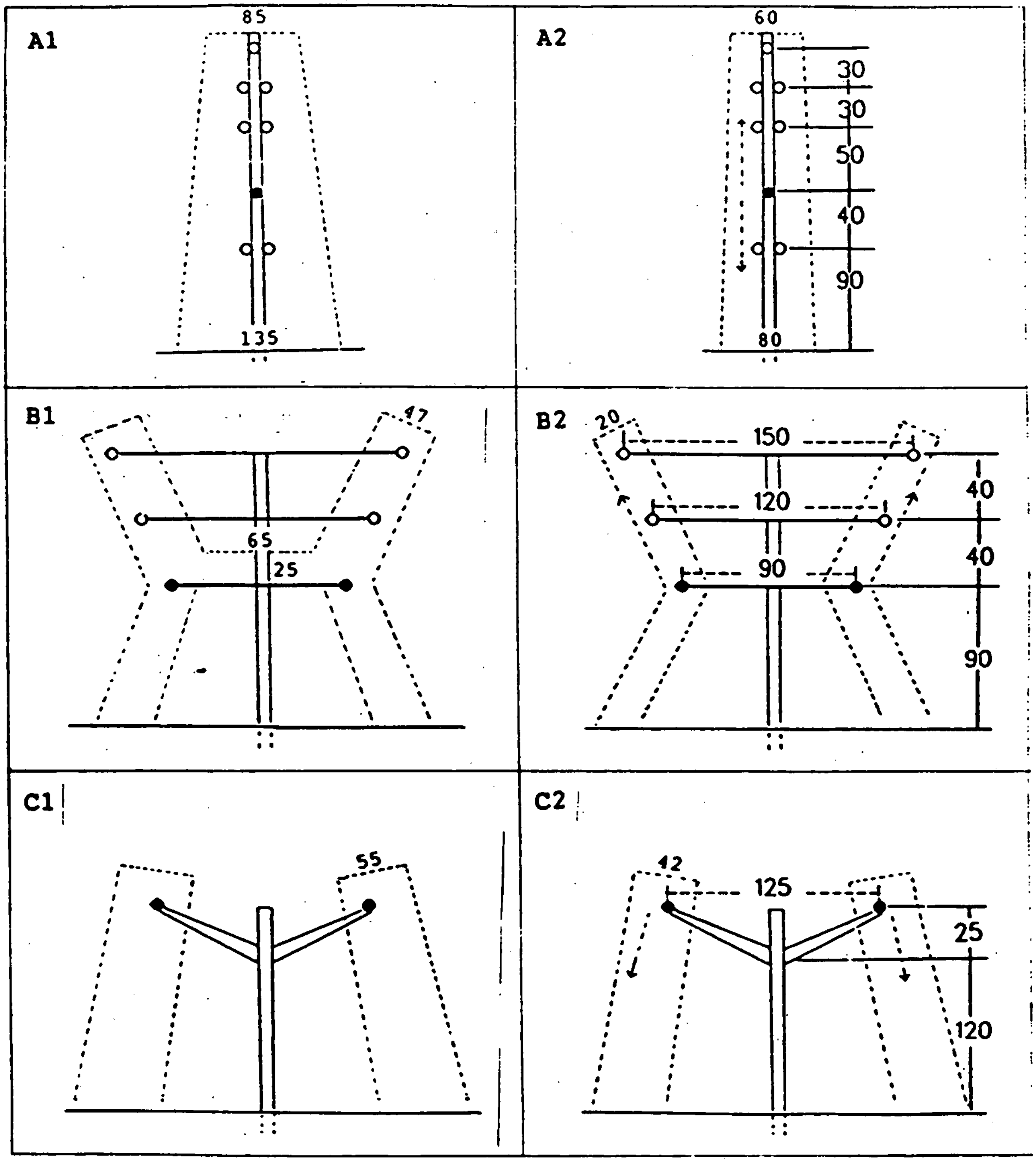


TABLE 1

EFFECTS OF TRELLISING ON CROP YIELD, FRUIT COMPOSITION AT HARVEST AND PRUNING WEIGHT OF CABERNET SAUVIGNON GROWN AT THE OAKVILLE EXPERIMENTAL VINEYARD, OAKVILLE, CA.

DATA ARE FOR FOUR YEAR MEANS, 1987-1990.

Fruit Composition at Harvest	**Bilateral Trellis System (BC)**	**Quadrilateral Trellis System (QC)**	**Significance (%)**
TSS °Brix	22.4	22.4	NS
pH	3.23	3.21	0.02
TA (g/L)	7.82	7.68	NS
Malic Acid (g/L)	2.07	1.88	NS
K (ppm)	1449	1437	NS
Anthocyanin (mg/g)	0.78	0.87	0.002
Yield Components			
Number Shoots per vine	60	74	0.02
Number Clusters per vine	99	116	0.0001
Berry Weight (g)	1.18	1.17	NS
Cluster Weight (g)	125	122	0.02
Crop Yield			
Kg/Vine	12.3	14.3	0.0001
mt/ha	18.9	22.0	0.0001
Tons/Acre	8.3	9.7	0.0001
Pruning			
Weight (Kg/vine)	3.27	2.90	0.06
Cropping Efficiency			
Yield/Pruning Wt Ratio	3.8	4.9	0.01

TABLE 2

EFFECTS OF TRELLISING ON GROWTH OF CABERNET SAUVIGNON VINES GROWN AT OAKVILLE EXPERIMENTAL VINEYARD, OAKVILLE, CA.

DATA ARE FOR FOUR-YEAR MEANS, 1987-1990.

Vine Growth	**Bilateral Trellis System (BC)**	**Quadrilateral Trellis System (QC)**	**Significance (%)**
Pruning Weight (kg/vine)	3.27	2.90	0.06
Pruning Weight (kg/m Cordon)	1.64	0.72	0.01
Total No. Shoots/vine	53.9	70.0	0.0007
Shoot Length (cm)*	175	147	0.002
Number nodes/primary shoot*	31.4	27.2	0.0006
Weight/cane (g)*	78.3	59.8	0.002
Leaf area/primary shoot (cm^2)*	2674	2234	0.002
Lateral leaf area/shoot (cm$^{2)}$*	1818	1248	0.008
Leaf area/shoot length (cm^2/cm)*	24.9	23.3	0.02

* Data is for shoots with 14 or more nodes.

TABLE 3

EFFECTS OF ROW SPACING ON CROP YIELD, FRUIT COMPOSITION AT HARVEST AND PRUNING WEIGHT OF CABERNET SAUVIGNON GROWN AT THE OAKVILLE EXPERIMENTAL VINEYARD, OAKVILLE, CA DATA ARE FOR FOUR YEAR MEANS, 1987 - 1990.				
	Row Spacing			
Fruit Composition at Harvest	**2.4 m (8 ft)**	**3.0 m (10 ft)**	**3.6 m (12 ft)**	**Significance (%)**
TSS °Brix	22.2	22.4	22.5	NS
pH	3.23	3.22	3.22	NS
TA (g/L)	7.64	7.81	7.81	0.05
Malic Acid (g/L)	1.97	1.93	2.01	NS
K (ppm)	1445	1442	1443	NS
Anthocyanin (mg/g)	0.83	0.84	0.81	NS
Yield Components				
Number Shoots per vine	68	67	68	NS
Number Clusters per vine	104	107	111	0.06
Berry Weight (g)	1.18	1.17	1.18	NS
Cluster Weight (g)	120	124	124	0.03
Crop Yield				
Kg/Vine	12.6	13.2	14.2	0.002
mt/ha	24.2	20.3	18.2	0.002
Tons/Acre	10.8	9.0	8.0	0.002
Pruning				
Weight (Kg/vine)	2.61	3.23	3.42	0.002
Cropping Efficiency				
Yield/Pruning Wt Ratio	4.8	4.1	4.1	0.002

TABLE 4

CABERNET SAUVIGNON TRELLISING-ROW SPACING TRIAL
OAKVILLE EXPERIMENTAL VINEYARD N-BLOCK

Principal Investigator: W. M. Kliewer

Treatment		Crop Yield								Average 1987-90 tons/ac
Row Spacing	Trellis System	1987		1988		1989		1990		
		kg/vine	tons/ac	kg/vine	tons/ac	kg/vine	tons/ac	kg/vine	tons/ac	
8 ft.	Bilateral single canopy	13.7	11.72	10.78	9.22	12.68	9.82	7.86	6.72	9.37
	Quadrilateral divided canopy	18.0	15.40	11.39	9.75	14.23	12.18	9.54	8.16	11.37
10 ft.	Bilateral single canopy	13.9	9.51	9.88	6.80	13.81	9.44	8.01	5.48	7.80
	Quadrilateral divided canopy	20.0	13.68	10.68	7.31	15.48	10.59	10.40	7.12	9.67
12 ft.	Bilateral single canopy	13.6	7.75	9.99	5.69	15.59	8.88	9.36	5.33	6.91
	Quadrilateral divided canopy	22.4	12.76	12.08	6.88	18.44	10.51	11.63	6.63	9.20

All treatments received a constant pruning level of 36 buds/vine.

TABLE 5

EFFECTS OF ROW SPACING ON GROWTH OF CABERNET SAUVIGNON VINES GROWN AT OAKVILLE EXPERIMENTAL VINEYARD, OAKVILLE, CA.

DATA ARE FOR FOUR YEAR MEANS, 1987-1990

	Row Spacing			
Vine Growth	**2.4 m (8 ft)**	**3.0 m (10 ft)**	**3.6 m (12 ft)**	**Significance (%)**
Pruning Weight (kg/vine)	2.61	3.23	3.42	0.002
Total No. Shoots/vine	60.2	62.3	63.4	NS
Shoot Length (cm)*	151	---	171	0.05
Number nodes/primary shoot*	27.7	---	30.8	0.05
Weight/cane (g)*	62.0	70.0	75.1	0.002
Leaf area/primary shoot (cm)*	2301	---	2607	NS
Lateral leaf area/shoot (cm^2)*	1331	---	1734	0.03
Leaf area/shoot length (cm^2/cm)*	23.6	---	24.8	0.007

* Data is for shoots with 14 or more nodes.

TABLE 6

EFFECTS OF PRUNING LEVEL ON CROP YIELD, FRUIT COMPOSITION AT HARVEST AND PRUNING WEIGHT OF CABERNET SAUVIGNON GROWN AT THE OAKVILLE EXPERIMENTAL VINEYARD, OAKVILLE, CA.

DATA ARE FOR FOUR YEAR MEANS, 1987-1990.

Fruit Composition at Harvest	**24 buds/vine**	**36 buds/vine**	**48 buds/vine**	**60 buds/vine**	**Significance (%)**
TSS °Brix	22.6	22.5	22.4	22.1	0.0001
pH	3.25	3.22	3.21	3.21	0.0001
TA (g/L)	7.88	7.84	7.74	7.56	0.0001
Malic Acid (g/L)	2.09	2.06	1.92	1.81	0.0001
K (ppm)	1446	1465	1424	1418	0.0001
Anthocyanin (mg/g)	0.80	0.82	0.85	0.83	0.03
Yield Components					
Number Shoots per vine	55	61	72	80	0.01
Number Clusters per vine	81	101	117	130	0.0001
Berry Weight (g)	1.16	1.19	1.18	1.17	0.0001
Cluster Weight (g)	119	127	123	125	0.0001
Crop Yield					
Kg/Vine	9.7	12.9	14.5	16.2	0.0001
mt/ha	14.9	19.8	22.3	24.9	0.0001
Tons/Acre	6.6	8.8	9.8	11.0	0.0001
Pruning					
Weight (Kg/vine)	3.40	3.20	2.99	2.76	0.0001
Cropping Efficiency					
Yield/Pruning Wt Ratio	2.8	4.0	4.8	5.9	0.0001

TABLE 7

EFFECTS OF PRUNING LEVEL ON GROWTH OF CABERNET SAUVIGNON GROWN AT OAKVILLE EXPERIMENTAL VINEYARD, OAKVILLE, CA

DATA ARE FOR FOUR YEAR MEANS, 1987-1990

Vine Growth	24 buds/vine	36 buds/vine	48 buds/vine	60 buds/vine	Significance (%)
Pruning Weight (kg/vine)	3.40	3.20	2.99	2.76	0.0001
Total No. Shoots/vine	46.8	59.8	67.1	74.2	0.0001
Shoot Length (cm)*	197	165	148	133	0.0001
Number nodes/primary shoot*	33.1	30.6	27.9	25.0	0.0001
Weight/cane (g)*	92.1	70.6	61.4	52.1	0.0001
Leaf area/primary shoot* (cm^2)	3021	2526	2249	2020	0.001
Lateral leaf area/shoot* (cm^2)	2384	1564	1200	982	0.0001
Leaf area/shoot length* (cm^2/cm)	26.8	24.4	23.0	22.2	0.0001

* Date is for shoots with 14 or more nodes.

TABLE 8

SENSORY ANALYSIS OF 1990 CABERNET SAUVIGNON WINES DUO-TRIO COMPARISONS*		
Treatment Comparisons	**Correct Responses**	**Significant Level**
Bilateral vs Quadrilateral (36 buds/vine)	19	**
Bilateral vs Quadrilateral (48 buds/vine)	17	*
Bilateral (24 buds) vs Bilateral (60 buds)	14	NS
Quadrilateral (24 buds) vs Quadrilateral (60 buds)	13	NS

* Total number of tasters = 24

TABLE 9

EFFECT OF SHOOT POSITIONING AND HEDGING ON PERFORMANCE OF SAUVIGNON BLANC GRAPEVINES, OAKVILLE, CA.

FIVE YEAR MEANS (1986 TO 1990)

Parameter	Not Shoot Ppsotopmed*	Shoot Positioned	Signif. Level
Yield (Kg/vine)	12.9	13.6	0.05
Yield (tons/acre)	7.3	7.7	0.05
Berry Wt (g)	1.48	1.49	NS
Cluster Wt (g)	117	121	0.02
No. Clusters/vine	110	111	NS
No. Berries/cluster	84	86	NS
TSS (°Brix)	23.0	21.7	0.0001
pH	3.05	3.01	0.0001
TA (g/L)	9.05	9.68	0.0001
Malic Acid (g/L)	2.70	2.99	0.0003
K (ppm)	1231	1168	0.0001
Pruning Wt (Kg/vine)	2.78	2.39	0.03
Yield/Pruning Wt Ratio	4.33	5.69	0.01

* Shoot positioned vines were hedged to approximately 15 nodes shortly after fruit-set. Vines not shoot positioned were not hedged.

TABLE 10

EFFECT OF SHOOT POSITIONING AND HEDGING ON PERFORMANCE OF CHARDONNAY GRAPEVINES, OAKVILLE, CA.

FIVE YEAR MEANS (1986 TO 1990)

Parameter	Not Shoot Positioned*	Shoot Positioned	Signif. Level
Yield (Kg/vine)	13.6	14.2	0.03
Yield (tons/acre)	7.7	8.1	0.03
Berry Wt (g)	1.29	1.28	NS
Cluster Wt (g)	131	139	0.002
No. Clusters/vine	103	101	0.08 (NS)
No. Berries/cluster	102	109	0.002
TSS (°Brix)	22.9	22.3	0.0001
pH	3.19	3.16	0.0001
TA (g/L)	6.73	6.79	NS
Malic Acid (g/L)	1.89	1.87	NS
K (ppm)	1228	1176	0.0001
Pruning Wt (Kg/vine)	2.42	2.04	0.001
Yield/Pruning Wt Ratio	5.62	6.98	0.001

* Shoot positioned vines were hedged to approximately 15 nodes shortly after fruit-set. Vines not shoot positioned were not hedged.

TABLE 11

EFFECT OF SHOOT POSITIONING ON PERFORMANCE OF CABERNET SAUVIGNON GRAPEVINES, OAKVILLE, CA. FIVE YEAR MEANS (1986 TO 1990)			
Parameter	**Not Shoot Positioned**	**Shoot Positioned**	**Signif. Level**
Yield (Kg/vine)	12.6	12.9	NS
Yield (tons/acre)	7.2	7.4	NS
Berry Wt (g)	1.11	1.12	NS
Cluster Wt (g)	118	122	0.07
No. Clusters/vine	109	108	NS
No. Berries/cluster	107	109	NS
TSS (°Brix)	23.2	22.5	0.0001
pH	3.23	3.21	0.0003
TA (g/L)	6.64	6.90	0.0001
Malic Acid (g/L)	1.23	1.34	0.007
K (ppm)	1292	1277	0.07
Pruning Wt (Kg/vine)	2.56	2.17	0.002
Yield/Pruning Wt Ratio	4.92	5.94	0.002

TABLE 12

SENSORY ANALYSIS BY DUO TRIO COMPARISONS OF NOT SHOOT POSITIONED (NSP) VS. SHOOT POSITIONED (SP) SAUVIGNON BLANC AND CHARDONNAY WINES (n = 24)

Treatment Comparisons	Cultivar	Correct Responses[x]
Bilateral Cordon, NSP vs. SP	Sauvignon blanc	18*
1 ft Quadrilateral Cordon, NSP vs. SP	Sauvignon blanc	24***
2 ft Quadrilateral Cordon, NSP vs. SP	Sauvignon blanc	22***
4 ft Quadrilateral Cordon, NSP vs. SP	Sauvignon blanc	15 NS
NSP vs. SP[y]	Chardonnay	18*

x NS - not significantly different; *, **, *** = difference significant at P <0.05, 0.01, or 0.001, respectively.

y NSP vs. SP Chardonnay wine comparisons was for composite samples obtained from bilateral cordon and 1, 2, 3 and 4 foot quadrilateral cordon trellis treatments.

TABLE 13

EFFECTS OF TRELLIS WIDTH ON PERFORMANCE OF CHARDONNAY GRAPEVINES. OAKVILLE EXPERIMENTAL VINEYARD

FIVE YEAR MEANS (1986 - 1990)

		Trellis Width				
Parameter	**Bilateral Cordon**	**1 Ft Quad**	**2 Ft Quad**	**3 Ft Quad**	**4 Ft Quad**	**Signif. Level**
Yield (kg/vine)	12.5	13.9	14.6	14.7	13.7	0.005
Berry wt (g)	1.29	1.29	1.29	1.29	1.27	NS
Cluster wt (g)	138	135	136	135	131	NS
No. cluster/vine	89	103	107	108	104	0.0001
No. berries/cluster	108	105	106	105	104	NS
TSS (°Brix)	22.6	22.4	22.4	22.8	22.8	0.08
pH	3.17	3.18	3.17	3.16	3.17	NS
TA (g/L)	6.97	6.80	6.78	6.75	6.49	0.005
Malic Acid (g/L)	1.98	1.93	1.89	1.87	1.74	0.05
K (ppm)	1192	1214	1200	1196	1208	NS
Pruning wt (kg/vine)	2.34	2.26	2.25	2.19	2.10	NS
Yield/pruning wt ratio	5.3	6.1	6.5	6.7	6.5	0.05

TABLE 14

EFFECTS OF TRELLIS WIDTH ON PERFORMANCE OF SAUVIGNON BLANC GRAPEVINES. OAKVILLE EXPERIMENTAL VINEYARD

FIVE YEAR MEANS (1986 - 1990)

		Trellis Width				
Parameter	**Bilateral Cordon**	**1 Ft Quad**	**2 Ft Quad**	**3 Ft Quad**	**4 Ft Quad**	**Signif. Level**
Yield (kg/vine)	12.9	13.0	13.9	13.5	13.1	NS
Berry wt (g)	1.49	1.50	1.50	1.47	1.47	NS
Cluster wt (g)	127	120	120	117	113	0.002
No. cluster/vine	101	107	115	114	116	0.0001
No. berries/cluster	89	84	84	85	81	0.002
TSS (°Brix)	21.6	22.1	22.4	22.5	23.1	0.0001
pH	3.02	3.03	3.04	3.03	3.04	NS
TA (g/L)	9.90	9.55	9.40	9.00	8.96	0.006
Malic Acid (g/L)	3.21	3.01	2.87	2.59	2.54	0.007
K (ppm)	1179	1212	1230	1160	1217	NS
Pruning wt (kg/vine)	2.76	2.64	2.70	2.27	2.56	NS
Yield/pruning wt ratio	4.7	4.9	5.1	5.9	5.1	NS

TABLE 15

EFFECTS OF TRELLIS WIDTH ON PERFORMANCE OF CABERNET SAUVIGNON GRAPEVINES. OAKVILLE EXPERIMENTAL VINEYARD

FIVE YEAR MEANS (1986 - 1990)

		Trellis Width				
Parameter	**Bilateral Cordon**	**1 Ft Quad**	**2 Ft Quad**	**3 Ft Quad**	**4 Ft Quad**	**Signif. Level**
Yield (kg/vine)	12.1	12.6	13.3	12.6	12.9	0.002
Berry wt (g)	1.15	1.12	1.12	1.09	1.09	0.009
Cluster wt (g)	131	117	120	117	114	0.0001
No. cluster/vine	96	109	113	110	115	0.0001
No. berries/cluster	114	106	107	108	105	0.002
TSS (°Brix)	22.5	22.6	22.7	23.0	23.2	0.0002
pH	3.24	3.23	3.21	3.21	3.22	0.002
TA (g/L)	6.92	6.72	6.77	6.70	6.75	0.08
Malic Acid (g/L)	1.51	1.30	1.28	1.17	1.16	0.0002
K (ppm)	1313	1282	1264	1268	1295	NS
Pruning wt (kg/vine)	2.55	2.27	2.46	2.17	2.35	0.004
Yield/pruning wt ratio	4.7	5.5	5.4	5.8	5.5	0.005

TABLE 16

Influence of trellis systems, shoot positioning, and leaf removal on photosynthetic photon flux density (μmol $m^{-2}s^{-1}$) in the fruiting region of 'Chenin blanc' grapevines during the 1988 and 1989 growing season.

Trellis System	Shoot Posi.	Leaf Removal	Date PPFD measured (μmol $m^{-2}s^{-1}$) 1988				1989				
			5/26	6/18	7/8	6/14	5/27	6/22	7/14	8/10	9/8
Vertical	No	None	59	44	69	196	106	131	103	231	266
	No	North	62	103	135	216	135	227	170	236	267
	No	Both	64	141	175	229	137	246	226	260	352
	Yes	None	33	31	28	133	116	37	72	78	146
	Yes	North	45	49	38	150	131	54	67	60	174
	Yes	Both	57	58	51	223	104	99	142	161	294
Signif level of interatcion			NS	NS	NS	NS	NS	NS	NS	NS	NS
Lyre (U)	No	None	73	70	97	121	182	142	122	144	159
	No	North	72	136	153	124	200	244	136	187	203
	No	Both	66	160	209	138	170	263	158	150	159
	Yes	None	85	74	109	112	161	180	214	241	227
	Yes	North	83	91	91	130	191	247	215	256	264
	Yes	Both	74	130	166	127	150	254	303	216	219
Signif level of interaction			NS	NS	NS	NS	NS	NS	NS	NS	NS
GDC	No	None	96	256	328	262	264	453	575	702	529
	No	North	133	263	290	276	209	598	583	645	608
	No	Both	117	314	337	287	224	727	662	716	624
	Yes	None	187	364	449	312	181	459	563	716	681
	Yes	North	195	375	461	341	208	674	656	758	716
	Yes	Both	181	400	497	401	233	1225	1058	1044	1005
Signif level of interaction			NS	NS	NS	NS	NS	***	**	*	**
Signif level of interaction of three ways											
			NS	NS	NS	NS	NS	***	*	NS	*

NS, *, **, *** indicates significant at P > 0.05, < 0.05, < 0.01, < 0.0001, respectively. Flowering, veraison and harvest occurred on approximately May 12, July 19, and August 30, 1988, and May 18, July 22, and September 20, 1989, respectively. Each data represents the average of 24 measurements in the Lyre and GDC trellises and 12 in the Vertical trellis.

TABLE 17

Influence of trellis systems, shoot positioning and leaf removal on R:FR ratio, evaporation potential (ml H_2O/h) and percent clusters with bunch rot in the fruiting region of 1Chenin blanc' grapevines during the 1989 growing season.

Trellis System	Shoot Posi.	Leaf Removal	R:FR Ratio 1989			Evapor Poten ml H_2O/h	Amount of bunch rot
			7/3	8.10	9/8		
Vertical	No	None	0.19	0.18	0.21	0.43	1.83
	No	North	0.27	0.18	0.23	0.46	2.83
	No	Both	0.39	0.24	0.36	0.54	1.00
	Yes	None	0.10	0.16	0.18	0.45	0.67
	Yes	North	0.23	0.24	0.21	0.47	1.33
	Yes	Both	0.24	0.26	0.30	0.56	0.33
Signif level of interaction			NS	NS	NS	NS	NS
Lyre (U)	No	None	0.11	0.16	0.16	0.39	15.35
	No	North	0.18	0.23	0.20	0.45	7.58
	No	Both	0.20	0.18	0.20	0.45	7.42
	Yes	None	0.13	0.21	0.24	0.41	7.50
	Yes	North	0.26	0.29	0.30	0.47	5.56
	Yes	Both	0.21	0.33	0.37	0.50	2.92
Signif level of interaction			NS	NS	NS	NS	NS
GDC	No	None	0.42	0.47	0.38	0.44	5.08
	No	North	0.50	0.44	0.58	0.46	5.17
	No	Both	0.50	0.60	0.62	0.53	4.42
	Yes	None	0.38	0.42	0.44	0.45	4.41
	Yes	North	0.47	0.50	0.49	0.47	1.25
	Yes	Both	0.72	0.74	0.71	0.57	1.00
Signif level of interaction			***	NS	NS	NS	NS
Signif level of interaction of three ways							
			***	NS	NS	NS	NS

NS, *, **, *** indicates significant at P > 0.05, < 0.05, < 0.01, < 0.001, respectively. Flowering, veraison and harvest occurred at approximately May 12, July 19, and August 31, 1988, and May 18, July 22, and September 20, 1989, respectively. Each data of R:FR ratio represents the average of 12 measurements in each trellis treatment. Each data of evaporation potential treatment represents six measurements.

TABLE 18

INFLUENCE OF TRELLIS SYSTEM ON CROP YIELD, CROP YIELD COMPONENTS AND PRUNING WEIGHT OF CHENIN BLANC GRAPEVINES AVERAGED OVER A PERIOD OF FOUR YEARS* (1987 - 1990), DAVIS, CA.

Trellis System	Number Clusters per vine	Berry Weight (g)	Cluster Weight (g)	Crop Yield		Pruning Weight	
				Kg/vine	mt/hc	Kg/vine	Kg/m canopy
Vertical	109	1.52	247	26.9	37.5	3.4	1.70
GDC	147	1.49	220	32.3	45.1	2.6	0.65
U	142	1.59	242	34.4	48.1	3.9	0.97
Signif Level	0.0001	0.05	0.004	0.006	0.006	0.001	0.001

* Data have been composited for shoot positioning and leaf removal treatments.

TABLE 19

INFLUENCE OF TRELLIS SYSTEM ON COMPOSITION OF CHENIN BLANC FRUIT AT HARVEST AVERAGED OVER A PERIOD OF FOUR YEARS* (1987 - 1990), DAVIS, CA.						
Trellis System	**Total Soluble (°Brix)**	**pH**	**Total Titratable Acidity (g/L)**	**Malate (g/L)**	**K^+ (ppm)**	**Crop Yield (kg/vine)**
Vertical	20.5	3.18	7.6	2.7	1381	26.9
GDC	20.8	3.20	7.1	2.3	1374	32.2
U	21.6	3.25	6.7	2.3	1419	34.4
Signif Level	0.006	0.001	0.0001	0.008	0.02	0.006

* Data have been composited for shoot position and leaf removal treatments.

TABLE 20

INFLUENCE OF TRELLIS SYSTEM ON FRUIT COMPOSITION OF CHENIN BLANC AT HARVEST, 1989
DAVIS CALIFORNIA

Treatment Trellis System	Crop Yield (kg/vine)	Total Soluble solids (°B)	pH	TA (g/L)	Malic acid (g/L)	K (ppm)	Arginine (μg/ml)	Total Phenols (μg/cm²)
Vertical	32.8	19.8	3.26	6.44	2.57	1132	134	27.9
GDC	39.2	20.1	3.29	6.03	2.39	1140	121	30.3
U	41.3	21.4	3.34	5.86	2.34	1198	118	28.5
Signif Level	0.0001	0.0001	0.0001	0.0001	0.009	0.0002	0.009	0.001

TABLE 21

INFLUENCE OF SHOOT POSITIONING ON CROP YIELD, CROP YIELD COMPONENTS AND PRUNING WEIGHT OF CHENIN BLANC GRAPEVINES AVERAGED OVER A PERIOD OF FOUR YEARS* (1987 - 1990), DAVIS, CA

Shoot Positioning	Number Clusters per vine	Berry Weight (g)	Cluster Weight (g)	Crop Yield		Pruning Weight (kg/vine)	Yield Pruning Weight
				Kg/vine	mt/hc		
No	134	1.58	247	33.1	46.2	3.7	9.3
Yes	131	1.48	223	29.3	40.9	2.9	10.3
Signif Level	NS	0.0005	0.008	0.004	0.004	0.01	0.01

* Data have been composited for trellising and leaf removal treatments.

TABLE 22

INFLUENCE OF SHOOT POSITIONING ON COMPOSITION OF CHENIN BLANC FRUIT AT HARVEST AVERAGED OVER A PERIOD OF FOUR YEARS* (1987 - 1990), DAVIS, CA.

Shoot Positioning Treatment	Total Soluble (°Brix)	pH	Total Titratable Acidity (g/L)	Malate (g/L)	K^+ (ppm)	Crop Yield (kg/vine)
No	21.1	3.23	7.03	2.47	1404	33.1
Yes	20.8	3.19	7.28	2.44	1379	29.3
Signif. Level	0.08	0.002	0.02	NS	0.02	0.004

* Data have been composited for trellising and leaf removal treatments.

TABLE 23

INFLUENCE OF LEAF REMOVAL ON CROP YIELD, CROP YIELD COMPONENTS AND PRUNING WEIGHT OF CHENIN BLANC GRAPEVINES AVERAGED OVER A PERIOD OF FOUR YEARS* (1987 - 1990), DAVIS, CA

Leaf Removal Treatment	Number Clusters per vine	Berry Weight (g)	Cluster Weight (g)	Crop Yield		Pruning Weight (kg/vine)	Yield Pruning Weight
				Kg/vine	mt/hc		
None	131	1.55	235	30.8	43.0	3.3	9.9
North Side	133	1.54	239	31.8	44.4	3.3	10.1
North & South Side	132	1.50	235	31.0	43.3	3.4	9.6
Signif. Level	NS	0.02	NS	NS	NS	NS	NS

* Data have been composited for trellis systems and shoot positioning treatments.

TABLE 24

INFLUENCE OF LEAF REMOVAL ON COMPOSITION OF CHENIN BLANC FRUIT AT HARVEST AVERAGED OVER A PERIOD OF FOUR YEARS* (1987 - 1990), DAVIS, CA						
Leaf Removal Treatment	**Total Soluble (°Brix)**	**pH**	**Total Titratable Acidity (g/L)**	**Malate (g/L)**	**K^+ (ppm)**	**Crop Yield (kg/vine)**
None	20.9	3.21	7.23	2.63	1392	30.8
North Side	20.8	3.20	7.19	2.46	1385	31.8
North & South Side	21.1	3.22	7.06	2.26	1397	31.0
Signif. Level	NS	NS	NS	0.0001	NS	NS

* Data have been composited for trellis system and shoot positioning treatments.

TABLE 25

CANOPY CHARACTERISTICS OF VERTICAL, LYRE, AND GDC TRELLISED CHENIN BLANC GRAPEVINES, 1989, DAVIS, CA.				
	Trellis System			
Parameter	**Vertical**	**Lyre**	**GDC**	**Signif. Level**
Total number shoots/vine	62.2a	68.1a	77.1b	0.0007
Average number primary leaves/shoot	14.7a	16.5b	16.9b	0.037
Average primary shoot length (cm)	109.8	120.8	108.1	NS
Average internode length (cm)	7.4a	7.2a	6.3b	0.001
Area/primary leaf (cm^2)	123.0a	102.2b	73.9c	0.001
Leaf area/primary shoot (cm^2)	1710a	1570a	1210b	0.01
Number laterals/primary shoot	7.2	6.9	5.1	NS
Average number nodes/lateral	4.1	3.8	4.2	NS
Average length/lateral (cm)	10.9	9.8	10.8	NS
Average area/lateral leaf (cm^2)	35.3a	25.0b	23.0b	0.01
Total lateral leaf area/shoot (cm^2)	1300a	1620a	840b	0.05
Total leaf area/shoot (cm^2)	3020a	3160a	1970b	0.05
Total leaf area/vine (m^2)	18.76a	21.43a	15.06b	0.05
Lateral leaf area as percent of total leaf area	43.0%	51.3%	42.6%	NS

TABLE 26

CANOPY CHARACTERISTICS OF SHOOT POSITIONED AND NOT SHOOT POSITIONED CHENIN BLANC GRAPEVINES, 1989, DAVIS, CA.			
Parameter	**Not Shoot Positioned[z]**	**Shoot Positioned[z]**	**Significant Level**
Total number shoots/vine	66.9	71.4	NS
Average number primary leaves/shoot	17.2	14.9	0.002
Average primary shoot length (cm)	126.8	99.0	0.0005
Average internode length (cm^2)	7.28	6.67	0.001
Area/primary leaf (cm^2)	96.1	102.9	NS
Leaf area/primary shoot (cm^2)	1560	1420	NS
Number laterals/primary shoot	7.1	5.7	NS
Number nodes/lateral	4.04	4.00	NS
Average length/lateral (cm)	10.8	10.2	NS
Average area/lateral leaf (cm^2)	28.5	26.9	NS
Total lateral leaf area/shoot (cm^2)	1600	980	0.05
Total leaf area/shoot (cm^2)	3120	2310	0.05
Total leaf area/vine (m^2)	20.6	16.7	0.05
Lateral leaf area as percent of total leaf area	51.3%	42.4%	0.05

z Data from Vertical, Lyre and GDC trellis systems have been combined and analyzed together, since there were no significant interactions between shoot positioning and trellising.

TABLE 27

SENSORY ANALYSIS OF CHENIN BLANC WINES BY DUO-TRIO COMPARISONS OF SHOOT POSITIONING (SP) AND TRELLISING TREATMENTS (n = 24)

1990 VINTAGE

Treatment Comparisons[y]	**Correct Responses**[z]
Vertical Bilateral Cordon, NSP vs. SP	21***
Lyre Trellis, NSP vs. SP	19**
Vertical Bilateral Cordon vs. Lyre	22**
Vertical Bilateral Cordon vs. GDC	23***
Lyre vs. GDC	12 NS

y NSP - Not shoot positioned
SO - shoot positioned vertically shortly following fruit-set

z NS - not significantly different; *, **, *** = different significantly at P < 0.05, 0.01, or 0.001, respectively

Manipulation of Fruiting

C. J. WRIGHT
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18

CANOPY MANIPULATION FOR OPTIMIZING VINE MICROCLIMATE, CROP YIELD AND COMPOSITION OF GRAPES

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Grapevine canopy microclimate and canopy management

CANOPY MICROCLIMATE

Currently there is world-wide interest in using various canopy management practices to improve vine microclimate, crop yields, and composition of grapes and wines, as has been recently reviewed (Smart, 1985a). The concept of microclimate in grape growing is often misunderstood being commonly confused with mesoclimate (Smart, 1982). Canopy microclimate as used in this communication is the climate within and immediately around the canopy, i.e., the leaf and shoot system of a vine or vines, following the definition of Geiger, 1961. Canopy microclimate differs from the above canopy ambient climate due mainly to the size, shape, arrangement and density of leaves within the canopy. Photosynthetic photon fluence rate (PPFR), red:far red (660/730 nm) ratio, wind speed, and evaporation rates are the climatic factors most influenced by grapevine canopies, whereas air temperature and humidity are much less attenuated (Smart, 1984; Smart *et al.*, 1985).

Grapevine canopy microclimate largely depends on the amount and distribution of leaf area in a given volume and its relationship with above-ground climate. The amount of leaf area in a given volume depends mainly on shoot density and shoot vigour. Shoot density as used here refers to the number of shoots per metre of canopy length and, therefore, is a measure of shoot crowding. Canopy density is defined as the amount of leaf area within a given volume. Indexes of canopy density can be developed in a number of ways: as leaf layer number (LLN) or the number of leaves contacted by a fine rod passing through a canopy cross-section in the bud renewal or fruiting area (Smart and Smith, 1988); as leaf area to canopy surface area ratio (LA/SA) as described by Smart (1982); as weight of cane prunings per unit canopy length (Shaulis, 1982) or as Leaf Area Index (Warren-Wilson, 1959) for horizontal canopies. Shoot vigour is usually described in terms of rate of growth (e.g., cm d^{-1}), however, length and weight per shoot, leaf area/shoot and total shoot leaf area per unit length of shoot are all indicators of shoot vigour. The latter parameter has been termed gamma (γ) by Smart (1985a) and indicates the leafiness of shoots. Table 18.1 lists values of six of the indices mentioned above found to be optimal in several wine grape cultivars (Smart and Smith, 1988).

Table 18.1 GRAPEVINE GROWTH AND YIELD INDICES FOR OPTIMAL WINEGRAPE CANOPY MICROCLIMATE* (AFTER SMART AND SMITH, 1988)

	Ideal	*Undesirable*
Total leaf area/surface area per vine	< 1.2	> 3
Leaf layer number (LLN)	0.7–1.5	> 3
Shoot spacing (# shoots/m canopy length)	10–15	> 20
Pruning wt (kg)/m cordon length	< 0.5	> 1.0
Crop yield/pruning wt ratio	4–9	< 3 or > 10
Mean cane weight (g)	20–40	> 70

*The indices are usally measured at or near harvest or after leaf fall.

The role that canopy microclimate plays on vine physiology, crop yield, fruit composition, and wine quality is shown in a conceptual model presented in Figure 18.1 (Smart *et al.*, 1985). This model shows that soil, climate, and cultural practices influence vine vigour, which in turn effects foliage characteristics, such as main and lateral shoot number and area per vine. The resultant foliage characteristics in combination with the training system imposed, determine the canopy microclimate, which in turn influences many physiological functions, such as photosynthesis, transpiration, photomorphogenesis, respiration, and translocation. These physiological functions ultimately determine crop yield, fruit composition, and wine quality. Of course, soil, climate and cultural decisions can directly influence vine physiological processes, yield and quality of grapes and wines as well. Of the cultural practices listed, the trellis-training system is singled out for emphasis since improvement in canopy microclimate, fruit composition, and crop yield by this means are readily achievable as has been well documented (Smart, 1985a, b; Kliewer, 1982).

Besides trellis-training systems, canopy microclimate can be manipulated by two other principal methods: (1) controlling shoot number and spacing, i.e., distance between shoots (Smart, 1988), and (2) by control of shoot vigour, especially the total number and size of primary and lateral leaves per shoot (Smart, 1985a). Shoot number can be controlled to a limited extent by pruning. Generally, the greater the number of buds retained at pruning, the lower the percentage budbreak (Clingeleffer and Possingham, 1987). However, this will vary with the variety, vigour and degree of exposure of shoots to solar radiation (May *et al.*, 1976; Winkler *et al.*, 1974). Disbudding and shoot removal, of course, can also be used to control shoot number and reduce shoot crowding; however, this operation is labour intensive and usually results in loss of yield. Shoot vigour is mainly influenced by available supplies of soil water and nutrients and, consequently, in deep fertile soil with high water holding capacity or where rain occurs throughout the period of fruit development and ripening, the means of controlling vigour are limited. Here site selection and choice of cultivars/rootstocks are important as well as using cultural practices that reduce levels of water and nutrients in soil, such as year around cover cropping.

Recent research indicates that canopy microclimate within the fruiting region may also be improved by removal of leaves adjacent to and opposite the cluster between fruit set and varaison (Kliewer *et al.*, 1988). Removal of leaves in the fruiting zone has become widely adopted in recent years in vineyards with dense canopies in California and New Zealand, and is a long-established practice in Europe.

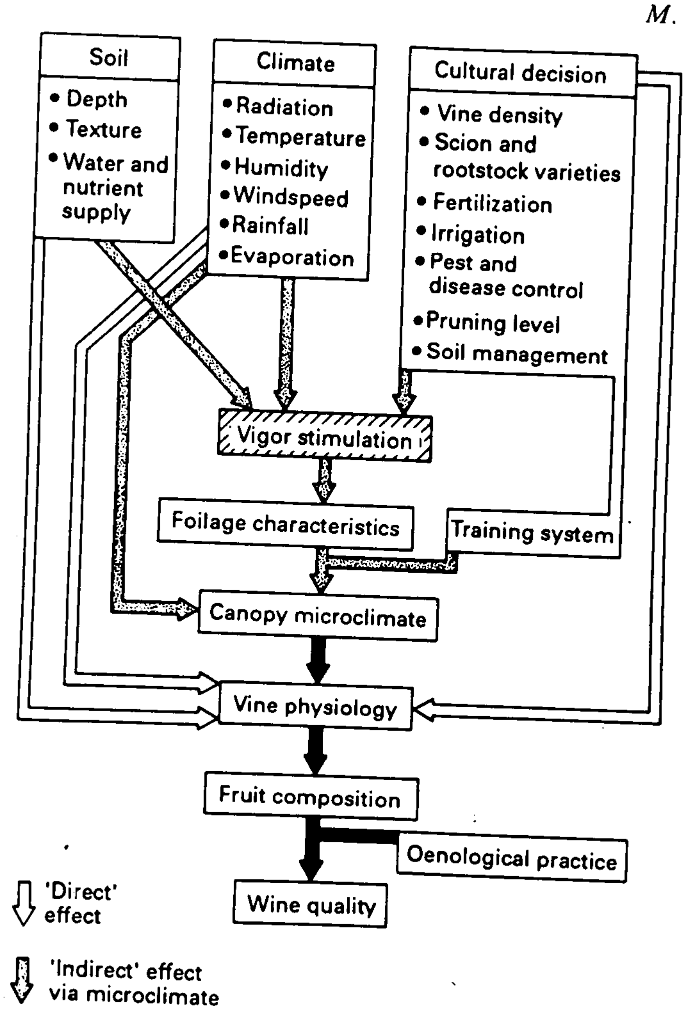

Figure 18.1 General model indicating how soil, climate and cultural decisions can affect fruit composition and wine quality via effects on canopy microclimate

CANOPY MANAGEMENT

Canopy management consists of any operation that produces a desirable canopy configuration, usually with the objective of improving canopy microclimate, fruit and wine composition, vine productivity, and reduction of fungal diseases in fruits. Major emphasis of canopy management is usually to reduce excessive canopy shading and increase air circulation in the fruiting region.

Canopy management practices commonly used to accomplish these objectives include trellis-training systems, pruning level and method, shoot positioning and direction, shoot removal, leaf removal in the fruiting zone, and shoot trimming. Other management 'tools' available to help control shoot vigour and reduce canopy shading include vine spacing within and between rows, row direction, rootstocks, irrigation and water status of soil, fertilization (particularly the amount of nitrogen fertilization), covercropping, and growth retardants. For recent reviews discussing various aspects of canopy management and vine microclimate the reader is referred to Kliewer (1982), Shaulis (1982), Smart (1984, 1985a, 1985b, 1987a), and Smart and Smith (1988).

SUNLIGHT EFFECTS

Sunlight fluxes have three important influences on grapevine physiology (Smart, 1987b): (1) the supply of energy for photosynthesis, i.e., radiation in the wave band 400 to 700 nm, termed photosynthetic photon fluence rate (PPFR); (2) tissue heating effects, i.e., radiation in the 300 to 1500 nm range; and (3) photomorphogenesis or phytochrome effects, i.e., ratio of red to far red radiation (R:FR or 660:730 nm). Shading has been identified as a major factor in reducing grapevine yields and fruit quality (Smart, 1985a), and the effects of canopy manipulation on PPFR and R:FR ratios will be examined. The effects of PPFR on photosynthesis of grapevines and how canopy density and shading influence photosynthesis have been extensively studied (Kriedemann, 1968; Kriedemann, 1977; Smart, 1974). However, the effects of light quality (R:FR light ratios) on phytochrome activity in grapevines has been little studied. A possible role of phytochrome in shade responses was raised by Smart *et al.*, 1982, when they showed close correspondence between levels of PPFR and R:FR ratios within grapevine canopies. Further, Smart, 1987a, suggested that phytochrome reactions regulate activity of key enzymes affecting fruit ripening, so that R:FR microclimate could influence wine quality. Grape leaves absorb about 95% of red light but only about 20% of far red light so that in dense canopies the R:FR ratio may be less than 10% of ambient conditions (Smart, 1987b). In grapevines there has not yet been a clear demonstration that phytochrome plays a role in fruit colouration, ripening or in fruit bud differentiation.

Several studies of grapevines have compared the composition of shaded fruit with well exposed fruit (Kliewer and Lider, 1968; Smart, 1982; Crippen and Morrison, 1986; Reynolds and Wardle, 1988). Exposed fruits are generally higher in sugar, total phenol, anthocyanin, arginine and free and bound monoterpenes and lower in pH, malate, potassium and titratable acidity; all generally considered desirable for high wine quality. In addition, experienced taste panels have generally scored wines made from highly shaded fruits lower than wines made from exposed fruits with respect to fruit character discerned on the nose and palate (Smart, 1982).

Light quality vs. light quantity effects on fruit composition and enzyme activities of 'Cabernet Franc' grapevines

As indicated in the previous section, effects of shade on grapevine physiology may be due to photosynthetic, phytochrome or thermal responses. The data reported here are part of an experiment designed to separate photosynthetic from phytochrome effects on fruit ripening and vine nutrition, and which will be subsequently reported (Smart *et al.*, in preparation). This report is limited to the activity of three light dependent enzymes, i.e., nitrate reductase (NR), phenylalanine ammonium lyase (PAL) and invertase, that are known to influence composition of grapes (Perez and Kliewer, 1982; Roubelakis-Angelakis and Kliewer, 1986; Smart, 1987b). Neutral shade cloth enables the PPFR value to be changed essentially independent of R:FR ratio (Smart, Smith and Winchester, 1988). Also, by altering or supplementing the light source of plants grown under natural shade conditions, especially by red light enrichment, the R:FR ratio can be changed independently of PPFR.

EXPERIMENTAL METHODS

Full details of the experiment will be presented subsequently (Smart *et al.*, in preparation) but the procedures were generally similar to those previously described (Smart, Smith and Winchester, 1988). *Vitis vinifera* L. 'Cabernet Franc' were grown from cuttings in 18 l pots under glasshouse conditions at Ruakura Agricultural Centre, Hamilton, New Zealand. Four treatments were used: (A) control (no shading), (B) three layers of neutral shade cloth, (C) dense natural vine shade, and (D) dense natural shade plus red light supplementation. There were five replicates with single plant plots. Red light supplementation was provided from dawn to dusk by 40W Thorn 'Super Gro' fluorescent tubes, which have a major emission peak at 660 nm (Smart, Smith and Winchester, 1988). The tubes were positioned about 20 cm from the clusters so that there was little difference in PPFR. Natural shade was provided by tightly grouping potted vines around the central test vine, and training shoots to cover the cluster region.

All plants were watered daily and received supplemental nutrient solution as required. Temperature within the glasshouse ranged between 12°C and 32°C. PPFR, R:FR ratio and fruit composition of the various treatments were determined as described by Smart, Smith and Winchester (1988).

In vivo nitrate reductase activity of the leaf opposite the cluster was measured on two occasions, but only data obtained from 15 January 1987 are presented. For this assay twelve, 10 mm diameter discs per leaf blade were used, following the procedure of Smith, Middleton and Edwards (1980). PAL enzyme extracts of berry skins sampled 27 January were prepared using liquid nitrogen to aid in pulverizing the skins. PAL enzyme activity was determined as described by Roubelakis-Angelakis and Kliewer (1985). Invertase activity of the berry pulp was determined on fruits at harvest using the procedure of Arnold (1965) as modified by Hawker (1969).

RESULTS AND DISCUSSION

A comparison of the light spectrum of treatments A, B, C and D is shown in Figure 18.2 and Table 18.2 summarizes the PPFR, R:FR ratio and temperature characteristics of the fruits from the four treatments. These data show that control fruits received 8 to 40 times more PPFR than the other three treatments; however, R:FR ratio of control fruits (treatment A) did not differ significantly from neutral shaded fruits (treatment B) and natural shaded fruits supplemented with red light (treatment D), but each of these three treatments had nearly 10-fold higher R:FR light ratios than the natural shaded fruits (treatment C), which had average R:FR ratio of 0.07. The main difference between treatments C and D was the higher amount of red wave band (660 nm) in the cluster region of the latter treatment. Therefore, differences in fruit composition and enzyme activities between treatments C and D are presumed to be phytochrome responses at low PPFR due to differences in R:FR light ratios, whereas differences between treatments A vs. B, A vs. D and B vs. D are considered mainly

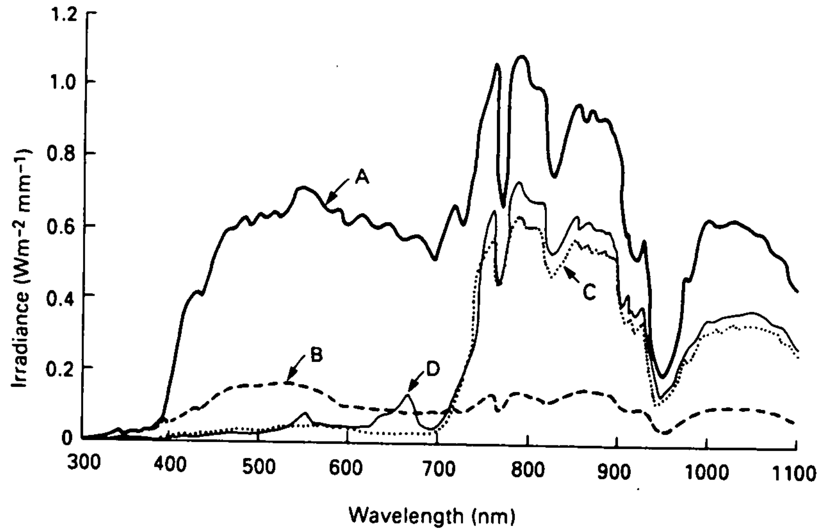

Figure 18.2 Spectral distribution of light measured in the cluster zone of treatments A, B, C, and D over the wavelength range of 300 to 1100 nm. A = control (full sun), B = two layers of neutral shade fabric, C = dense natural shade in cluster zone, and D = dense natural shade plus red light

Table 18.2 LIGHT QUANTITY, QUALITY AND TEMPERATURE CHARACTERISTICS OF 'CABERNET FRANC' FRUIT GROWN UNDER FOUR DIFFERENT LIGHT CONDITIONS*

	Treatment	*PPFR of exposed leaves at top of vine* (μEm $^{-2}$s $^{-1}$)	*Cluster microclimate*		
			PPFR (μEm $^{-2}$s $^{-1}$)	*Quantum ratio* (660–730 nm)	*Temperature* (°C)
A	Control (full sun)	1076a†	321a	0.74a	25.3a
B	Neutral shade	1058a	42b	0.67a	26.2a
C	Natural vine shade	1039a	8c	0.07b	24.9a
D	Natural vine shade + supplemental red light	1070a	16c	0.62a	25.3a

*Data represents the mean of measurements made mid-day on five different days under sunny conditions.
†Means within a column followed by the same letter did not differ significantly at the 5% level using Duncan's Multiple Range Test.

photosynthetic responses due to differences in the levels of PPFR. The fruiting region of the control vines received a much higher level of PPFR than the other three treatments (Table 18.2). Also, note that vines enclosed with neutral shade fabric on the basal portion of shoots had significantly higher PPFR than treatments C and D vines, but considerably less than the control. The apical portion of shoots of all treatments was well exposed and received the ambient level of PPFR that entered the glasshouse. The average glasshouse transmission of sunlight over the 400 to 700 nm waveband was about 66% that of the sky outside the glasshouse as measured by a spectroradiometer (Smart, Smith and Winchester, 1988).

Fruit clusters exposed to red light (treatment D) that were otherwise naturally shaded (< 1% of ambient PPFR) had considerably higher levels of sugar (total soluble solids) and anthocyanin than natural shaded fruits that received no supplemental red light (treatment C) on both 15 and 27 January sampling dates (Table 18.3). Natural shaded fruits were lighter in weight, had less colour, and did not ripen as fast as similar fruits that received supplemental red light. The exposure of natural shaded fruits to red light advanced ripening by 7 to 10 days compared to similar fruit receiving no supplemental red light (Table 18.3). However, control fruits, which received the highest level of PPFR, but had similar R:FR ratio as treatments B and D, ripened about one week ahead of fruits shaded by the neutral shade cloth or natural shaded fruits receiving supplemental red light (Table 18.3). These data indicate that both high levels of PPFR and R:FR light in the cluster region are needed for maximum accumulation of sugar and anthocyanins as well as for highest berry weight. It is also interesting to note that neutral shaded fruits and natural shaded fruits supplemented with red light, both of which had similar R:FR ratios but slightly different amounts of PPFR (Table 18.2) did not differ in fruit composition or enzyme activity at any of the three sampling dates (data not presented) except on 27 January, when °Brix of neutral shaded fruits was greater than treatment D fruits (Table 18.3). This difference was probably a photosynthetic response.

Reduced levels of photosynthetic and red light significantly reduced the activity of nitrate reductase in the leaf opposite the cluster and PAL and invertase activities in fruits (Table 18.3). These data strongly suggest that phytochrome was playing a role in activation of nitrate reductase in leaves and PAL and invertase enzymes in fruits. High levels of PPFR in the fruiting region also further stimulated the activities of both enzymes so that apparently both photosynthetic and phytochrome effects were involved. Perez and Kliewer (1982) have shown that low PPFR markedly increased nitrate in petioles and blades and decreased nitrate reductase activity in several grape varieties. Roubelakis-Angelakis and Kliewer (1986) also found that PPFR stimulated PAL activity in grape berry skins. They showed that PAL activity in skins of intact grape berries held in the dark declined by more than 80% over a period of 60 hours.

In a recent glasshouse experiment, Smart, Smith and Winchester (1988) reported that red light supplementation of potted vines shaded with three layers of neutral shade cloth increased the nitrate reductase activity of leaves and the concentration of

Table 18.3 INFLUENCE OF LIGHT QUALITY AND QUANTITY ON COMPOSITION OF 'CABERNET FRANC' BERRIES AND PHENYLALANINE AMMONIUM LYASE (PAL), INVERTASE, AND NITRATE REDUCTASE (NR) ACTIVITIES*

Treatments		*Berry wt* (g)†	°*Brix*†	*Anthocyanins* (*OD units* @ 525 nm)	PAL‡	*Invertase*‡	*NR*§
A	Control (full sun)	1.30a	21.05a	0.54a	0.63a	9.8a	4.1a
B	Neutral shade	1.16b	19.60b	0.42b	0.39b	5.4b	2.5b
C	Dense vine shade in cluster zone	0.95c	16.84d	0.24d	0.18c	3.4c	1.4c
D	Dense shade plus red light	1.05b	18.08c	0.35b.c	0.30b	5.5b	2.0b

*Within a column, means followed by the same letter did not differ significantly using Duncan's Multiple Range Test.

†Data are for fruits sampled on 27 January 1987.

‡PAL and invertase enzyme activities were determined on berry skin and pulp tissues, respectively, from fruits sampled on 27 January and at harvest. Units of activity are µmol trans cinnamic acid $g^{-1}hr^{-1}$ and µmol glucose · g^{-1} · 10 min^{-1}.

§NR = nitrate reductase activity of leaf opposite cluster sampled on 15 January. Units of activity are µmol NO_2 $hr^{-1}g^{-1}$.

sugar in the fruits at harvest compared to similar shaded vines that received no red light enrichment. They also observed an earlier fruit colour in the former treatment; however, at harvest fruit colouration between the two treatments did not differ. In their experiment the quantum ratio of R:FR light was 0.86 or greater for all treatments and, therefore, could not provide as clear a discrimination between photosynthetic and phytochrome effects as the experiment reported here. Similar findings were found in the present study when natural shaded clusters in a low R:FR environment (< 0.1) received supplemental red light. In both of these studies, reducing the level of PPFR in the cluster region markedly delayed sugar accumulation in fruits and anthocyanin formation in berry skins.

Presumably, phytochrome was controlling some aspects of fruit ripening in both cases. The increased activity of PAL and invertase in fruits in the presence of red light in an otherwise low PPFR environment suggest that these two enzymes may be playing a direct role in increasing the level of anthocyanin and sugar in grape berries.

Recent vineyard field studies by Kliewer *et al.* (1988) revealed that leaf removal in the fruiting zone also increased the concentration of sugar in Sauvignon blanc fruit at harvest compared to no leaf removal. Since leaf removal in the fruiting region increased the amount of PPFR and R:FR light ratio of fruits (Kliewer *et al.*, 1988), the increased level of sugar in fruits from leaf removed vines may be due to enhanced activities of PAL and invertase enzymes caused by higher levels of PPFR and/or red light.

Trellis-training systems for improvement of canopy microclimate, productivity and fruit quality

Modification of canopy architecture by trellis-training systems provides a relatively easy method of increasing the amount of exposed canopy surface area, R:FR ratio and reducing shoot and fruit crowding. These changes in the canopy microclimate are generally accompanied by increased productivity as well as improvement in grape and wine quality. In recent years several new types of trellis-training systems have been designed that divide grapevines either horizontally or vertically into two or more separate canopies. The characteristics of these trellis systems have been reviewed by Shaulis and Smart (1974), Kliewer (1982), Shaulis (1982), Smart (1985a, b), Smart (1987a) and Smart and Smith (1988).

METHOD

A recent trellising experiment was conducted at the University of California experimental vineyard, Davis, comparing four different types of trellis systems (Figure 18.3), using 'Sauvignon Blanc' grapevines over a period of three years. The details of this experiment are published in a thesis (Schuck, 1987). The U, V, and Wye (W) trellis systems are horizontally divided canopy type trellis systems, whereas the 'T'-trellis is a non-divided trellis system commonly found in commercial vineyards in California and served as a control. All treatment vines were cordon trained and spur pruned to 64 buds per vine. Shoots from vines on the U, V, W and T-trellis systems were directed to grow respectively to vertically upward, at a 45° angle, mostly downward, and at various intermediate angles. Light measurements were made at hourly intervals with a LI-191SB line quantum sensor between 1000 and 1400 hours

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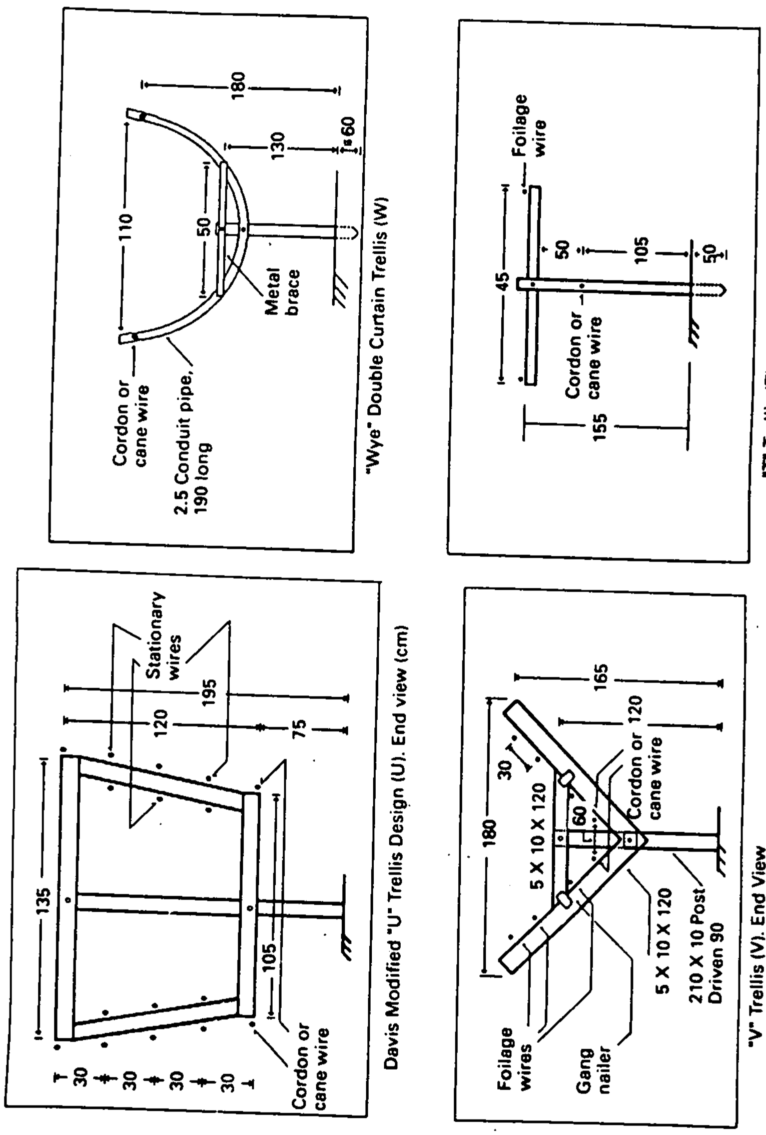

Figure 18.3 End view showing the size and dimensions of four trellis systems used for growing 'Sauvignon Blanc' grapevines. Vines trained to the U, V, and W-trellis systems had divided canopies, whereas T-trellised vines were a single canopy

with the sensor held horizontal facing upward in the fruiting region on six separate sunny days between veraison and harvest in 1986 and 1987. This sensor overestimates mean light levels if sunflecks are incident on it.

RESULTS

Crop yields of the U, V and W divided canopy trellis systems were 53 to 67% higher than the single canopy T-trellis, which is equivalent to an increase of 13.2 to 16.8 t ha^{-1} (Table 18.4). The increase in yield was due to greater number of clusters per vine and higher fruit set or numbers of berries per cluster (Table 18.4). The increase in cluster number resulted mainly from increase in the number of basal shoots that developed from the whorl of buds at the base of two node spurs. The PPFR at mid-day in the fruiting region was four to eight times greater in the U, V and W-trellis systems compared to the non-divided T-system. The PPFR was directly correlated with the increase in bud break of base buds.

Pruning weights of the U and V-trellis systems were significantly greater than the W and T-trellis systems (Table 18.4). Shoot vigour, as indicated by the number of primary leaves per shoot and cane weight, was lowest in W-trellised vines and highest

Table 18.4 INFLUENCE OF TRELLIS SYSTEM ON YIELD, YIELD COMPONENTS, VINE GROWTH AND FRUIT COMPOSITION OF 'SAUVIGNON BLANC' GRAPEVINES AT HARVEST, DAVIS, CA (AUGUST 1985 AND 1986 SEASON)

Parameter	*Trellis system*				
	Divided canopies			*Single canopy*	
	U	*V*	*W*	*T (control)*	*LSD (α 5%)*
Crop yield (kg/vine)	34.4	37.1	33.9	22.2	3.2
(t/ha)	38.5	41.6	38.0	24.8	3.6
No. cluster/vine	197.1	190.3	191.6	128.7	13.0
Berry weight (g)	2.45	1.53	1.44	1.66	0.10
Cluster weight (g)	175.9	195.5	176.3	173.2	15.6
No. berries/cluster	122.1	127.7	122.8	91.0	11.2
Total no. shoot/vine	73.9	71.6	71.4	48.5	7.4
No. basal shoots/vine	33.7	31.5	35.7	17.8	5.9
No. secondary shoots/vine	5.0	10.5	14.0	7.2	6.9
Pruning wt (kg/vine)	6.3	5.2	3.8	4.0	1.3
Pruning wt (kg)/m cordon length	1.31	1.01	0.79	1.67	0.28
No. leaves/shoot	36.5	37.2	27.3	37.9	3.6
No. yellow leaves/shoot	2.5	2.0	1.1	6.4	0.95
Cane wt (g/shoot)	118.2	101.2	71.4	147.6	17.4
Crop wt/pruning wt ratio	5.5	7.1	8.9	5.5	1.4
Total soluble solids in berry juice (°Brix)	21.8	22.9	23.8	21.4	1.2
Total sugar in fruit/vine (kg)	7.50	8.50	8.06	4.75	0.54
Titratable acidity (g/l)	10.1	8.9	8.8	9.5	0.62
pH	3.24	3.25	3.20	3.26	0.04
Malate (g/l)	3.7	2.8	2.5	3.5	0.39
Potassium (ppm)	1643	1543	1559	1685	117
PPFR in cluster zone (% of ambient)	6.4	31.2	35.4	4.2	

in the T-trellis with U and V vines intermediate (Table 18.4). The weight of pruning per unit of cordon length of W-vines (0.79 kg m^{-1}) was about half that of T-vines (1.67 kg m^{-1}) but still above that considered optimal for an ideal microclimate in a cool climatic region (see Table 18.1). The ratio of crop weight to pruning weight or so called conversion factor was significantly higher for the W-trellis than the other three trellis systems, indicating that this system was the most efficient in converting vegetative growth into fruit production. W-vines had the highest PPFR in the cluster region, fewest number of yellowing or senescent leaves at harvest as well as the highest concentration of sugar or total solubles in fruits, all indicative of favourable canopy light microclimate (Table 18.4).

The highly shaded fruit cluster environment of the T and U-fruits (4 to 6% of ambient) was reflected by the relatively low level of sugar and high levels of titratable acidity, malate and potassium compared to V and W-fruits (Table 18.4). W-fruits also had significantly lower pH than the other treatments. These findings are in general agreement with several other studies dealing with shading effects on composition of grapes (see Smart, 1982, 1985a, b, 1987a and references cited therein).

Leaf removal in the fruiting region of dense canopy vineyards

In dense canopy vineyards leaf removal in the fruit zone offers a convenient way to reduce fruit shading and improve the canopy microclimate, i.e., increase PPFR, air movement, evaporation rate, daytime temperatures and reduce relative humidity (Gubler and Marois, 1987; Bledsoe, Kliewer and Marois, 1988; Kliewer *et al.*, 1988). These changes in the microclimate after leaf removal, especially the PPFR, were negatively correlated with the level of hydrogen ions (pH), titratable acidity, malate and potassium in berry juice (Bledsoe, Kliewer and Marois, 1988) and also with reduced incidence and severity of *Botrytis* bunch rot (Gubler and Marois, 1987). An increase in the rate of air movement in the cluster region after leaf removal has been shown to be mainly responsible for the reduced amount of *Botrytis* bunch rot (Thomas, Marois and English, 1988).

In a highly vigorous 'Sauvignon Blanc', Napa County, California, vineyard, leaf and lateral shoot removal from three to four nodes immediately adjacent and opposite the clusters at fruit set resulted in significant increases in cluster temperature, PPFR, R:FR ratio, evaporation rate and reduction in RH during the final week before harvest (Table 18.5). Leaf removal increased the PPFR and R:FR ratio in the fruit zone at harvest about five and four-fold, respectively. As was previously shown (Bledsoe, Kliewer and Marois, 1988), leaf removal significantly increased the level of total soluble solids in the fruit and reduced titratable acidity, malic acid, pH, potassium and arginine (Table 18.5).

In the third year of the leaf removal trial the Merbein bunch count procedure (Antcliff *et al.*, 1972) was used to determine the sources of yield variation between the leaf removed and no leaf removed vines (Table 18.6). Leaf removal increased the number of shoots/node, clusters/shoot, flowers/cluster, fertilized berries/cluster, cluster weight, crop weight and crop weight/pruning weight ratio, but had no effect on fruit-set, berry weight and pruning weight. The increase in shoots/node, clusters/shoot and flowers/cluster in leaf removed vines was directly related to increases of PPFR and R:FR ratio in the cluster region, and also to cluster temperature. What contribution each of these climatic factors had on enhancement of the crop yield and yield components is not known; however, both PPFR and temperature are known to

Table 18.5 INFLUENCE OF LEAF REMOVAL ON THE MICROCLIMATE IN THE CLUSTER REGION AND COMPOSITION OF 'SAUVIGNON BLANC' BERRY JUICE AT HARVEST (26 AUGUST 1986). NAPA VALLEY, CA

	Control (No leaf removal)	*Leaf removal in fruit zone**	*LSD @ 5%*
Cluster temp. (°C)†	26.8	27.5	0.35
PPFR (% of ambient)‡	3.9	20.7	4.8
660/730 nm ratio	0.16	0.61	0.12
Relative humidity (%)	37.0	33.6	2.9
Total soluble solids (°Brix)	21.1	21.8	0.40
Titratable acidity (g/l)	12.2	11.8	0.26
Malic acid (g/l)	5.5	4.8	0.21
pH	3.19	3.11	0.02
Potassium (mg/l)	1595	1483	37
Arginine (mg/l)	1340	1060	98

*Leaf removal consisted of removal of the leaf and subtending lateral from one node above, opposite and one node below clusters on each shoot at fruit-set.
†Cluster temperature represents the average temperature from 0600 to 1800 hours using a Cambell CR21 micrologger and CSI 101 probes positioned within clusters. Average ambient temperature was 27.9°C.
‡PPFR is the photosynthetic photon fluence rate measured with a Li Cor 185 light meter and 1905B quantum line sensor between 1100 and 1300 hr. Ambient PPFR = 2080 $\mu Em^{-2}s^{-1}$.

Table 18.6 INFLUENCE OF LEAF REMOVAL IN THE CLUSTER REGION ON CROP YIELD, YIELD COMPONENTS AND PRUNING WEIGHT OF 'SAUVIGNON BLANC' GRAPEVINES. DATA ARE FOR THE THIRD YEAR OF LEAF REMOVAL

	Control (No leaf removal)	*Leaf removal in fruit zone*	*LSD @ 5%**
Shoots/node	1.21	1.44	0.18
Clusters/shoot	1.45	1.54	0.08
Flowers/cluster	207	254	41
Fertilized berries/cluster	82.7	93.8	8.8
Fruit-set (%)	46.0	45.4	NS
Berry wt (g)	1.74	1.76	NS
Cluster wt (g)	144	166	17
Crop wt (kg/vine)	11.5	14.1	2.1
Pruning wt (kg/vine)	6.8	6.6	NS
Crop wt/pruning wt	1.69	2.14	0.32

*Indicates difference between treatment means at the 5% level.
NS = not significant.

have marked effects on fruit primordia formation in grapevines (Winkler *et al.*, 1974). Whether phytochrome plays a role in initiation of fruit primordia is not known and more work in this area is urgently needed.

In order to determine if the effects of leaf removal in the cluster region on fruit composition was due to increased amount of cluster exposure to light or differences in cluster temperature, an experiment was conducted using vines in the same vineyard as that described previously. Two clusters per vine from 12 leaf removed and 12 no leaves removed vines at fruit-set were enclosed with aluminum foil bags to exclude all light from the clusters from fruit set (7 June) until harvest on 22 August. Ventilation of the clusters was provided by small openings at the ends of the bags. A Cambell CA21 micrologger was used to monitor temperature and PPFR. Temperature of bagged and unbagged clusters differed by $< 0.5°C$ and bagged clusters received essentially no PPFR ($< 1\ \mu Em^{-2}s^{-1}$). The PPFR of clusters not bagged from vines in each treatment ranged from 10 to 80 (leaves removed) and 60 to 450 (leaves not removed) $\mu Em^{-2}s^{-1}$ between 800 and 1600 hours. Exclusion of all light from clusters reduced the concentration of sugar, pH, and arginine and increased the level of titratable acidity and malate in the berry juice at harvest (Table 18.7). There was an interaction between bagging and leaf removal treatments with respect to berry weight and potassium. Exclusion of light from clusters had no effect on berry weight and concentration of K in berry juice of vines with no leaf removal but significantly reduced berry weight and increased the level of K in fruits of leaf removed vines. The PPFR in the cluster region of vines with no leaf removal was at about the light compensation point, i.e., $30\ \mu Em^{-2}s^{-1}$, for most of the day and further reduction of PPFR had little effect on berry weight and K. However, exclusion of light from clusters of leaf removed vines by bagging, which were exposed to PPFR well above the light compensation point (Table 18.5), reduced berry weight and the concentration of all the constituents measured in the fruits compared to the non-bagged fruits (Table 18.7). However, this experiment does not distinguish whether the effects of cluster bagging on grape composition and berry weight were due to photosynthetic or phytochrome effects.

Leaf removal in the cluster region of vines bagged and not bagged reduced the concentration of arginine in fruits at harvest compared to control fruits (Table 18.7). Shading the fruit clusters of vines with no leaf removal also reduced the level of arginine in the fruits; however, in leaf removed vines, excluding light from cluster only minimally reduced arginine in fruits. Why cluster bagging markedly reduced the concentration of arginine in fruits from control vines (not leaf removed) but not in fruits from basal leaf removed vines is not known. However, previous studies have shown that shading whole vines markedly alters the nitrogen metabolism, resulting in

Table 18.7 INFLUENCE OF LEAF REMOVAL IN THE CLUSTER REGION AND EXCLUSION OF LIGHT FROM CLUSTER BY BAGGING ON COMPOSITION OF 'SAUVIGNON BLANC' GRAPES AT HARVEST (22 AUGUST 1986), WOODEN VALLEY, CA*

Parameter	*No basal leaf removal*		*Basal leaf removal*	
	Not cluster bagged	*Cluster bagged*	*Not cluster bagged*	*Cluster bagged*
Berry wt (g)	1.46a	1.42a	1.69b	1.39a
TSS (°Brix)	21.8c	20.4a	22.5d	21.0b
pH	3.28d	3.10b	3.15c	3.06a
TA (g/l)	11.45b	13.10c	10.4a	13.2c
Malate	5.0b	5.9d	4.1a	5.5c
Potassium (mg/l)†	1610c	1580bc	1445a	1522b
Potassium berry (μg)	4605b	4080a	4667b	4043a
Arginine (μg/g)	1710a	940b	1110b	1010b

*Within a row means followed by the same letter did not differ significantly at the 5% level using Duncan's Multiple Range Test.
†Potassium determined on centrifuged berry juice sample.

increased levels of NO_3, NH_4, total N and arginine in fruits (Kliewer and Lider, 1968; Perez and Kliewer, 1982; Smart, Smith and Winchester, 1988b). The current study showed that localized shading of fruit clusters or leaf removal in the fruiting region markedly reduced the accumulation of arginine in 'Sauvignon Blanc' berries.

Conclusions

Both light quality (R:FR ratio) and quantity (PPFR) effects on fruit composition and ripening of grapes were found. Exposure of dense naturally shaded grape clusters (R:FR ratio < 0.1) to supplemental red light that increased the R:FR ratio to 0.6 to 0.7 without significantly changing the PPFR, advanced the beginning of fruit ripening by seven to ten days, markedly enhanced berry weight and levels of sugar and anthocyanin in fruits and increased the activities of PAL, invertase and NR enzymes. Exposure of fruits to full sunlight (high levels of PPFR ($> 300\,\mu Em^{-2}s^{-1}$) and R:FR ratio (~ 0.70) further increased sugar and anthocyanin formation and activity of the three enzymes above that of fruits exposed to low PPFR ($< 50\,\mu Em^{-2}s^{-1}$) but with R:FR ratios similar to exposed fruit. These findings indicate that both phytochrome and photosynthesis influence fruit composition and ripening of grapes.

Leaf removal in the cluster zone as well as canopy division by trellising greatly improved the canopy microclimate, especially the PPFR and R:FR ratio in the cluster region. Closely associated with these microclimate changes were increased levels of sugar in fruits and reduction in titratable acidity, pH, malate and potassium in berry juice, all generally considered positive for high wine quality. Trellis systems that reduced interior canopy shading also had the added advantage of increasing crop yield, mainly through increase in development of shoots from basal buds that increased the number of clusters per vine as well as greater number of berries per cluster. Canopy division by trellising is a proven means of maintaining a desirable microclimate for high shoot numbers per hectare and producing high crop yield of quality fruit.

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Influence of Shoot Orientation on Growth and Yield Development in Cabernet Sauvignon

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Beginning shortly after budbreak, 28 shoots from 14 mature field grown Cabernet Sauvignon vines at Davis,California, were trained to grow upward, horizontally, and downward. The plastochron index (PI) and leaf initiation rate (LIR) of each shoot were determined at four-day intervals until they reached a PI of 19. Cane pruning weight and time of budbreak were related to shoot growth rate and were thus used as covariates for testing the effects of growth direction. Downward-trained shoots generally exhibited reduced vigor as demonstrated by lower LIR and shoot extension rate, smaller primary leaves, fewer lateral leaves, and a lower cane dry weight density than did upward or horizontal shoots. The period from budbreak to bloom for downward-trained shoots averaged 2.3 days less than that for upward-trained shoots. At veraison, °Brix of fruits from upward-trained shoots was significantly higher than that for downward shoots. Percent fruitset did not differ between upward and downward shoots but was lower for horizontal shoots. The number of berries per shoot, however, did not differ among growth direction treatments.

KEY WORDS: Cabernet Sauvignon, shoot positioning

Currently, there is worldwide interest in developing canopy management practices that improve canopy microclimate and grape and wine quality through reduced shoot vigor. Several new trellis-training systems have been described in the last 10 to 20 years that change the arrangement and direction of shoot growth (7). The Geneva double curtain, introduced by Shaulis et al. (10), developed the idea of dividing grapevine canopies and directing shoots to grow downward by shoot positioning. Other training systems promote shoot growth vertically upward, as in the "U" or lyre (2), Te Kauwhata two tier (TK2T) (11), and Bordeaux traditional (2); horizontally as in the Tendone and Lincoln trellis (5); or inclined at intermediate angles as in the Tatura (12) and South African wide slanting arm trellis (13). Visual observations of shoot growth on several of the above trellis systems in a Davis, California, vineyard revealed that shoots directed to grow downward did not grow as long nor did they develop as many strong laterals as shoots trained upward, horizontally, or at inclined angles. This suggests that directing shoots to grow downward may be a useful technique to control excessive growth in high-vigor vineyards. With mechanization of most vineyard operations quickly becoming a reality as a means of reducing cost of production, methods of pruning and training shoots to grow in a fixed direction are certainly possible.

Effect of shoot direction on characteristics of shoot development, such as growth rate, leaf initiation rate, fruiting, and lateral growth has received little investigation. May (8,9) found that vertically trained Sultana shoots exhibited higher vigor and bud fruitfulness and produced larger inflorescence primordia than horizontally trained shoots. When dormant, vertically trained shoots also had higher dry weights per unit length than horizontal or "normal" habit shoots. Detailed information on how shoot direction influenced vegetative and reproductive development in the current year was not obtained. Other studies have found that positioning shoots to grow downward at flowering results in a reduction of vine pruning weights (9,10). The purpose of this investigation was to determine the influence of growth direction on the vegetative and reproductive development of individual well-exposed Cabernet Sauvignon shoots.

Materials and Methods

Fourteen, 12-year-old own-rooted Cabernet Sauvignon vines (FPMS clone #8) located at the UC Davis experimental vineyard were used in this study. The vine × row spacing was 2.4 × 3.6 m in east to west rows. Training was to a four-wire double crossarm trellis with the lower arm 0.4 m wide and 1.1 m from the ground, and the upper arm 0.9 m wide and 0.4 m above the lower crossarm. Fruiting and foliage catch-wires were attached to the ends of the lower and upper crossarms, respectively.

Each vine was dormant-pruned on 9 March 1987, to two, two-year-old cordons on the south side of the vines and two 15- to 18-node canes on the north side. Each cordon was pruned to three, seven-node canes and three, two-node spurs. The section from nodes 8 to 11 of each of the seven-node canes was kept for determinations of fresh and dry weight, internode length, flatness, and arginine content (6). Flatness was determined by dividing the thickest by the thinnest diameters of the most proximal internode of the cane sections.

To promote shoot development from the center node on the seven-node canes, each cane was bent to a bow shape and tied to the cordon. During budbreak, this

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node was allowed to develop a single shoot and all other shoots were removed. Shoots developing from the two-bud spurs were retained for vigor control only and were directed toward the north side of the vine to insure that the experimental shoots on the seven-node canes obtained uniform full sun exposure. Three training directions (vertical upward, horizontal, and vertical downward) were randomly assigned to the shoots developing from the three canes on each cordon. To facilitate the upward and downward training, 2-m bamboo stakes were fastened to the fruiting wire and to the cordon adjacent to the selected shoots. Shoots selected to grow horizontally were tied to the fruiting wires. Training of each shoot began about 10 days after leaves were first visible. Growth was maintained in the desired direction by tying each shoot to the stake or wire at four-day intervals.

Shoot growth rates were monitored until nine weeks after budburst by measuring the lamina lengths of expanding primary leaves every four days. At each time, the plastochron index (PI) (4) was calculated using a lamina reference length of 30 mm. An average leaf initiation rate (LIR) for each shoot was calculated as the coefficient from a linear regression of PI upon time.

When each shoot achieved a PI of 19, it was cut back to 15 nodes. At this time, the downward-trained shoots reached the ground, making it impossible to continue the training in a downward direction. Immediately after trimming each shoot, the lengths of all primary leaves and internodes retained were measured and the number of lateral leaves were counted at each node position. These data were collected at the time growth stopped for shoots that completed growth before they reached a PI of 19. The areas of all primary leaves were calculated by using the relationship between lamina length and leaf area found previously for Cabernet Sauvignon in the same plot (1).

To determine the number of flowers on each shoot, the clusters were enclosed with fine mesh transparent polyethylene bags (Delmel, Hercules Inc., Wilmington, Delaware) before bloom. After fruitset, the bags were removed and the number of abscised flowers and set berries were counted. The clusters were harvested on 20 July during veraison so that differences in fruit maturity could be easily distinguished. Total soluble solids (°Brix) of a random berry sample of each cluster was measured with an American Optical Model 10419 temperature-compensating refractometer. The number of berries per shoot was considered an estimate of yield.

Maximum and minimum air temperature data measured daily at the University of California, Davis, weather station (0.9 km from the research plot site) was used to calculate degree day accumulation. Growth rate profiles were plotted as change in PI per day versus days and change in PI per degree day versus degree days. These plots were compared to determine the influence of ambient temperature on the pattern of growth.

In the following winter, the dormant shoots (now canes) were harvested for final size determinations. Fresh and dry weights were measured on the canes and laterals separately. Cane volume was measured to determine cane dry weight density.

Statistical analysis: To determine the effects of growth direction on LIR, primary leaf size, and the number of lateral leaves, a set of covariates was first selected by regressing each upon several variables measured prior to growth. These included some chemical and physical properties of the dormant cane sections, time of budbreak, cane position along the cordon, and vine pruning weight. Both primary leaf size and the number of lateral leaves were related only to time of budbreak. Average LIR was related to spur flatness, vine pruning weight, and time of budbreak, but only the latter two were used as covariates, since spur flatness could be expressed as their linear combination. Multivariate profile analysis of repeated measures was used to analyze the effects of growth direction upon the shoot growth rate profiles and upon the distribution patterns of primary leaf sizes and lateral leaf numbers along the shoots. Two-dimensional partitioning (TDP) of yield variation (1,3) was used to analyze the effect of growth direction on yield development. The yield components analyzed were clusters per shoot, flowers per cluster, and berries per flower.

Results and Discussion

Shoot growth rate: The PI versus time profiles were cubic (Fig. 1). Growth direction affected the linear

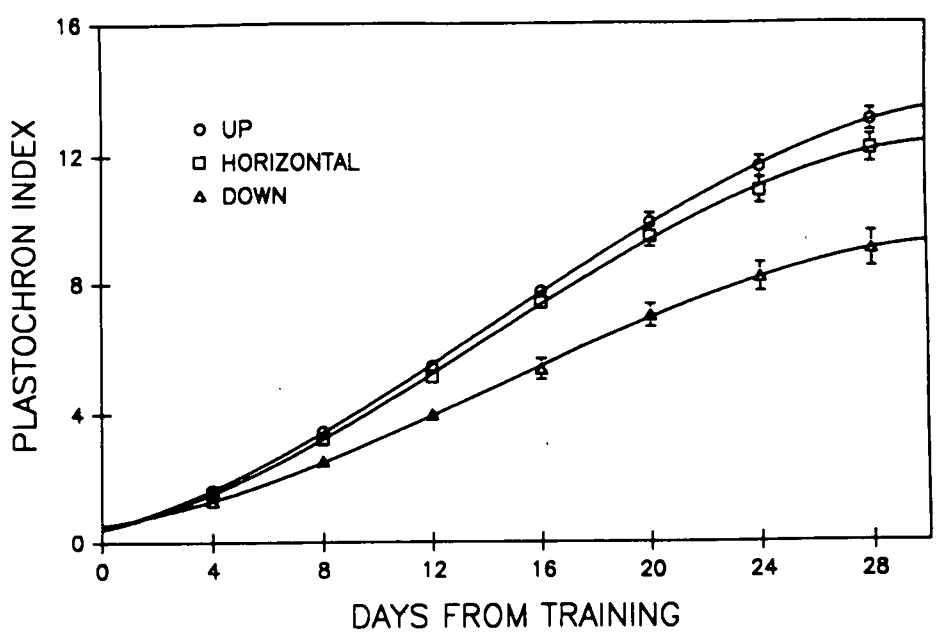

Fig. 1. Mean plastochron index versus days from training for Cabernet Sauvignon shoots trained in three directions. Vertical bars are ± SE. Training began approximately 10 days after budburst.

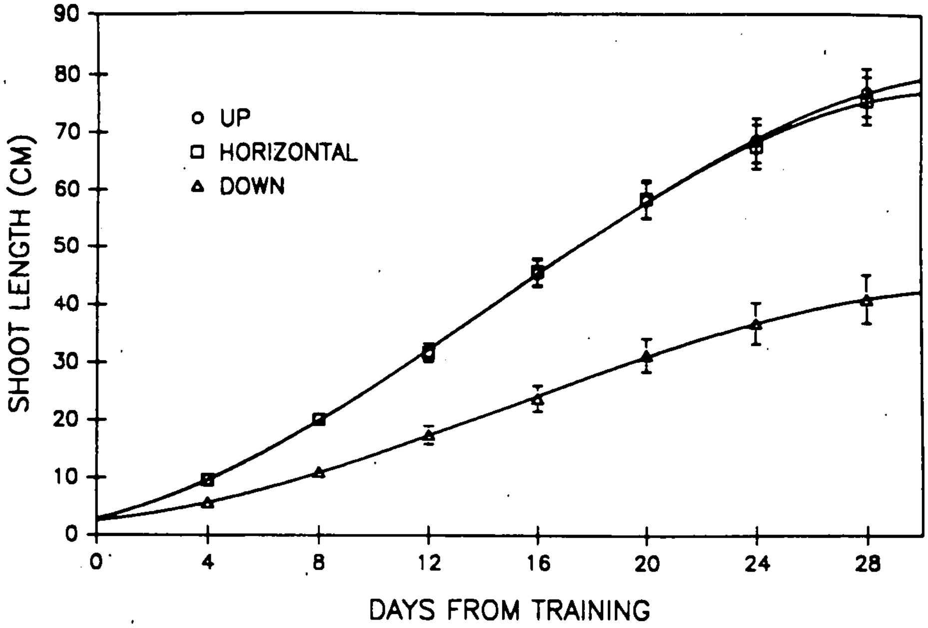

Fig. 2. Mean shoot length versus days from training for Cabernet Sauvignon shoots trained in three directions. Vertical bars are ± SE. Training began approximately 10 days after budburst.

component of the curves but not the quadratic or cubic components. Leaf number (PI) at 28 days from training was greatest for the upward-trained shoots followed by those trained horizontally and downward.

The shoot length versus time profiles were also cubic (Fig. 2). Growth direction affected both the linear and quadratic components of curves. Shoot length at 28 days from training for the upward and horizontally trained shoots was about double that of the shoots trained downward (Fig. 2). These great differences in shoot length resulted from both fewer leaves (lower PI) and shorter internodes on the downward-trained shoots (Table 1).

Table 1. Influence of growth direction on means of shoot and lateral characteristics in Cabernet Sauvignon.

		Shoot direction[x]	
Characteristic	Up	Horizontal	Down
Total primary leaf area per shoot (cm^2)	1795 a	1744 a	1226 b
Area per primary leaf (cm^2)	120 a	116 a	82 b
Internode length (cm)	5.77 a	6.04 a	4.22 b
Dry wt of dormant cane (g)	50.3 a	50.2 a	11.2 b
Dry wt per internode of dormant cane (g)	4.18 a	4.15 a	1.12 b
Dry wt density of dormant cane (g/cm^3)	0.18 ab	0.24 b	0.13 a
Total number of lateral leaves	39.0 a	37.3 a	17.3 b
Lateral leaves per node	2.6 a	2.5 a	1.1 b
Total dry wt of dormant laterals (g)	37.6 b	79.0 a	5.8 c

[x]Means within each row followed by the same letter did not differ significantly at $p = 0.05$ using Tukey's test.

The shoot growth rate profiles were generally quadratic. Growth direction affected overall growth rate with upward and horizontal shoots generally growing faster than downward-trained shoots. Time of budbreak was negatively related to overall growth rate, indicating that early developing shoots generally grew faster. The shape of the growth rate profiles was also influenced by time of budbreak. There was a tendency for leaf initiation to increase until the beginning of May, then decrease until mid- to late May, regardless of time of budbreak. An additional growth spurt toward the end of May was exhibited by shoots trained upward and by some shoots trained horizontally. The two growth flushes are best defined in the growth rate profiles plotted on a degree day basis (Fig. 3,4,5). A probable explanation for the first growth flush is the utilization and depletion of stored reserves such as carbohydrates and nitrogen. The second flush might have corresponded to the utilization of nutrients taken up by the roots, or when the majority of leaves on a shoot began exporting more photosynthate than they imported from stored reserves. It is not known why shoots trained down only showed one major growth flush (Fig. 5), while those trained up or horizontally showed two spurts of growth (Fig. 3, 4). Apical dominance, which is under hormonal control, may also have played a role in regulating the pattern of growth.

Primary leaf size: Profiles of the primary leaf size versus node number were fifth order (Fig. 6). Overall leaf size was negatively related to time of budbreak, indicating that early breaking shoots generally had larger leaves. Growth direction affected both overall leaf size and the shape of the leaf size profile (Fig. 6). From nodes 5 to 7, primary leaves were largest on upward shoots followed by horizontal and downward shoots. From nodes four through 15, leaves on downward shoots were smaller than those on both upward and horizontal shoots. Mean leaf size and total leaf area per shoot did not differ between upward and horizontal shoots but were smaller for downward shoots (Table 1). The direction to which a shoot is trained may thus affect its total leaf area by affecting both the number and size of primary leaves.

Lateral leaf number: Profiles of lateral leaf number versus node number were seventh order (Fig. 7). Shoots that broke late produced fewer total lateral leaves than shoots that broke early. Growth direction influenced both the mean number of lateral leaves per node (Table 1) and the shape of the lateral leaf number profile (Fig. 7). Downward-trained shoots generally produced stronger laterals near the shoot base (nodes 2 and 3) and weaker laterals at all other node positions

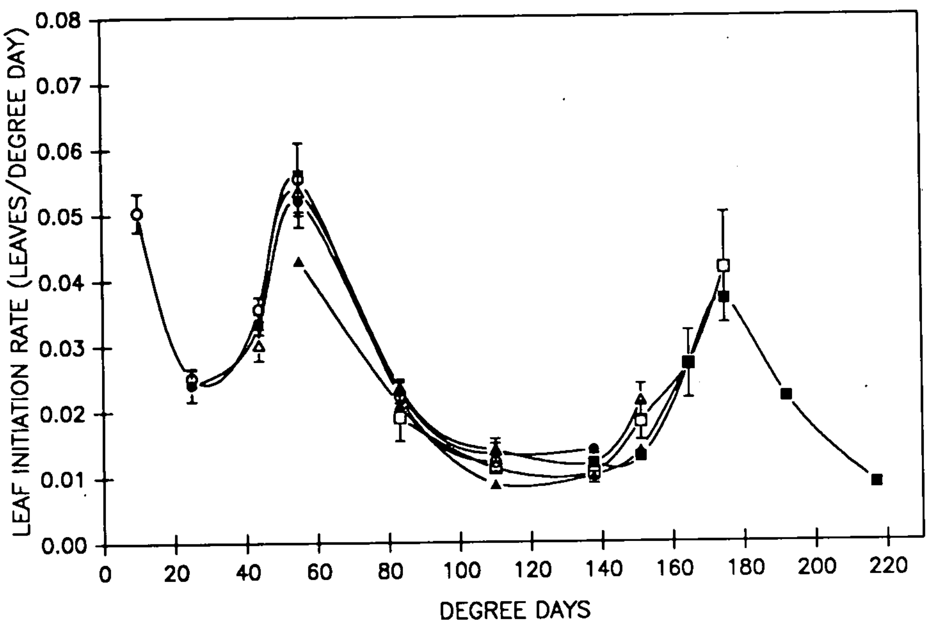

Fig. 3 (left). Mean leaf initiation rate expressed as leaves per degree day versus degree days accumulated since 20 April for six groups of shoots trained up. Each group consists of shoots trained on the same day. Vertical bars are ± SE.

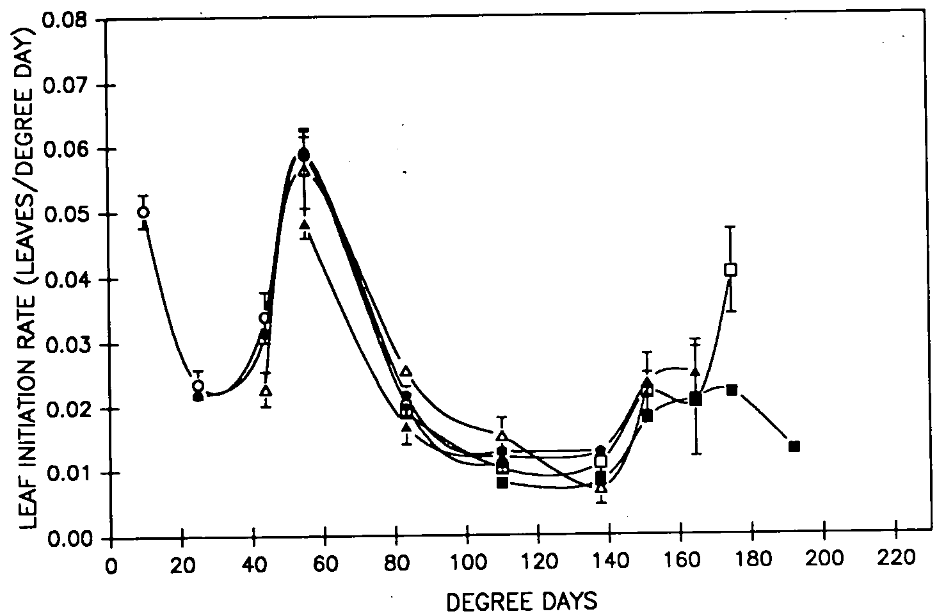

Fig. 4 (right). Mean leaf initiation rate expressed as leaves per degree day versus degree days accumulated since 20 April for six groups of shoots trained horizontally. Each group consists of shoots trained on the same day. Vertical bars are ± SE.

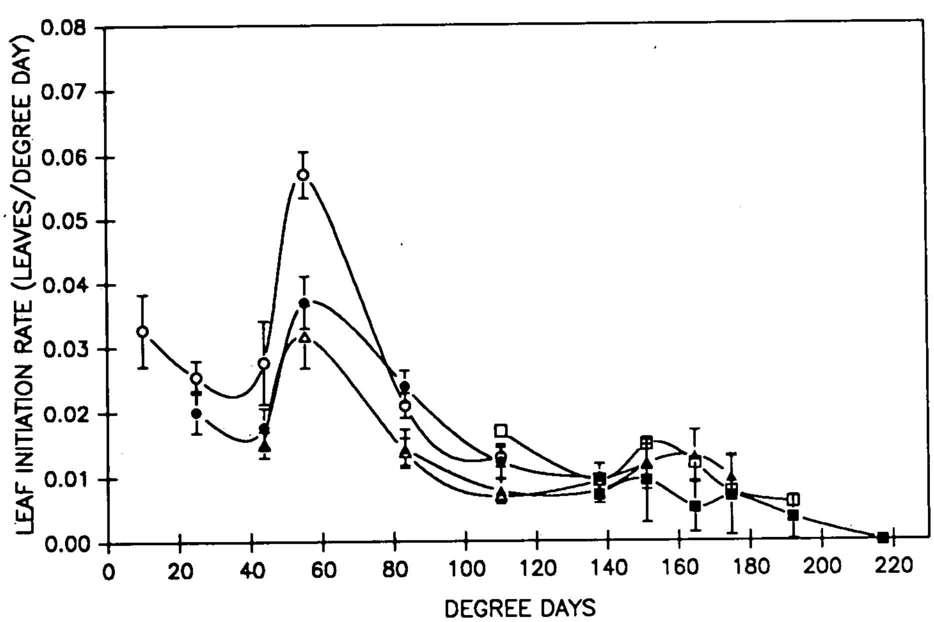

Fig. 5 (left). Mean leaf initiation rate expressed as leaves per degree day versus degree days accumulated since 20 April for six groups of shoots trained down. Each group consists of shoots trained on the same day. Vertical bars are ± SE.

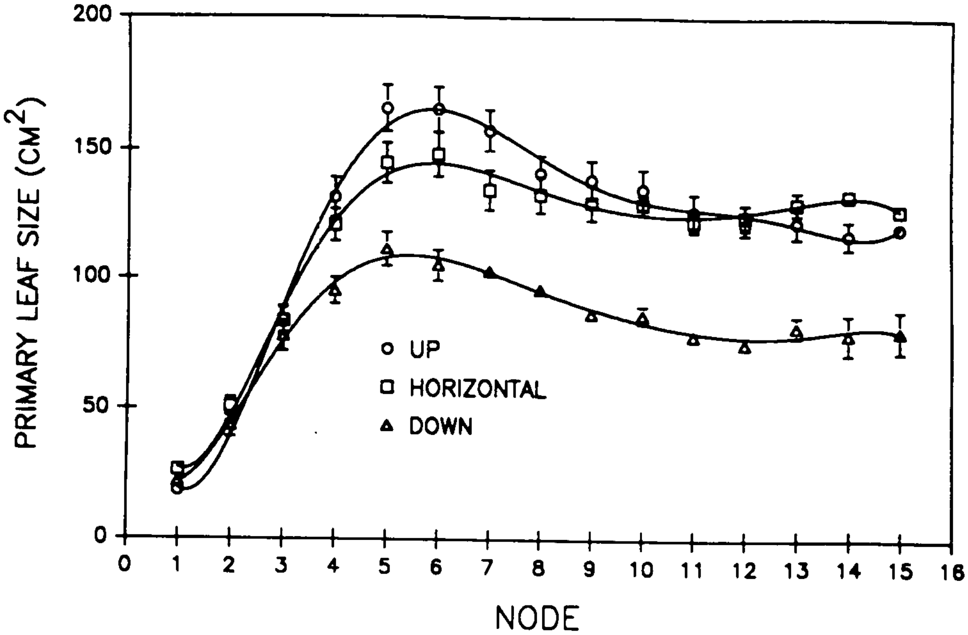

Fig. 6. Mean primary leaf size (cm²) versus node number from the base of the shoot for shoots trained in three directions.

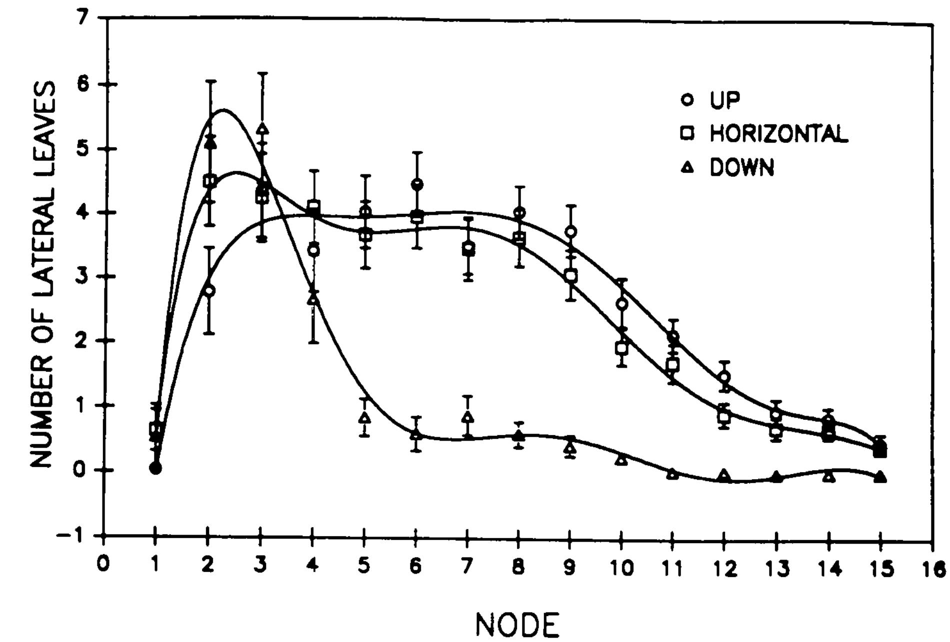

Fig. 7. Mean number of lateral leaves versus node number from the base of the shoot for shoots trained in three directions.

than did shoots trained upward or horizontally. Horizontal shoots produced similar laterals to those of upward shoots, except at node 2, where they produced a stronger lateral. In general, laterals tended to grow strongest where shoots were bent in training; *i.e.*, at nodes 2 and 3. Growth of laterals appeared to be influenced by apical dominance, since the strong growth of basal laterals on downward and horizontal shoots coincided with weaker lateral growth along the remainder of the shoots (Fig. 7).

Weights of dormant canes and laterals: Cane dry weight of downward-trained shoots was about one-fifth that of horizontal and upward-trained shoots (Table 1). Cane fresh weight followed the same pattern but was about 35% greater overall (untabulated). Cane dry weight per internode of the downward-trained shoots was about one-fourth that of upward and horizontal shoots. Cane dry weight density of downward shoots was less than that of horizontal shoots but not different from that of upward shoots.

Fresh and dry weight of dormant laterals on horizonatally trained shoots was about twice that of upward shoots and about twelve times that of downward-trained shoots. Lateral growth after the shoots were trimmed was, therefore, much stronger on horizontal shoots than on both upward and downward shoots.

Yield development: The period from budbreak to bloom for downward shoots was shorter (2.3 days less) than that for upward shoots but not different from that of horizontal shoots (Table 2). Percent fruit set for upward shoots was greater than that for horizontal shoots, but not different than that of downward shoots. When the fruit was harvested on 20 July, the °Brix of fruit from upward shoots was greater than that for downward shoots. Thus, although bloom was earlier on downward shoots than on upward shoots, fruit development was slower. This may have been due to the smaller total leaf area on downward shoots (Table 1).

Although percent fruit set differed among growth direction treatments, differences in total berries per shoot were not significant due to the high variation within treatments (Table 2). The partitioning of total variation in berries per shoot among yield components and among treatment sources is shown by the TDP results in Table 3. Partitioning among yield components is shown along the bottom row of the table. Cluster number and berries per flower (fruit set) were about equally important in determining berries per shoot. Flowers per cluster were less important. Variation in berries per flower or fruit set is partitioned among treatment sources in the third column of the table. Fruit set is shown to have varied most among individual vines, although differences attributable to growth direction were also significant. In the last column, treatment contributions to the variation in berries per shoot are shown to be sums of the treatment contributions to the individual yield components. The effect of growth

Table 2. Influence of growth direction on yield development characteristics in Cabernet Sauvignon.

Characteristic	Shoot direction[x] Up	Horizontal	Down
Budbreak to bloom (days)	29.4 a	28.2 ab	27.1 b
Fruit set (%)	33.1 a	24.7 b	28.8 ab
Berries per shoot	224 a	186 a	187 a
Fruit soluble solids (%)[y]	5.7 a	5.1 ab	4.1 b

[x]Means within each row followed by the same letter did not differ significantly at p = 0.05 using Tukey's test.

[y]Measured on 20 July at veraison.

Table 3. Two-dimensional partitioning of yield variation showing the percent contributions of variation sources to the number of berries on individual Cabernet Sauvignon shoots.

Sources of variation	Clusters	Flowers/ cluster	Berries/ flower	Interactions among components	Berries/ shoot
Vines	6	6	17*	-3	26
Cordons within vines	6	2	2	4	14
Shoot direction	1	1	3	-1	4
Residual	28	7	21	0	56
Total	41	16	43		100

*Significant at p = 0.05

direction on berries per flower is shown ultimately to have had a negligible effect on berries per shoot, since it accounted for only 3% of the total variation. Neither of the other treatment sources (individual vines and cordons within vines) contributed significantly to variation in berries per shoot.

Conclusions

Results of this study indicate that downward training reduces shoot vigor in Cabernet Sauvignon. Compared to shoots trained upward or horizontally, shoots trained downward exhibited reductions in growth rate, leaf size, internode length, lateral leaf number, and dormant shoot dry weight. Positioning shoots to grow downward may thus be desirable in highly vigorous vineyards, not only to increase the light exposure of the renewal zone (10) but also to reduce excess shoot growth. However, our results indicate that maturity may be slightly delayed on downward-trained shoots.

Time of budbreak influenced both shoot vigor and growth rate pattern. Early developing shoots generally had higher growth rates, larger primary leaves, and more lateral leaves than late developing shoots. Because the vines exhibited two growth flushes, the growth rate pattern of individual shoots depended on the time they began developing. Shoots trained downward, however, did not exhibit a second growth flush.

The shorter period from budbreak to bloom on downward-trained shoots indicates that early stages of cluster development were promoted by downward training. However, the lower °Brix of fruit and the reduction in total leaf area indicate that berry development was limited by insufficient leaf area on downward shoots, when training was begun shortly after budbreak. Downward shoot positioning at the time of flowering, as recommended for GDC training (10), would likely have little or no detrimental effect on fruit development and consequently would be more desirable for reducing shoot growth in highly vigorous vineyards.

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Influence of Grapevine Canopy Management on Evaporative Potential in the Fruit Zone

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Influence of Grapevine Canopy Management on Evaporative Potential in the Fruit Zone

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Evaporative potentials (the capacity of the atmosphere to evaporate water as quantified with atmometers) of canopies of two grape varieties were evaluated in relation to method of vine training and removal of basal leaves around grape clusters. In canopies of Chenin blanc, evaporative potentials were significantly less in bilateral cordon-trained vines supported by a standard U trellis than in bilateral and quadrilateral cordon-trained vines supported by one-wire and Geneva double curtain trellises, respectively. In Sauvignon blanc, evaporative potentials were significantly less in bilateral cordon-trained vines supported by a 46-cm, T-crossarm trellis than in quadrilateral cordon-trained vines supported by Davis modified U and extended Wye double curtain trellises. Leaf removal increased evaporative potentials significantly in vine canopies of all training and support systems. Evaporative potential was correlated significantly with the density of canopies associated with imposed training methods and leaf removal treatment. As the number of leaf layers through a canopy decreased, evaporative potential increased.

KEY WORDS: *Botrytis cinerea*, canopy management, evaporation, trellising

Bunch rot is a serious disease of grapes (*Vitis vinifera* L.) caused by *Botrytis cinerea* Pers. In recent years, efforts have been made to control this disease by modifying the structure of grapevine canopies. In particular, removal of basal leaves from shoots in the fruiting zone of vines has been found to control bunch rot effectively (2,3). This cultural practice has been adopted by many growers in California and has reduced considerably the need to apply fungicides for disease control in the absence of prolonged rainfall events.

Development of bunch rot is favored by cool temperatures, high humidity, and long periods of free moisture on surfaces of grape berries (4,5,7,8). Efforts have been made to determine if removal of leaves alters the microclimate in ways which are inhibitory to disease development. English *et al.* (2) found that removal of basal leaves changed temperature, atmospheric humidity, wind speed, and leaf wetness around grape clusters only slightly as compared to non-treated canopies. However, when these variables were considered simultaneously with multivariate statistical methods, differences in microclimates of treated and non-treated canopies could be discerned.

Evaporative potential, the capacity of the atmosphere to evaporate water, is a variable which was not included in initial studies of grapevine canopy microclimates. The magnitude of evaporative potential in a canopy depends largely upon vapor pressure deficit and wind speed (1,6,10). Evaporative potential provides a measure of the atmospheric moisture conditions around plant surfaces which influence critical events in the life history of *B. cinerea,* including spore germination, infection, and reproduction.

The potential importance of evaporative potential was shown in laboratory experiments in which growth and reproduction of *B. cinerea* on surfaces of infected berries decreased with increasing values of evaporative potential (10). Interruptions of these processes should slow development of bunch rot epidemics. In subsequent field experiments, evaporative potential was increased significantly by removal of leaves in the fruit region (1). The level of evaporative potential attained also was influenced by canopy density, described as the number of leaf layers through a canopy, associated with different degrees of leaf removal (1).

Removal of leaves from the fruit zone may represent only one means of reducing canopy density and increasing evaporative potential. Thus, investigations were undertaken to examine how the method of training and supporting vines influences canopy density and evaporative potential in the fruit zone.

Materials and Methods

In 1987, evaporative potentials were quantified in grapevine canopies of Chenin blanc and Sauvignon blanc. Experiments were performed in the vine training comparison plots established by W. M. Kliewer on the campus of the University of California, Davis. Vines of both varieties were established on A × R rootstock in 1984 and 1982, respectively. During 1987, experimental plots were furrow-irrigated with 60 mm of water during the first week of June and the second week of July. There was no rain, fog, or dew during the measurement period. No fertilizer was applied at any time. Growth of all vines was vigorous; pruning weights of all training systems examined averaged over 1.2 kg/m of cordon length.

Within each cultivar, a split plot design was employed to evaluate the effects of training system and removal of leaves in the fruit zone on canopy density and evaporative potential of the canopy atmosphere. The

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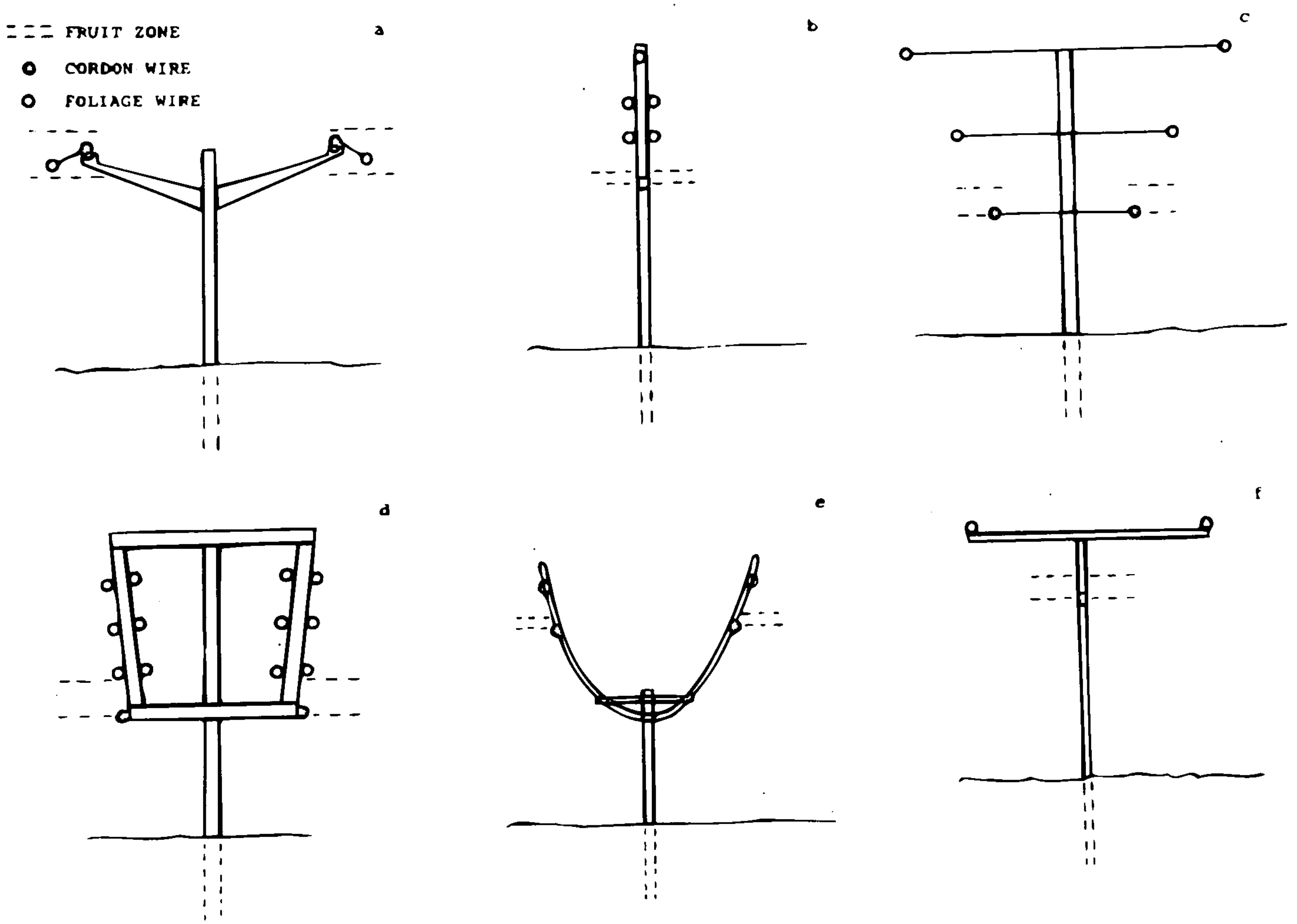

Fig. 1. Schematic drawings of (a) Geneva double curtain, (b) one-wire, (c) standard U, (d) Davis modified U, (e) extended Wye double curtain, and (f) 18-inch, T-crossarm trellises. Relevant canopy dimensions are presented in Table 1.

main plot factor was the training and support system, and the leaf removal treatments were randomly assigned within each main plot. Characteristics of training and support systems are presented in Table 1 and Figure 1.

Quadrilateral cordon-trained vines of Sauvignon blanc were supported by extended Wye double curtain and Davis modified U trellises. Bilateral cordon-trained vines were supported by a 46-cm, T-crossarm trellis (Fig. 1). Vines were established at a spacing of 2.4 m × 3.6 m (vine by row). Quadrilateral cordon-trained vines of Chenin blanc were supported by Geneva double curtain and standard U trellises (Fig. 1). Bilateral cordon-trained vines were supported by a one-wire trellis. These vines were established at a spacing of 2.1 m × 3.1 m. Vine rows of both varieties were oriented in an east-west direction. Chenin blanc vines were pruned to 24 two-node spurs, with six spurs per cordon on trellises with four cordons and 12 spurs per cordon on trellises with two cordons. Sauvignon blanc was pruned to 32 two-node spurs with eight spurs per cordon on trellises with four cordons and 16 spurs per cordon on trellises with two cordons. Shoots of both varieties were positioned initially in late May at 50% bloom and subsequently three weeks later.

In early August, at veraison, an estimate of canopy density at the height of the fruit zone was made in each treatment using a point quadrat system (9). In the quadrilateral cordons, measurements were made in both canopy walls. Every 10 cm along the length of each treated vine, counts were made of the number of leaf and cluster contacts with a rod passed horizontally through the canopy at the height of clusters. The average number of leaf and fruit contacts with the probe was determined from these measurements.

Within each training and support system, evaporative potentials were measured in vine canopies in which leaves had or had not been removed from the fruit zone. In treated canopies, leaves were removed from the node opposite each grape cluster and from the first nodes above and below each cluster. In control canopies, leaves were left in position. Four single-vine replicates per leaf removal treatment were established within each vine training system. Evaporative potentials were determined from the amount of water which evaporated in a defined time period from spherical, white porcelain atmometers (C & M Meteorological Supply, Riverside, CA). Each atmometer bulb was 5 cm in diameter and carried a correction coefficient for standardization of readings among bulbs. Each atmometer was filled with deionized water and was attached to a 1-L polyethylene water reservoir. Reservoirs were covered with foil to minimize differences in temperatures among treatments and to inhibit algal growth.

One atmometer was placed in the center of the canopy at the level of grape clusters in each treated or control vine of each training and support system. In the case of quadrilateral cordon-trained vines, atmometers were placed in the canopies on the north sides of the vine rows. The degree to which atmometers were shaded varied over the course of each day. Two replicate atmometers also were placed at a height of 2 m above the tallest canopy to measure ambient conditions. Atmometers were weighed before and after placement in the field to determine water loss. Evaporative potential was expressed in terms of mL water evaporated per hour during the five or six days in which the instruments were left in the field. Measurements were made in canopies of both Chenin blanc and Sauvignon blanc before veraison (19 June) and during veraison (30 July). Measurements also were made (12 August) in canopies of Chenin blanc three weeks before harvest. The influences of training and support system and leaf removal on evaporative potential were evaluated by designed F-tests.

Prior to harvest, assessments of incidence and severity of bunch rot were made in all treatments. However, because conditions at the site were dry (no fog, rain, or dew) during the season, no discernable bunch rot developed. Therefore, the relationships of disease to canopy characteristics and evaporative potential were not addressed.

Results and Discussion

In vines of Chenin blanc and Sauvignon blanc, canopy densities varied with training and support system (Table 1). In Chenin blanc, canopies of bilateral cordon-trained vines (without leaves removed) supported by the one-wire trellis consisted of 4.1 leaf layers at the height of clusters. Vines of quadrilateral cordon-trained vines supported on the Geneva double curtain or standard U trellis had 3.1 and 3.5 layers of leaves through the canopy walls, respectively. In Sauvignon blanc, canopies of the bilateral cordon-trained vines (without leaves removed) supported on the T-crossarm trellis consisted of 4.1 leaf layers. Vines of the quadrilateral cordon-trained vines trained on either of the other trellises had less than three layers of leaves through canopy walls at the height of clusters.

Removal of basal leaves generally reduced canopy densities to a greater degree in vines of Chenin blanc than Sauvignon blanc. In Chenin blanc, leaf removal reduced the number of leaf layers through canopy walls between 47% and 57%. In Sauvignon blanc, leaf removal generally reduced the number of leaf layers only 23% to 29%. The reasons for this difference in density reduction are uncertain. However, they may relate to varietal differences in canopy structure such as leaf size, leaf angle, or abundance of lateral shoot production.

Table 1. Characteristics of training and support systems used for vines of Chenin blanc and Sauvignon blanc.

Training/ support system	Leaf removal	Height to fruit zone (cm)	Cordon separation (cm)	Canopy wall thickness (cm)[a]	Leaf layer number[b]
Chenin blanc					
Bilateral cordon/one-wire trellis	+	120	NA[c]	50	1.8
	–	120	NA	50	4.1
Quadrilateral cordon/Geneva double curtain trellis	+	140	140	30	1.9
	–	140	140	30	3.5
Quadrilateral cordon/standard U trellis	+	80	110	50	1.3
	–	80	110	50	3.1
Sauvignon blanc					
Quadrilateral cordon/Davis modified U trellis	+	70	110	60	2.1
	–	70	110	60	2.8
Quadrilateral cordon/extended Wye double curtain trellis	+	130	110	60	2.1
	–	130	110	60	2.7
Bilateral cordon/18-inch T-crossarm trellis	+	80	NA	170	2.9
	–	80	NA	170	4.1

[a]Thickness of wall of single cordon at the height of fruit clusters.

[b]Average number of leaf contacts per insertion of a probe passed horizontally through canopy wall at height of clusters. Estimates of leaf layer numbers were made in canopies of Chenin blanc and Sauvignon blanc on 4 August and 29 July, respectively (9). Averages are based on 20 insertions per trellis. For quadrilateral systems, values are the average of both canopy walls.

[c]Not applicable for bilateral cordon trellises.

Table 2. Influence of training and support system and removal of leaves from around grape clusters on evaporative potential in canopies of Chenin blanc.

Canopy treatment	Evaporative potential (mL water evaporated/h)[a] One-wire trellis	Geneva double curtain trellis	Standard U trellis
June			
Leaves removed	1.13 (0.11)[bc]	1.0 (0.10)	0.87 (0.03)
Not removed	0.78 (0.09)	0.86 (0.05)	0.75 (0.03)
July			
Leaves removed	1.94 (0.13)	1.78 (0.20)	1.52 (0.07)
Not removed	1.50 (0.12)	1.52 (0.09)	1.23 (0.12)
August			
Leaves removed	0.90 (0.09)	0.85 (0.10)	0.75 (0.06)
Not removed	0.60 (0.05)	0.67 (0.04)	0.58 (0.04)

[a]Evaporative potentials of the atmosphere above canopies in June, July, and August were 1.94, 3.75, and 1.68 mL water evaporated per hour, respectively.

[b]Within each trellis system and at each sampling date, evaporative potential was increased significantly by removal of leaves from around fruit clusters ($p < 0.05$).

[c]Values in parentheses are standard errors of means.

Table 3. Influence of training and support system, and removal of leaves from around grape clusters on evaporative potential in canopies of Sauvignon blanc.

Canopy treatment	Evaporative potential (mL water evaporated/h)[a] Davis modified U trellis	Extended Wye double curtain trellis	18-inch, T-crossarm trellis
June			
Leaves removed	1.39 (0.03)[bc]	1.28 (0.04)	1.02 (0.08)
Not removed	1.07 (0.05)	1.10 (0.08)	0.91 (0.01)
July			
Leaves removed	1.40 (0.08)	1.27 (0.06)	1.10 (0.02)
Not removed	1.08 (0.04)	1.19 (0.08)	0.88 (0.05)

[a]Evaporative potentials of the atmosphere above canopies in June and July were 2.19 and 2.31 mL water evaporated per hour, respectively.

[b]Within each trellis system and at each sampling date, evaporative potential was increased significantly by removal of leaves from around fruit clusters ($p < 0.05$).

[c]Values in parentheses are standard errors of means.

Evaporative potentials in canopies of both grape varieties varied greatly over the course of experiments (Tables 2, 3). A maximum evaporative potential of 1.94 mL water evaporated per hour was observed during July in vines of Chenin blanc supported by the one-wire trellis in which leaves had been removed from the fruit zone. A minimum value of 0.58 mL water evaporated per hour was recorded in vines of Chenin blanc supported by the standard U trellis in which leaves were left in position. Evaporative potentials in all vines of Chenin blanc were significantly greater in July than in either June or August ($p < 0.05$). Values did not differ significantly over time in any canopies of Sauvignon blanc.

Evaporative potentials of canopy atmospheres were influenced by method of vine training and support and removal of leaves from the fruit zone. At all sampling dates, within each leaf removal treatment, evaporative potentials in canopies of Chenin blanc supported by the standard U trellis were significantly less than in canopies supported by the one-wire and Geneva double curtain trellises ($p < 0.05$) (Table 2). Within each leaf removal treatment of Sauvignon blanc, evaporative potentials of vines supported by an 18-inch, T-crossarm trellis were significantly less than in canopies of vines supported by the Davis modified U and extended Wye double curtain trellises (Table 3).

Within each training and support system, removal of leaves around clusters significantly increased evaporative potential when compared to control canopies ($p < 0.05$) (Tables 2, 3). Removal of leaves in canopies of either Chenin blanc or Sauvignon blanc increased evaporative potentials to levels greater than 0.75 mL and 1.0 mL water evaporated per hour, respectively.

Prior to this study, evaporative potential had been evaluated only in canopies of bilateral cordon-trained vines supported by a two-wire, vertical trellis at three different vineyards (1). In that training and support system, removal of leaves around clusters (in the same manner as the present experiment) increased evaporative potential significantly as compared to control canopies, and it was always associated with control of Botrytis bunch rot. Evaporative potentials in canopies with leaf removal varied between 0.53 mL and 1.24 mL water evaporated per hour.

The significant effects of training and support system and leaf removal on evaporative potential most likely resulted from differential changes brought about in canopy density; as canopy density decreased, evaporative potential increased. Evaporative potentials of canopies of Chenin blanc measured in August were significantly, negatively correlated ($p < 0.05$) with canopy densities measured at that same time, regardless of canopy treatment. The correlation coefficient for that relationship was –0.63. In a similar manner, evaporative potentials of Sauvignon blanc measured in July were significantly, negatively correlated with canopy densities measured at that same time, regardless of canopy treatment. The correlation coefficient for that relationship was –0.91. These observations agree closely with results of earlier experiments in which the correlation between leaf layer number and evaporative potential in canopies of vines supported by a two-wire vertical trellis was –0.91.

Regardless of the macroclimate conditions in a particular grape growing region, it is desirable to promote climatic conditions in canopies which discourage development of bunch rot and other diseases. Results of this experiment suggest that growers have many options for doing this within the constraints of their particular management system. In establishing new vineyards, it should be possible to select training and support systems to attain definable canopy densities and subsequently evaporative potential. In instances where vines are already in place, leaf removal might be considered to achieve this effect. Canopy densities might be controlled further by combining these types of canopy management practices with other cultural practices. The many possibilities bear further investigation. The use of canopy density measurements such as leaf layer number in combination with atmometers provided a simple, inexpensive method to compare the influence of canopy management practices on the evaporative potential within fruit zones. Such a manageable predictive system is an important first step away from empirical approaches to development of canopy management

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Relative effectiveness of leaf removal, shoot positioning, and trellising for improving winegrape composition

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Abstract

Two leaf removal (LR) experiments were conducted with Sauvignon blanc grapevines. One was the effect of LR at three different times (fruit set, 4 and 7 weeks after fruit set) and at four different levels on crop yield and fruit composition over a period of three years. The second dealt with studying the interaction of LR in the fruiting region and different types of trellis systems. LR of vines with low levels of photosynthetic photon fluence rate (PPFR) in the cluster region (5 to 6% of ambient) increased the level of sugar in the fruit and decreased titratable acidity, malic acid, pH and K concentration in berry juice. Yield, cluster number, cluster weight and berry weight were not significantly affected by LR averaged over a period of three years. However, in the third year of the trial the two highest levels of LR vines had greater number of clusters per shoot, flowers per inflorescence, and fertilised berries set per cluster. LR in the cluster region of vines on trellis systems with relatively high PPFR in the cluster zone did not affect fruit composition or crop yields. LR significantly increased the PPFR, cluster temperature, and evaporation rate in the cluster region compared to non-leaf removed vines.

Introduction

The canopy density of grapevines is primarily determined by the number of shoots and laterals per unit canopy length, shoot vigour and leaf size. Reducing the number of shoots per unit canopy length and/or shoot vigour and size will generally improve the light exposure of fruits. Trellis systems that divide canopies into separate curtains of foliage, shoot thinning, shoot positioning, and leaf removal have all been used to improve the PPFR of grapevine canopies (Kliewer 1982; Smart 1985; Bledsoe et al.; 1988).

A recent communication reported that removal of the leaves in the immediate vicinity of the fruit at any time between fruit set and veraison increased the level of sugar in the fruit and reduced the concentration of titratable acidity, malic acid, pH and potassium without significantly affecting yield, cluster number, cluster weight, and berry weight of Sauvignon blanc (Bledsoe et al., 1988). In another recent study (Gubler et al., 1987) basal leaf removal markedly reduced the incidence and severity of bunch rot caused by *Botrytis cinerea*.

The main objective of this study was to determine the long term effects of time and severity of leaf removal on vine productivity, bud fruitfulness and composition of Sauvignon blanc grapevines. A further objective was to determine the interaction of leaf removal and trellising on composition and microclimate of Sauvignon blanc grapes.

Materials and methods

Vineyard sites: Two experiments were conducted; a three year trial was established in 1985 in a 12 year old, quadrilateral cordon trained Sauvignon blanc vineyard in Wooden Valley, Napa County, CA, and the second with five year old Sauvignon blanc vines at Davis, CA, using four different trellis-training systems.

Treatments: The experimental methods and first year's results of the Napa County experiment is currently in press (Bledsoe et al., 1988) and most of the details of this experiment will not be reported here. Leaves and their subtending laterals were removed at three different times – at fruit set, and four and seven weeks after fruit set. Four levels or severities of leaf removal were used at each of the three times: control, no leaf removal; level 1 = basal leaves removed from one node above, opposite and one node below clusters; level 2 = basal leaves plus scattered leaves from top of canopy and level 3 = basal leaves removed plus approximately three consecutive leaves at top of south facing portion of canopy to form an open "window" to further increase light penetration to the canopy interior.

The same treatments and experimental design initiated in 1985 were continued in 1986 and 1987 using the same vines for the same treatments so that any carryover effects could be determined. In the third year of this trial (1987) the effect of severity of leaf removal on the number of flowers per inflorescence, number of fertilised and unfertilised berries set per cluster and number of abscised flowers was determined using 25 x 30 cm Delmet polyethylene fine mesh bags to enclose the flower clusters as they entered anthesis. The number of flowers and flower clusters present on shoots derived from two node spurs of 12 vines selected randomly from each treatment was determined in the spring of 1987 to determine if leaf removal had an effect on bud fruitfulness.

The trellis systems used in the Davis experiment were a T, Davis modified U, Wye and an Extended Wye. Each trellis system consisted of one 25 vine row at 2.4 by 3.6 meter vine and row spacing. The construction and dimensions of these systems have been described by Kliewer

(1986). Each of the four different trellis systems were divided into three, four vine replicate blocks. The leaf and laterals immediately above, opposite and below each cluster were removed at fruit set from two adjacent vines of each replicate. No leaves were removed from the other two adjacent vines of each replicate and served as controls.

The methods used for measuring PPFR, yield components, fruit composition, and statistical analysis have been described previously (Bledsoe et al., 1988). The relative evaporation rates of canopies with or without leaf removal were assessed using porcelain atmometers (C & M Meteorological Supply, Riverside, CA 92507), based on the procedure of Livingston (1935), which measures the amount of water loss from a 5 cm diameter porcelain sphere connected to a reservoir filled with water over a period of time. The average ratio of red (660 nm) to far red (730 nm) light was determined with a Syke SKR100 light meter by positioning the sensor probe horizontally upward, downward and to each side of clusters during the mid part of the day. The data presented in Table 4 are the averages of readings made from the four positions.

Results and discussion

Yield components: Crop, cluster, berry and pruning weights did not differ significantly due to either time or severity of leaf removal when averaged over a period of three years (Table 1). However, in the third year of the trial the number of shoots from count nodes, number of clusters per shoot (bud fruitfulness), number of flowers per inflorescence, and number of fertilised berries set per cluster were significantly greater in the levels 2 and 3 leaf removal treatments compared to control and level 1 leaf removal treatment (Tables 2 and 3). Table 4 shows that levels 2 and 3 leaf removal treatments had significantly higher amounts of PPFR in the cluster region than level 1 and the basal leaf removal treatment (level 1) in turn was higher than control vines. Since it is well known that the amount of exposure of basal buds and/or subtending leaf blades to sunlight is directly related to bud fruitfulness (Smart et al., 1982a,b; Shaulis and Smart 1974), the higher amounts of PPFR in the basal region of shoots of the levels 2 and 3 leaf removal treatments compared to control and level 1 treatments may account for the improved bud fertility and greater number of flowers per inflorescence.

Microclimate measurement: All leaf removal treatments significantly increased the PPFR reaching the canopy interior cluster region between 1100 and 1300 hrs at veraison (Table 4). Similar data were obtained from light measurements made at fruit set and four weeks after fruit set (Bledsoe et al., 1988). The removal of basal leaves only (level 1) approximately doubled the PPFR in the cluster zone compared to the control. Levels 2 and 3 leaf removal treatments had PPFR about 5- and 6-fold greater, respectively, than control vines (Table 4).

The evaporation rate in the cluster zone as measured by atmometers was also significantly greater in levels 2 and 3 leaf removal treatments compared to the control, suggesting that air movement in this part of the canopy was greater where leaves had been removed (Table 4). English et al., (1987) showed that removal of leaves around clusters significantly increased the amount of air movement through the canopy and this mainly accounted for reduced incidence of bunch rot in leaf removal treatments. Temperature data collected with the aid of microloggers revealed that average cluster temperatures of leaf removal treatments were increased by 0.5 to 1.1°C above the control during the period 0600 to 1800 hrs (Table 4). The increase in cluster temperature was directly related to the amount of leaf area removed. Data obtained from the first year of this study (Bledsoe et al., 1988) showed that significant negative correlations existed between PPFR and pH, malate and potassium concentration of the berry juice at harvest. PPFR was also highly correlated (R=0.98) with the amount of leaf area removed by the three different severity treatments.

Table 1. Influence of time and severity of leaf removal on crop yield, yield components and pruning weight of Sauvignon blanc grapevines. Data are treatment means over a period of three years (1985 to 1987).

	Berry weight (g)	Crop weight (kg/vine)	Cluster number	Cluster weight (g)	Cane prunings (kg/vine)
Time of leaf removal [a,b]					
Time 1	1.36	13.2	109	121	6.9
Time 2	1.39	13.6	110	123	6.6
Time 3	1.40	13.5	112	121	6.4
Level of leaf removal [c]					
Control	1.39	13.8	112	123	6.7
Level 1	1.40	13.5	110	122	6.5
Level 2	1.38	13.6	112	120	6.4
Level 3	1.38	13.4	110	121	6.5

[a]No significant differences due to either timing or level of leaf removal among any of the yield components. No significant interaction between timing or level of leaf removal

[b,c]See Materials and methods for explanation of time and level of leaf removal treatments.

Table 2. Influence of severity of leaf removal on the number of flowers per inflorescence, number of fertilised and unfertilised berries set per cluster, and on the number of flowers abscised per cluster from Sauvignon blanc grapevines. Data are for the 1987 season (third year of leaf removal treatments)[y]

Severity of leaf removal[x]	No. of flowers per cluster	No. of fertilised berries set per cluster	No. of shot berries per cluster	No. of abscised flowers per cluster	Percent berry set
Control	207 a	95 a	28	84 a	46.0
Level 1	202 a	86 a	24	92 a	44.0
Level 2	252 b	110 b	34	107 b	45.3
Level 3	254 b	112 b	32	110 b	45.4
Signif. level[z]	***	***	NS	*	NS

[x]See Materials and methods for explanation of severity of leaf removal.

[y]Data are the mean of 31 clusters per severity treatment.

[z], *** indicates differences between treatment means at the 5% and 0.1% levels, respectively. Values within a column followed by the same letter did not differ significantly at the 5% level (Tukey's Test).*

Fruit composition: Timing of leaf removal did not significantly affect the composition of the fruit in any of the three years of the study (Table 5). However, fruit from vines with leaves removed earlier in the season tended to be slightly higher in sugar than later leaf removal. Average degree Brix were 23.6, 23.4 and 23.1 for time 1, 2 and 3, respectively, over the three years.

Fruit at harvest from the three leaf removal treatments was significantly higher in total soluble solids and lower

Table 3. Influence of severity of leaf removal on budbreak and bud fruitfulness of Sauvignon blanc grapevines (data are for 1987, third year of leaf removal treatments)[x,y]

Severity of leaf removal	No. of shoots from count nodes per vine	No. of clusters from count nodes	No. of clusters per shoot
Control	24.2 a	35.1 a	1.45 a
Level 1	27.4 ab	36.1 a	1.32 a
Level 2	26.5 a	40.5 ab	1.54 b
Level 3	28.8 b	44.2 b	1.54 b
Signif. level	**	*	*

[x]*Data are the mean of the two south cordon from 12 vines of each treatment.*

[y]*Letters within a column followed by the same letter did not differ significantly at the 5% level (Tukey's test).*

Table 4. Influence of severity of leaf removal on the microclimate in the cluster region of Sauvignon blanc grapevines. Measurements are for the period July 27 to August 6, 1987.

Severity of leaf removal	Daytime average cluster temp[x] (°C)	PPFR[y] in cluster zone at veraison (% of ambient)	660 nm/730 nm Ratio	Atmometer evaporation rate in cluster region (ml H_2O/11 days)	% of ambient
Control	26.4	5.1 a	0.17 a	191 a	42
Level 1	26.9	12.2 b	0.41 b	215 ab	48
Level 2	27.2	24.8 c	0.58 c	220 b	49
Level 3	27.5	32.4 c	0.64 c	243 b	54
Ambient	28.1	(2120 μ $Em^{-2}s^{-1}$)	1.14	451	

[x]*Temperature means represent the average temperature from 0600 to 1800 hours measured over an 11 day period using a Cambell CR 21 micrologger and CSI 101 temperature probes positioned within clusters and in ambient air.*

[y]*PPFR = Photosynthetic photon fluence rate measured with a LiCor 185 light meter and 190 SB quantum line sensor between 1100 and 1300 hrs.*

Table 5. Influence of time and severity of leaf removal on fruit composition of Sauvignon blanc fruit at harvest. Data are treatment means over a period of three years (1985–1987).

	Total soluble solids (°Brix)	Titratable acidity (g tartaric/L)	Malic acid (g/L)	pH	K^+ (mg/L)
Time of leaf removal[a]					
Time 1	23.6	11.1	5.0	3.18	1744
Time 2	23.4	11.0	5.1	3.19	1754
Time 3	23.1	11.3	5.4	3.16	1724
Level of leaf removal[b]					
Control	22.5	11.7	5.9	3.20	1820
Level 1	23.0	11.2	5.4	3.19	1774
Level 2	23.0	11.0	5.0	3.16	1716
Level 3	23.0	10.7	4.8	3.16	1691

[a]*No significant differences due to timing of leaf removal.*

[b]*Leaf removal had a significant effect on the above listed parameter at p = 0.05. Levels 2 and 3 significantly differ from level 1 in pH and potassium concentration at p = 0.05. No significant interaction between timing and level of leaf removal.*

in titratable acidity, malic acid, pH and potassium than fruit from the control treatment (Table 5). The reduction in total acidity was mainly due to reduced levels of malic acid. The lower pH was positively correlated to the level of potassium (r^2 = 0.71) and malate and potassium were also closely positively correlated (r^2 =0.75). With increased severity of leaf removal, there was further reduction in titratable acidity, malic acid, pH and potassium.

The higher level of total soluble solids in fruits from the leaf removal treatments compared to control fruits may be due to the slightly higher temperatures of leaf removed fruits and/or to the presence of greater amounts of red light (660 nm) in and around the clusters. Leaves absorb about 95% of red light but only about 21% of far red (730 nm) resulting in low ratios of R:FR in the interior parts of dense grapevine canopies (Smart 1987). Leaf removal treatments markedly increased the R:FR ratios in the cluster region. The R:FR ratio of incident radiation determines the phytochrome state between the physiologically active form (P_{fr}) and the inactive form (P_r) (Smith 1982). Phytochrome is known to play a direct role in regulating the activity of several light sensitive enzymes including malic enzyme, phenylalanine ammonium lyase, nitrate reductase and invertase to mention a few (Smart 1987). Since leaf removal increased the F:FR ratio in the fruiting region of the vines used in the current study this may have increased the activity of enzymes involved in sugar accumulation in fruits and explain at least in part, why leaf removed fruit consistently was higher in sugar than control fruits. The higher R:FR ratios of leaf removed fruit may also account for the lower pH and potassium in these fruits as well.

Table 6. Influence of four different types of trellis systems, each with and without leaf removal in the cluster region, on the amount of photosynthetic photon fluence rate (PPFR), crop yield and fruit composition at harvest of Sauvignon blanc grapevines. 1987 season, Davis, CA.

Treatment: Trellis system[a]	Basal leaf removal	PPFR in cluster zone (% of ambient)	Crop yield (kg/vine)	TSS (°Brix)	TA (g/L)	pH
T	No	4.2	27.3	22.8	7.0	3.28
T	Yes	12.8***	25.7	23.5*	7.1	3.34
Modified U	No	5.4	29.8	22.1	7.0	3.34
Modified U	Yes	18.6***	32.8	23.0*	6.8	3.36
Wye	No	30.2	26.9	23.0	8.5	3.18
Wye	Yes	45.8*	27.3	23.2	8.1	3.19
Extended Wye	No	34.6	28.2	24.4	6.0	3.36
Extended Wye	Yes	48.5*	30.7	23.9	6.5	3.33

*,****Indicates that difference between treatment means within a single type of trellis system was significant at the 5% and 0.1% levels, respectively, with respect to leaf removal.*

[a]*The Wye trellis was harvested on August 17 and the other three trellis systems on August 25, 1987.*

Trellis effects: Leaf removal in the fruiting region of young Sauvignon blanc vines trained to four different types of trellis systems significantly increased the level of sugar in fruits from the T and modified U trellises but not in the Wye and Extended Wye trellised fruit (Table 6). The Wye and Extended Wye fruit of vines with no leaf removal were well exposed to sunlight (PPFR 30 to 35% of ambient); whereas, the T and Modified U fruit were highly shaded (PPFR 4 to 5% of ambient). These data indicate there is no improvement in the level of sugar in fruit from leaf removed vines that have well exposed fruit prior to leaf removal. Titratable acidity, pH and potassium of leaf removed and control fruit did not differ significantly in the four different trellis systems.

Acknowledgements

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