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Leaf Area/Crop Weight Ratios of Grapevines: Influence on Fruit Composition and Wine Quality

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Abstract: The fruiting capacity of grapevines in a given climatic region is largely determined by their total leaf area and by the percentage of the total leaf surface area that is exposed to full sunlight, provided other factors are not limiting growth and the initiation of fruit primordia. A wide range of leaf area/crop weight ratios were investigated by pruning to different levels of buds per vine, by different degrees of defoliation, and/or by cluster thinning of grape cultivars Thompson Seedless, Tokay, Chenin blanc, and Cabernet Sauvignon located at Davis or Oakville, California. For single-canopy (SC) type trellis-training systems, the leaf area/crop weight ratio required for maximum level of total soluble solids, berry weight, and berry coloration at harvest ranged from 0.8 to 1.2 m^2/kg, whereas for horizontally divided-canopy (DC) type trellis-training systems (GDC, lyre, wye), this ratio was reduced to 0.5 to 0.8 m^2 leaf area per kg fruit. Optimal crop yield/pruning weight, pruning weight (kg) per m canopy length, leaf area (m^2) per m canopy length, and leaf area density (m^2/m^3) for SC systems ranged from 4.0 to 10, 0.5 to 1.0 kg/m, 2 to 5 m^2/m, and 3 to 7 m^2m^{-3}, respectively. Similarly, for DC systems these ratios ranged from 5.0 to 10, 0.4 to 0.8 kg/m, 2 to 4 m^2/m, and 3 to 6 m^2m^{-3}, respectively. Grapevines with ratios that fell within the ranges given above for each of these five parameters were considered well balanced and capable of producing high-quality fruit and wines.

Key words: canopy management, trellising, fruiting capacity, yield

Vine balance can be characterized in several different ways. Winkler (1930, 1954, 1958) and Winkler and Williams (1939) defined a grapevine as being well balanced and not overcropped when the vine brings its fruit from flowering to a given degree Brix, depending on the use to which the fruit will be used, with a given summation of degree days of heat, which is constant for a given variety. Dormant vine pruning weights, expressed as kg per meter of canopy length, has also been widely used to indicate if vines are well balanced, i.e., with neither too little nor too much growth (Shaulis 1982, Shaulis et al. 1966, Smart and Robinson 1991). Values of 0.3 to 0.6 kg pruning weight per meter of canopy length are generally considered to be in the optimal range (Shaulis 1982, Smart and Robinson 1991); however, recent studies in California (Dokoozlian 1990, Dokoozlian and Kliewer 1995, Kliewer et al. 1988, 2000) showed that values up to 1.0 kg/m for Cabernet Sauvignon were capable of producing high-quality wines without loss in productivity due to excessive canopy shading. More recently, crop load or the ratio between crop yield and dormant vine pruning weight, has gained wide acceptance as a good criterion of vine balance (Bravdo et al. 1984, 1985, Kliewer et al. 2000, Smart 1985, Smart and Robinson 1991). Generally, vines with crop load values between 5 to 10 are considered in the optimal range (Bravdo et al. 1984, 1985). However, for small-clustered wine cultivars, such as Pinot noir, grown in cool climates, the optimum crop load ratio appears to be somewhat lower, in a range from 3 to 6 (unpublished information).

Smart (1985), Smart et al. (1991), and Smart and Robinson (1991) introduced an 80-point scoring system to evaluate vineyard balance and potential fruit quality assurance through the use of point quadrant analyses of canopy density and microclimate. These analyses took into account leaf layer number, percent canopy gaps, and percentage interior and exterior leaves and clusters, while five other measures related to the physiological status of grapevines (leaf size, leaf color, shoot length, lateral growth, and presence of active shoot tips during the ripening period). These latter five characteristics are assessed by visual observation and require some advanced experience of what is desirable. Each of the eight characteristics is assigned zero to 10 points (maximum). Open-type canopies that have moderate shoot vigor and minimal amounts of lateral shoot growth are rated highest. However, more data is needed to determine how each of the eight characteristics should be weighed for their effects on wine quality. In general, canopies with well-exposed leaves and fruits have scored highest in wine quality by taste panels (Dokoozlian 1990, Kliewer 1982, Kliewer et al. 1988, Schuck 1987, Smart 1982, Smart et al. 1991).

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In this communication, emphasis on defining the optimum level of cropping will be in terms of leaf area required per unit weight of fruit, expressed as m^2/kg, to produce berries of maximum total soluble solids, skin color, and total sugar accumulation in fruits. The premise for this criterion is that the ultimate source of sugar produced in grapevines is from leaf photosynthesis, which is dependent on the total amount of exposed leaf area. Since the type of trellis-training system used has such a dominant influence on the amount of leaf area exposure, the optimal leaf area/crop weight ratio of single- and divided-canopy training systems are compared from field experiments of several cultivars conducted at Davis and Oakville, California (Johnson 1988, Kliewer et al. 1988, 2000, Schuck 1987, Yang 1991). Most of the data presented are from grapevines grown in warm-climate regions (>3000 degree-days) of California. Since temperature and light for maximum photosynthesis are frequently more limiting in cool-climate regions, it is likely that the leaf area/fruit weight ratios for optimal fruit composition and wine quality will be somewhat higher for these regions.

The ratio between crop weight and dormant pruning weight per vine is also used as an indication of good vine balance in the field studies presented herein. The relationship between crop weight/pruning weight and leaf area/crop weight ratios was also investigated.

Materials and Methods

Some of the data here are from studies previously published (Kliewer 1970, Kliewer and Ough 1970, Kliewer and Weaver 1971) and are appropriately referenced where used. However, a considerable amount of the material is from unpublished information of the author and from student thesis projects supervised by Kliewer (Johnson 1988, Schuck 1987, Yang 1991).

Tokay pruning-level cluster-thinning trial. A wide range in leaf area/crop weight ratios in the cultivar Tokay was obtained by differential vine pruning and cluster thinning. The trial was conducted at Davis, California, and each treatment was replicated five times in randomized blocks, four vines per replicate. Regression analysis was conducted to determine the relationship between leaf area per unit weight of fruit and total soluble solids at harvest, proline level in berry juice, fruit coloration of berry skins, and berry weight. See Kliewer and Weaver (1971) for further details of the methods used.

Thompson Seedless defoliation cluster-thinning trials. The Thompson Seedless data presented herein was obtained from three trials conducted at the UC Davis Experimental vineyard using own-rooted vines growing in an irrigated vineyard pruned to three or four 15-node canes (Kliewer 1970, Kliewer and Ough 1970). The canes were trained to two horizontal wires 0.8 m apart and 1.4 m from the ground. A wide range of leaf area/crop weight ratios was obtained by either defoliating every fifth, fourth, third, or second leaf on each shoot and lateral per vine at two weeks post anthesis or by thinning the crop to 80, 60, 40, and 20 clusters per vine with no defoliation. In another trial conducted at the same site, 0, 25%, and 50% of the leaves were removed at three different times (2 June, 25 June, and 18 July). There were six vines in each treatment with each vine serving as a replicate in a randomized complete block design. The treatments were continued over a period of four years (1970 to 1973). The total leaf area per vine was determined in early October by leaf weight-leaf area relationship as described previously (Kliewer and Antcliff 1970).

Thompson Seedless trellis-canopy exposure trial. In another experiment at the same Davis site described above, four different trellis-training systems were compared with widely different canopy volumes and amounts of leaf area exposure. The four systems consisted of a single open canopy, a divided GDC-type canopy, and restricted horizontal and vertical canopies with estimated canopy volumes of 1.9, 2.6, 1.3, and 1.3 m^3 per vine, respectively. The restricted horizontal and vertical canopies were obtained by using shoot-positioning wires to restrict the canopy within the dimensions of 1.2 x 1.2 x 0.3 m and 1.2 x 0.3 x 1.2 m, l x width x height, respectively. All treatments were pruned to 60 nodes per vine (four 15-node canes). The single-canopy trellis system had dimensions of 1.8 x 1.2 x 0.9 m, while the divided-canopy system consisted of two curtains of foliage, each curtain with a volume of about 1.8 x 1.2 x 0.6 m. The single-curtain and restricted vertical and horizontal trellised vine were each comprised of six single-vine replicates, whereas there were 18 double-curtain trained vines.

Cabernet Sauvignon pruning-level trellising trial. In a simulated mechanical pruning trial at the UC Oakville Experimental Vineyard with Cabernet Sauvignon vines on A5R#1 rootstock, three types of pruning were imposed on vines trained to a single-canopy two-wire bilateral cordon as well as to a horizontally divided canopy quadrilateral cordon system. The three pruning methods were standard spur pruning to 24 two-node spurs, hedge pruning to a single level plane with spur lengths averaging two to three nodes, and minimal pruning leaving all buds above the cordon wires. The three pruning methods produced an average of 36, 191, and 314 shoots, respectively, per vine on single-canopy trained vines and 41, 244, and 362 shoots on the divided-canopy vines. Each of the six treatments was replicated six times, three vines per replicate, in a randomized complete block design. Spacing was 2.2 m between vines and 3.6 m between rows. Regression analysis was conducted to determine the relationship between leaf area (m^2) per kg crop weight and the level of total soluble solids (Brix) in individual treatment replicates at harvest. Leaf area of 10 random shoots per vine was determined with a decagon leaf area meter, which was then used to estimate the total leaf area per vine from total shoot counts per vine. For more details of experimental methods see Johnson (1988).

Cabernet Sauvignon trellising, vine spacing, rootstock trial. In a trial comprised of six trellis-training systems (vertical-shoot position, Scott-Henry, Te Kauwhata Two Tier [TK2T], GDC, lyre, and a wide V), three in-row vine spacings (1, 2, and 3 m), and two rootstocks (O39-16 and 110R) located at the Oakville Experimental Vineyard, a wide range of leaf area/crop weight ratios was produced with Cabernet Sauvignon vines over a period of three years (1993 to 1995). Each spacing and rootstock treatment was replicated four times with three vines per replicate in a randomized split plot design. The vines of each treatment were pruned leaving a two-node spur approximately every 15 cm along the length of the cordons. Thus the one-, two-, and three-meter single-canopy vines were pruned to 12, 24, and 36 nodes/vines, respectively; the divided-canopy vines were pruned to 24, 48, and 72 nodes/vine, respectively. The vines were not hedged or cluster thinned, except for the TK2T trained vines, which required shoots originating from the lower cordon to be trimmed to prevent their growth into the upper-cordon fruit zone. The vines were drip irrigated beginning at about fruit set with neutron probes used to monitor soil moisture. Vine growth, leaf area, crop yield, and fruit composition were determined as described by Kliewer et al. (2000).

Chenin blanc trellising trial. Eight-year-old Chenin blanc vines grafted on A5R#1 rootstock were used in this study conducted from 1988 to 1990 at the UC Davis experiment vineyard. The row and vine spacing was 3.2 x 2.1 m. The treatments consisted of three trellis systems (vertical, lyre, and GDC) with the dimensions and wire locations indicated in Figure 15. Each of the three trellis systems was replicated six times in a randomized block design, each replicate consisting of three 24-vine rows, the center row used for data collection. Half of the vines within each trellis system were shoot-positioned, beginning at flowering, as depicted in Figure 15; the remaining half were not shoot-positioned. All vines were cordon trained and pruned to 24 two-node spurs. The soil was a deep alluvial Yolo fine sandy loam with very high potential for vine growth and crop yields. The vineyard was clean cultivated and furrow irrigated, receiving two 15-cm irrigations. Standard pest and disease control measures were used. Leaf area per vine was determined shortly before harvest with a delta T decagon leaf area meter on 10 random shoots of buffer vines adjacent to data vines. The total amount of primary and lateral leaf area per vine was estimated by multiplying the averages of the 10 shoots by the total number of shoots per vine. For more details of the experimental methods used see Yang (1991).

Results and Discussion

Over the past 30 years, numerous field experiments were conducted with table, raisin, and winegrape varieties in which the leaf area/crop weight and crop yield/pruning weight ratios differed over a wide range by imposing different levels of pruning, cluster thinning, differential defoliation and by using different types of trellis-training systems (Johnson 1988, Kliewer 1970, Kliewer and Antcliff 1970, Kliewer and Ough 1970, Kliewer and Weaver 1971, Kliewer et al. 2000, Schuck 1987, Yang 1991). Some of this information has been published and will be reviewed in this communication. However, a considerable amount of the data presented has not been published previously in reviewed journals and provides new information for defining vine balance in terms of leaf area/fruit weight ratios needed to fully ripen fruit to an acceptable level of sugar.

Tokay pruning-level and cluster-thinning trial. For the table-grape cultivar Tokay grown at Davis and trained to a single-canopy three-wire "T"-trellis, the crop level per vine ranged from 11.0 to 26.7 kg, imposed by differential pruning, with or without cluster thinning (Kliewer and Weaver 1971). The m^2 leaf area per kg fruit required for maximum sugar concentration in fruit at harvest (20 Brix) was 1.1 to 1.2 (Figure 1). In addition, maximum berry weight, fruit skin coloration, and proline concentration in berry juice was also obtained when m^2 leaf area per kg fruit ranged between 1.1 to 1.4 (Figures 2, 3, and 4). These ratios were equivalent to 38 to 42 primary leaves per kg fruit weight at harvest with a crop yield pruning weight ratio of approximately 6. When the leaf area (m^2) per kg fruit of vines fell below 1.0, the crop yield/pruning weight ratios were al-

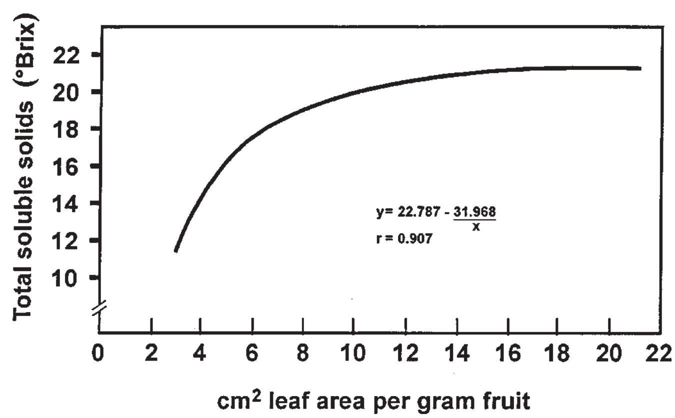

Figure 1 Regression of total soluble solids (Brix) of Tokay berry juice at harvest on leaf area per unit crop weight (cm^2/g).

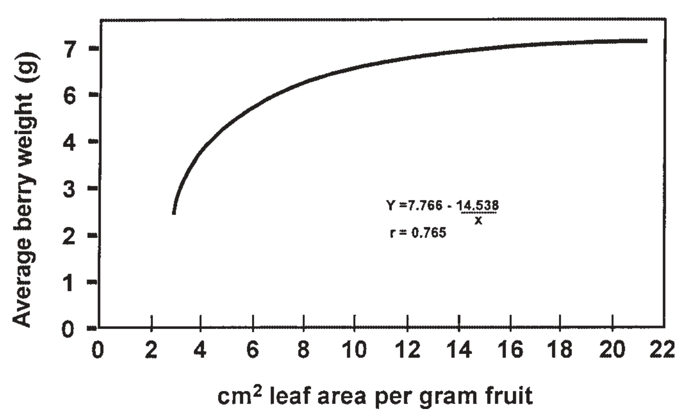

Figure 2 Regression of average berry weight (g) of Tokay fruit at harvest on leaf area per unit crop weight (cm^2/g).

ways above 10, indicative of overcropping (Kliewer 1970, 1982). These data indicate that a minimum of 1.0 to 1.4 m^2 leaf area per kg fruit was needed to fully mature the Tokay crop grown at Davis on a single-canopy-type trellis system. The finding that berry weight, fruit coloration, and the proline concentration in berry juice also reach maximum levels at 1.2 to 1.4 m2 leaf area per kg fruit further supports the leaf area data needed for maximum fruit sugar.

Thompson Seedless defoliation and cluster-thinning trials. Three other field trials were conducted at Davis with Thompson Seedless grapevines over a period of four years (1969 to 1972). One trial used differential defoliation in which every fifth, fourth, third, or second leaf on every shoot and lateral per vine was removed 15 days after anthesis. In a second trial, 0, 25%, and 50% of the leaves were removed at three different times: 2 June (fruit set), 25 June, and 18 July (veraison). In the third crop level trial, the number of clusters per vine were adjusted to 80, 60, 40, and 20 with no defoliation (Kliewer 1970, Kliewer and Ough 1970). These treatments produced a wide range of leaf area/crop weight ratios and were used to calculate the amount of leaf area needed to fully ripen the fruit. In each of the three trials the relationship between the level of total soluble solids of fruits at harvest and leaf area per unit weight of fruit for all vines, irrespective of treatment, was determined each year. In the differential defoliation trial, 1.0 to 1.4 m^2 leaf area per kg fruit was required to mature the crop to 23 Brix in both the 1969 and 1972 seasons (Figures 5 and 6). Based on the total number of leaves per vine and average leaf size, it was estimated that about 4000 cm^2 leaf area was required per average size cluster, which was equivalent to 16 to 18 primary leaves per cluster or 32 to 36 leaves per kg fruit. In the trial in which vines were defoliated to either 0, 25%, or 50% at three different stages of fruit development, the data also revealed that 1.0 to 1.2 m^2 leaf area per kg fruit was needed to maximize the concentration of sugar in the fruits at harvest (Figure 7). These data indicate that even after four years of defoliation at the levels indicated above, the amount of leaf area needed to ripen the fruit to 23 Brix did not change materially nor did the time of leaf removal significantly alter the leaf area/crop weight ratio required to fully ripen the crop.

In the third Thompson Seedless trial, comparison of the growth, fruit composition, and wine quality of Thompson Seedless vines cropped at 20, 40, 60, and 80 clusters per vine showed leaf area (m^2)/crop weight (kg) ratios of 4.0

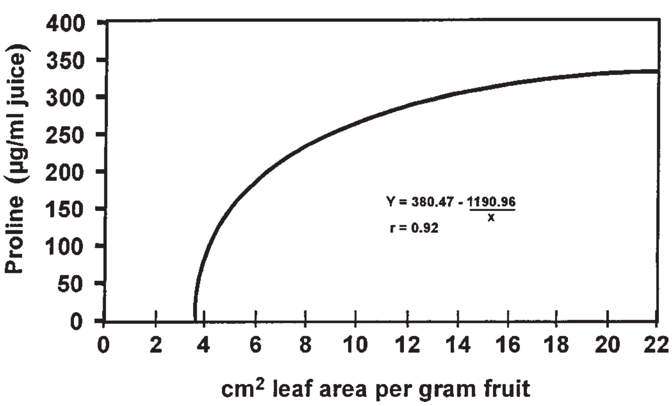

Figure 3 Regression of concentration of proline (µg/mL) of Tokay fruit at harvest (24 Sept) on leaf area per unit crop weight (cm^2/g).

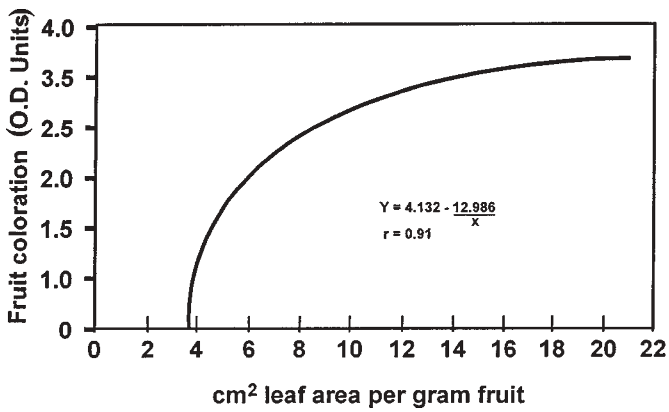

Figure 4 Regression of total soluble solids (OD units/cm^2 skin tissue/ 20 mL ethanol) of Tokay berry juice at harvest (24 Sept) on leaf area per unit crop weight (cm^2/g).

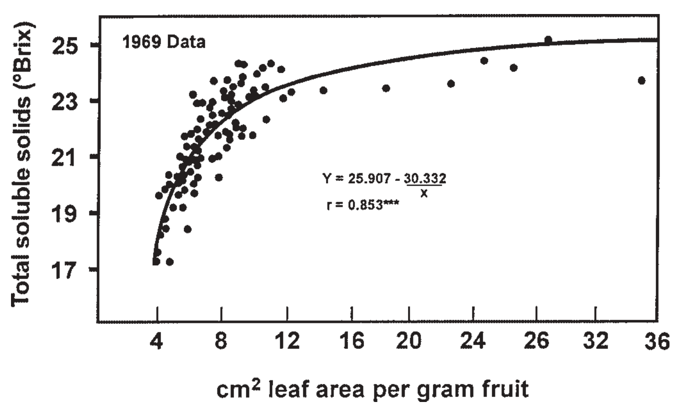

Figure 5 Regression of total soluble solids (Brix) of Thompson Seedless berry juice at harvest on leaf area per unit crop weight (cm^2/g). 1969 was the first year of defoliation treatments.

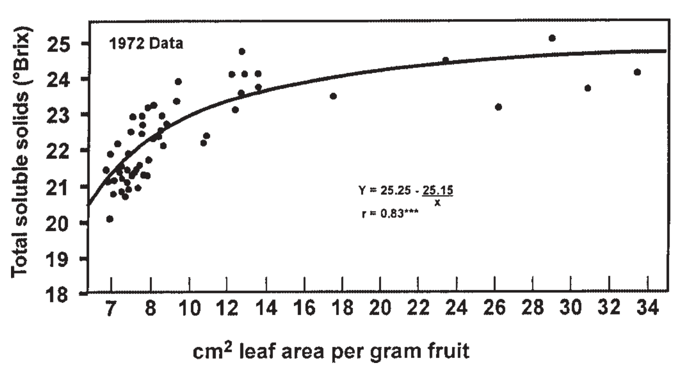

Figure 6 Regression of total soluble solids (Brix) of Thompson Seedless berry juice at harvest on leaf area per unit crop weight (cm^2/g). 1972 was the fourth year of defoliation treatments.

(20 clusters/vine) to 0.8 (80 clusters/vine) and crop weight/pruning weight ratios of 1.57 to 7.4 (Table 1). Fruit from vines thinned to 20 clusters reached 22 Brix about 20 days earlier than vines cropped at 80 clusters and had considerable higher titratable acidity and lower pH and Brix/acid ratios (Table 1). Even though there was a 3-fold range in crop level per vine (9 to 28 kg), sensory evaluation of the vines showed no significant differences in wine-tasting scores (Table 1). These data suggest that a leaf area/crop weight ratio of 0.8 m^2/kg was adequate for producing good fruit and wine quality.

Thompson Seedless trellis-canopy exposure trial. To test the leaf area/fruit weight requirement of single-curtain- (SC) compared to double-curtain- (DC) type trellised vines and how restricting the canopy volume by shoot positioning influences this ratio, a replicated field experiment was conducted at the same site as described above with Thompson Seedless vines over a period of four years (1970 to 1973). The four-year summary data are presented in Table 2. The restricted vertical- (RV) and restricted horizontal- (RH) trained vines had significantly lower crop yield and total vine leaf area than the DC vines (Table 2). Pruning weight and leaf area per m canopy length were significantly greater in the SC, RV, and RH vines compared to DC vines (Table 2). The leaf area/fruit weight ratio when DC fruit reached 23 Brix did not differ significantly between treatments; however, the level of total soluble solids and total amount of sugar in fruits of SC, RH, and RV fruits were significantly less than in DC fruits (Table 2). Regression analysis conducted to show the relationship between the level of TSS of fruits at harvest and cm^2 leaf area per gram of fruit in 1972 (Figure 8) and 1973 (Figure 9) revealed that the DC vines required about 0.8 m^2 leaf area per kg fruit to reach 23 Brix compared to 1.1 to 1.4 m^2/kg for SC, RV, and RH fruits. The rate of sugar accumulation and the level of TSS in fruits of SC, RH, and RV vines were significantly less in DC fruits at all sampling dates during the 1973 season (Figure 10). These data clearly show that the leaf area/fruit weight ratio of DC vines needed to ripen fruits to 23

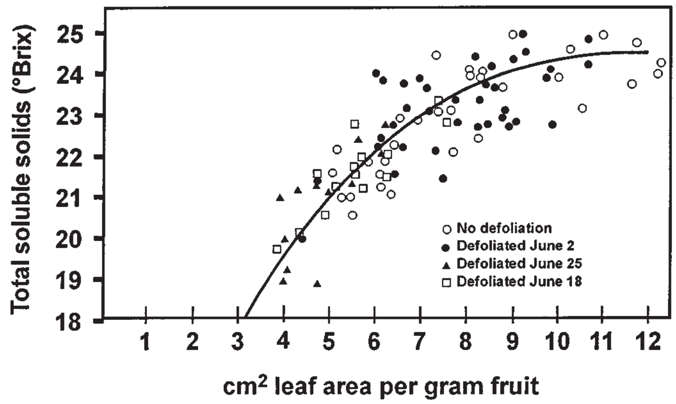

Figure 7 Regression of total soluble solids (Brix) of Thompson Seedless berry juice at harvest on leaf area per unit crop weight (cm^2/g). The equation of the curve was Y = 25.907 - 30.332 / x with a correlation of r = 0.85. From Kliewer (1970).

Table 1 Crop level effect on vine growth, fruit composition, and wine quality of Thompson Seedless grapevines, Davis, California. Data are the mean of six replicates (1969-1970).

	No. of clusters per vine			
Parameter	20	40	60	80
Crop wt (kg/vine)	9.08	17.23	24.17	28.3
Pruning wt (kg/vine)	5.77	4.44	4.3	3.82
Crop wt/pruning wt	1.57	3.88	5.56	7.40
Total leaf area/vine (m^2)	36.2	26.8	25.4	23.2
Date fruit harvested	Aug 10	Aug 20	Aug 27	Sept 4
Total soluble solids (Brix)	22.2	22.6	22.2	22.9
Titratable acidity (g/100 mL)	0.85	0.71	0.66	0.62
pH	3.27	3.49	3.44	3.49
Brix/acid ratio	26.1	31.8	33.6	36.9
Leaf area/crop wt (m^2/kg)	3.99	1.55	1.05	0.82
Wine-tasting score (20 points)	12.38	13.0	12.85	13.06

Table 2 Influence of trellising and restriction of leaf exposure of Thompson Seedless grapevines on growth, yield, bud fruitfulness, canopy density, and amount of fruit sugar produced per vine. Data are the average of six single vine replicates over four seasons (1970-1973).

	Canopy				
Parameter	Divided	Single open	Restricted horizontal	Restricted vertical	LSD (5%)
Crop yield (kg/vine)	21.9	20.6	18.9	16.5	2.5
Pruning wt (kg/vine)	4.29	2.95	3.45	2.99	0.63
Crop wt/pruning wt	5.10	6.9	5.48	5.53	ns
Pruning wt/m canopy length	0.87	1.20	1.40	1.22	0.21
Total leaf area/vine (m^2)	20.51	18.84	17.26	15.14	2.4
Canopy density (m^2/m)	4.15	7.66	7.0	6.15	1.60
Leaf area (m^2)/kg fruit	0.94	0.92	0.91	0.92	ns
Total soluble solids (Brix)	23.0	21.8	21.6	21.5	0.95
Total sugar in fruit/vine (kg)	5.03	4.49	4.08	3.55	0.51
Bud fruitfulness (clusters/shoot)	1.23	1.13	1.09	1.07	0.13

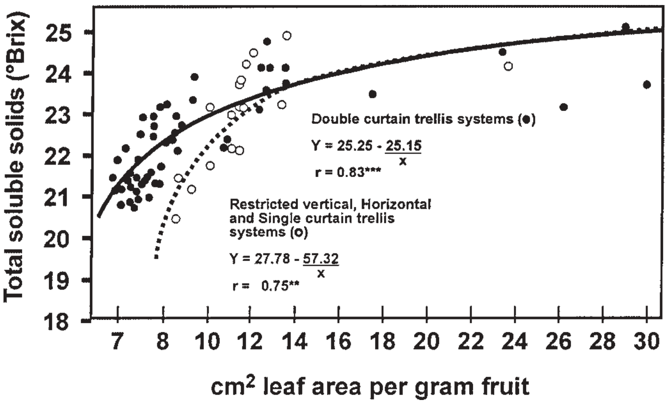

Figure 8 Regressions of total soluble solids (Brix) of Thompson Seedless berry juice at harvest on leaf area per unit crop weight (cm²/g) of vines trained to a divided-canopy double curtain and vines trained to single-curtain, restricted-vertical, and horizontal trellis systems in 1972.

Brix was about 50% less than that needed for SC, RV, and RH vines.

Cabernet Sauvignon trellising, vine spacing, rootstock trial, Oakville. The three-year average crop yield of the six trellis-training systems ranged from 9.9 (single canopy vertical) to 18.6 (divided canopy "V" trellis) mt/ha (Table 3). The number of shoots and leaf area (m^2) per m of canopy length ranged from 9 to 14 and 2.9 to 4.7, respectively. Pruning weight (kg) per m of canopy length ranged from 0.48 to 0.9; weight per cane (g) ranged from 38 to 64; and yield/pruning weight ratio ranged from 4.9 to 7.5 for the six trellis systems (Table 3). Only the VSP-trained vines at 1.0 m in-row vine spacing had excessively dense vine canopy as judged by leaf layer number in fruiting region (2.5), total leaf area per m canopy length (6.8 m^2/m), and pruning weight per m canopy length (1.52 kg/m). With

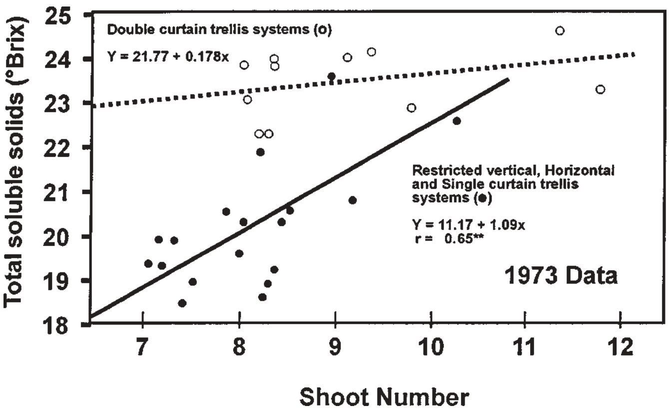

Figure 9 Regressions of total soluble solids (Brix) of Thompson Seedless berry juice at harvest on leaf area per unit crop weight (cm²/g) of vines trained to a divided-canopy double curtain and vines trained to single-curtain, restricted-vertical, and horizontal trellis systems in 1973.

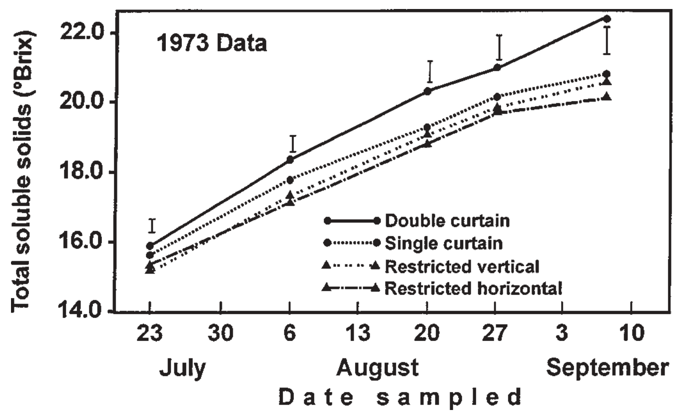

Figure 10 Comparison of the rates of soluble solids accumulation in fruit of Thompson Seedless trained to double-curtain, single-curtain, restricted-horizontal, and restricted-vertical trellis systems during the 1973 season.

Table 3 Influence of trellis system on the amount of shoot and leaf growth and crop yield of Cabernet Sauvignon. Data represents the average of three in-row vine spacings (1 m, 2 m, and 3 m) and two rootstocks (110R and O39-16) for three years, 1993-1995.

	Trellis-training system						
Parameter	**Vertical**	**Scott-Henry**	**TK2T**	**GDC**	**Lyre**	**V-trellis**	**Signif.**
No. shoot/vine	27.3	34.8	46.3	45.3	46.8	49.7	0.0001
No. shoot/m canopy	14.0	9.1	12.0	11.8	12.3	13.2	0.0001
Shoot length (cm)	130	142	102	120	103	136	0.0001
No. node/shoot	24.0	25.5	20.2	23.8	21.3	25.2	0.0001
Internode length (cm)	5.3	5.5	5.0	5.1	4.9	5.3	0.0002
Primary leaf area/shoot (cm^2)	2280	2470	1790	2120	1810	2380	0.0001
Lateral leaf area/shoot (cm^2)	1050	1190	610	900	600	950	0.0003
Lateral leaf area (%)	28.5	30.5	24.5	28.7	23.9	17.0	0.003
Total leaf area/vine (m^2)	8.4	11.6	10.7	13.2	11.0	15.8	0.0001
Total leaf area/m canopy (m^2)	4.72	3.20	2.90	3.52	2.98	4.51	0.0001
Leaf area/g fruit (cm^2/g)	14.4	15.9	11.9	13.1	11.2	15.5	0.002
Pruning wt (kg/vine)	1.58	2.04	1.74	1.99	1.73	2.51	0.002
Pruning wt/m canopy (kg/m)	0.89	0.59	0.50	0.54	0.48	0.72	0.005
Crop yield (mt/ha)	9.9	12.8	15.3	15.9	16.8	18.6	0.0001
Yield: pruning weight ratio	4.9	4.9	6.4	7.0	7.4	5.8	0.0001
Shoot weight (g)	64	64	40	44	38	53	0.003

increased in-row vine spacing from 1.0 to 3.0 m, there were more shoots per vine but shoot length and internode length were shorter, less leaf area and weight per shoot, higher crop yield/pruning weight ratios, and lower leaf area/crop weight ratios (Kliewer et al. 2000). All vine growth measurements were less for vines grafted to O39-16 compared to 110R rootstock.

Regression analyses were conducted between the concentration of total soluble solids of fruits at harvest and leaf area (m^2) per kg of fruit for all vines, irrespective of treatment, for data obtained in 1994 (Figure 11). The data show that 0.9 to 1.1 m^2 leaf area per kg fruit was required to mature the fruit to 22.5 to 23.0 Brix and that differences between treatments were mainly due to variations in leaf area per unit weight of fruit. Regression analysis was also conducted between the ratios of crop weight/pruning weight and leaf area/crop weight of individual vines, disregarding treatment. The data in Figure 12 reveal a close negative linear relationship, i.e., as the leaf area/crop weight ratio increased the crop weight/pruning weight ratio decreased. If we accept the published values (Bravdo et al. 1984, 1985) of crop weight/pruning weight ratios within the range of 5 to 10 as indicative of vines well balanced (not over- or undercropped), then the corresponding leaf area/crop weight ratios fall between 0.8 to 1.2 m^2 leaf area per kg fruit and agree very closely with the fruit total soluble solids leaf area/crop weight relationship shown in Figures 11 and 12. The data indicate that crop yield/pruning weight ratios within the range of 5 to 10 and leaf area/fruit weight ratios between 0.8 and 1.2 m^2/kg are both good indices of vines well balanced between the amounts of crop and foliage leaf area for Cabernet Sauvignon grown at the site of this trial. There were no significant differences in wine-tasting scores between trellis systems, vine spacing, and rootstock treatments from the 1994 vintage (Table 3).

Cabernet Sauvignon pruning-level trellising trials, Oakville. Vine growth, crop yield, fruit total soluble solids, and crop load ratios of Cabernet Sauvignon vines spur pruned (SP) to 48 nodes/vine, hedge pruned (HP), and minimal pruned (MP) on vines trained to either a single-canopy (SC) two-wire bilateral cordon or to a horizontally divided-canopy (DC) quadrilateral cordon are presented in Tables 4 and 5. HP and MP vines had 6 to 9 times more shoots per vine than SP vines and 3 to 4 times more clusters. Crop yield of HP and MP vines were approximately twice that of SP vines. Shoot length and nodes per shoot of HP and MP vines were about one-third and one-fourth that of SP vines. A negative curvilinear relationship was found between shoot number per vine and shoot length with a correlation coefficient of 0.70 (Figure 13). Leaf area/crop weight ratios of SC spur-, hedge-, and minimal-pruned vines were 1.65, 1.17, and 1.26, respectively, and similarly for DC-trained vines the ratios were 1.25, 0.86, and 0.82, respectively (Tables 4 and 5). The yield/pruning weight ratios of spur-pruned SC and DC vines were well within the acceptable range of "normal" cropped vines; however, HP and MP vines had ratios well over 10, indica-

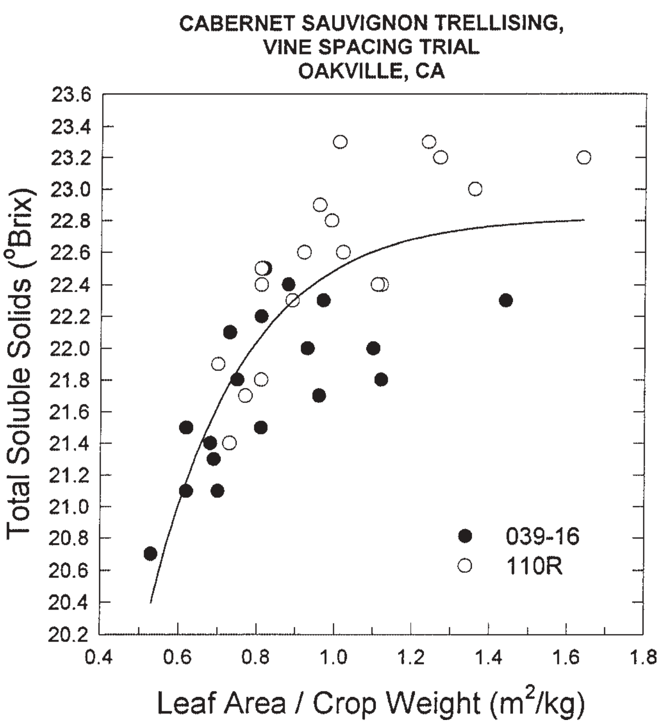

Figure 11 Regressions of total soluble solids (Brix) of Cabernet Sauvignon berry juice at harvest on leaf area per unit crop weight (m^2/kg) for the 1994 season. Treatments regressed included six trellis-training systems and three in-row spacings.

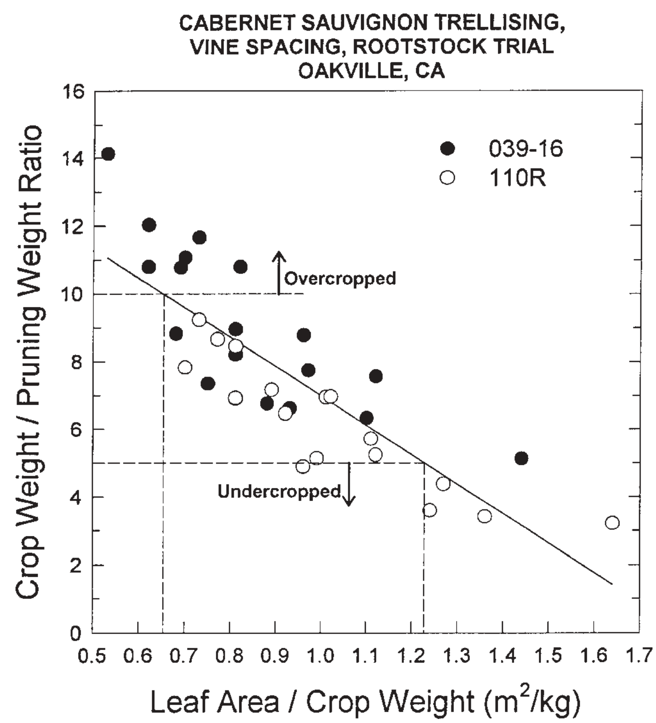

Figure 12 Regression of crop weight/pruning weight ratios against leaf area/crop weight ratios of Cabernet Sauvignon vines for the 1994 season. Treatments regressed included six trellis-training systems, three in-row spacings (1, 2, and 3 m), and two rootstocks (039-16 and 110R).

tive of overcropping. The high yield/pruning weight ratios of HP and MP vines were reflected in the lower level of sugars in fruits at harvest compared to SP vines (Tables 4 and 5).

Regression analysis was done to determine the relationship between fruit total soluble solids at harvest and leaf area/crop weight ratios of individual vine replicates of SP, HP, and MP single-canopy and divided-canopy trained vines (Figure 14). For DC fruits to reach 22 Brix required 0.9 to 1.0 m^2 leaf area per kg fruit, whereas SC fruits needed 1.3 to 1.4 m^2 leaf area for each kg fruit to reach 22 Brix (Figure 14). These data agree with the finding of Thompson Seedless vines trained to a DC trellis system reported previously and indicate the greater efficiency of DC-trained vines to ripen fruit per m^2 leaf area. This finding is not unexpected since several investigators have shown that DC-trained vines have a higher percentage of their leaf area at light saturation than SC-trained vines (Amberg and Shaulis 1966, Gladstone 1999, Kliewer 1982, Kliewer et al. 1988, May et al. 1976, Schultz 1995, Shaulis 1982, Shaulis et al. 1966, Shaulis and May 1971, Smart 1982, Smart et al. 1991, 1982).

Sensory evaluation of wines from the different treatments revealed than the taste panel could distinguish between SP wines compared to HP and MP wines made from the SC training system (Tables 6 and 7). They could also distinguish between HP and MP wines from both SC and DC training systems (Table 6). However, the taste panel could not tell a DC-SP wine from a DC-HP wine. The general consensus of the taste panel was that SP vines produced the most fruity and herbal wines; SP wines were the most astringent, but still fairly fruity; and MP wines were the least fruity, had weedy, stemmy character, were more acidic, and had some aldehyde off odor compared to SP and HP wines (Table 7).

Table 4 Influence of pruning method and level on vine growth, crop yield, and cropping indicies of Cabernet Sauvignon trained to a single-canopy bilateral cordon trellis system, Oakville, California, 1992 season.

	Single-canopy bilateral cordon			
Parameter	Standard spur pruned[a]	Hedge pruned	Minimal pruned	Signif.
Total shoots/vine	36	191	314	0.0001
Total clusters/vine	69	225	299	0.0001
Shoot length (cm)	152	60	41	0.0001
Nodes/shoot	33.7	16.3	13.4	0.0001
Total leaf area/vine (m^2)	16.2	23.8	20.1	0.0001
Crop yield/vine (kg)	9.8	20.2	15.9	0.0001
Pruning wt/vine (kg)	1.30	1.53	0.29	0.0001
Yield/pruning wt (kg/kg)	7.5	13.2	54.8	0.0001
Leaf area/crop wt (m^2/kg)	1.65	1.17	1.26	0.001
Total soluble solids (Brix)	22.4	20.8	20.7	0.0001

[a]24 two-bud spurs.

Table 5 Influence of pruning method and level on vine growth, crop yield, and cropping indicies of Cabernet Sauvignon trained to a divided canopy quadrilateral trellis system, Oakville, California, 1992 season.

	Divided-canopy quadrilateral cordon			
Parameter	Standard spur pruned[a]	Hedge pruned	Minimal pruned	Signif.
Total shoots/vine	41	244	362	0.0001
Total clusters/vine	75	233	274	0.0001
Shoot length (cm)	127	56	32	0.0001
Nodes/shoot	29.4	15.3	11.0	0.0001
Total leaf area/vine (m^2)	14.8	21.0	18.2	0.0001
Crop yield/vine (kg)	11.8	24.3	22.0	0.0001
Pruning wt/vine (kg)	1.41	2.14	0.46	0.0001
Yield/pruning wt (kg/kg)	8.4	11.3	47.8	0.0001
Leaf area/crop wt (m^2/kg)	1.25	0.86	0.82	0.001
Total soluble solids (Brix)	22.1	20.4	19.9	0.001

[a]24 two-bud spurs.

Chenin blanc trellising trials. Chenin blanc grapevines grown on a very deep, irrigated, fertile soil at the UC Davis vineyard were trained to two horizontally divided canopy trellis systems (GDC and lyre) and compared to a single-canopy vertical (V) trellis system (Figure 15). At this site the vines were very productive, producing yields of 40 to 49 mt/ha for the V trellis and 52 to 60 mt/ha for the GDC and lyre trellis systems. The crop yield/pruning weight ratios of the V-, lyre-, and GDC-trellised vines averaged 8.0, 8.5, and 12.1, respectively, with corresponding leaf area/crop weight ratios of 0.68, 0.55, and 0.40 m^2/kg (Table 8). The level of total soluble solids in fruits at harvest for the V, lyre, and GDC trellis systems averaged 19.8, 21.6, and 20.6 Brix, respectively (Table 8). The leaf area/crop weight data of individual replicates of each of the three trellis systems was regressed against the level of total soluble solids at harvest (Figure 16). The data in Figure 16 shows that the m^2 of leaf area per kg fruit required to mature Chenin blanc fruit to 22 Brix for V-, lyre-, and GDC-trellised vines was approximately 0.9, 0.6, and 0.5, respectively. The average area per primary leaf of V, lyre, and GDC vines was 123, 102, and 74 cm^2, respectively. Based on these values, the number of primary leaves required per cluster to ripen fruit to 22 Brix for V-, lyre-, and GDC-trellised vines was 12 to 13, 10 to 11, and 10 to 11, respectively. These data indicate that the amount of leaf area needed to support a unit weight of fruit was considerably less for lyre- and GDC-trellised vines compared to V vines, in agreement with the findings of trellising trials with Thompson Seedless and Cabernet Sauvignon reported above. It is interesting to note that the leaf area/crop weight ratio needed to mature Chenin blanc fruit to 22 Brix for both single-canopy and divided-canopy trained vines was less than that found for Cabernet Sauvignon. Chenin blanc, a medium-clustered to large-clustered wine variety, generally produces higher yields than small-clustered wine varieties such as Cabernet Sauvignon (Winkler et al. 1994). Whether the differences in leaf area/crop weight ratios required to mature fruit between cultivars were due to genetic, physiological, or site location differences is not known.

Sensory analysis of the Chenin blanc wines with duo trio comparisons of the three trellis treatments revealed that the taste panel could detect differences between wines made from V- and lyre-trellised vines and between V and GDC wines, but not between the lyre and GDC wines (Table 9). The lyre and GDC wines were generally less vegetative and more fruity than wines made from the V-trellised vines.

Values given in the literature for the amount of leaf area needed to support a unit weight of fruit vary considerably, depending on the cultivar, climatic region, cultural conditions, and method of measurement. May et al. (1969) reported that about 0.7 m^2 of leaf area per kg of fruit was required to ripen Thompson Seedless berries, whereas Kliewer and Antcliff (1970), Kliewer and Ough (1970), and Kliewer (1970), using the same cultivar, found that 1.0 to 1.2 m^2 of leaf surface was necessary. Winkler (1930), using girdled shoots of Muscat of Alexandria, reported 1.1 to 1.5 m^2 leaf area per kg of fruit was needed for full maturation of a cluster. Buttrose (1966), using the same cultivar, indicated that 1.7 m^2 per kg of fruit was needed for unhindered development of all parts of one-year-old vines grown in pots. Amberg and Shaulis (1966) indicated a requirement of 1.5 m^2/kg fruit for the cultivar Concord grown under New York conditions. Kaps and Cahoon (1992), using the French-American hybrid cultivar Seyval blanc grown under greenhouse conditions in pots, found 0.8 to 1.0 m^2 leaf area per kg fruit was needed to produce maximum berry weight and Brix in fruits; however, 1.5 m^2/kg was required to maximize dry weight of leaves, stems, and roots. In the

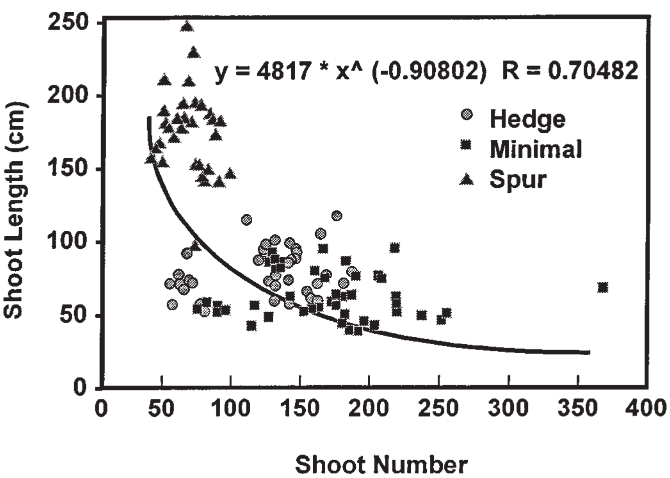

Figure 13 Regression of shoot length (cm) of Cabernet Sauvignon vines against the number of shoots per vine for data averaged over three seasons (1988 to 1990). Data from spur-pruned, hedge-pruned, or minimal-pruned vines.

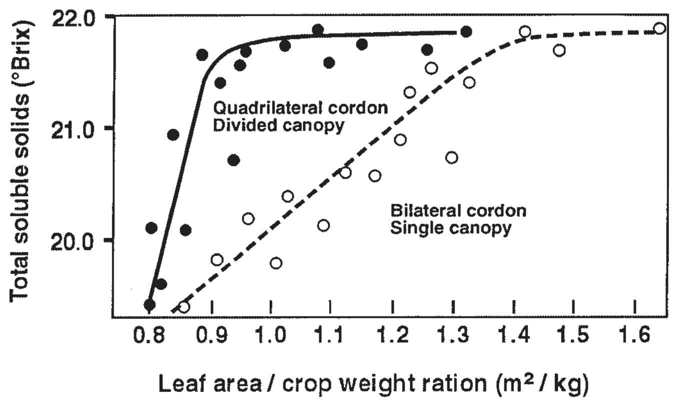

Figure 14 Regressions of total soluble solids (Brix) of Cabernet Sauvignon berry juice at harvest on leaf area per unit crop weight (m^2/kg) of vines trained to either single-canopy or divided-canopy systems.

Table 6 Wine sensory evaluation of Cabernet Sauvignon pruning level trial, Oakville, California, 1992 season.

	Standard spur vs. hedge	Spur vs. minimal	Hedge vs. minimal
Bilateral cordon	26/36**	25/32***	23/32**
Quadrilateral cordon	19/32 ns	23/24***	21/28**

, *, and ns indicate significance between wines at the 1%, 0.1%, and not significant levels, respectively.

Table 7 Incidence of comments from taste panel judges on how Cabernet Sauvignon wines differed among pruning treatments from the Oakville trial, 1992 season.

	Bilateral cordon			Quadrilateral cordon		
Parameter	Standard spur pruned	Hedge pruned	Minimal pruned	Standard spur pruned	Hedge pruned	Minimal pruned
More fruitness	6	9	2	11	6	1
More herbal character	7	3	1	11	0	0
Off odors	0	0	13	0	1	4
More acidic	0	4	14	2	1	2
More astringent	3	8	1	2	3	12
More body	2	1	0	0	1	0

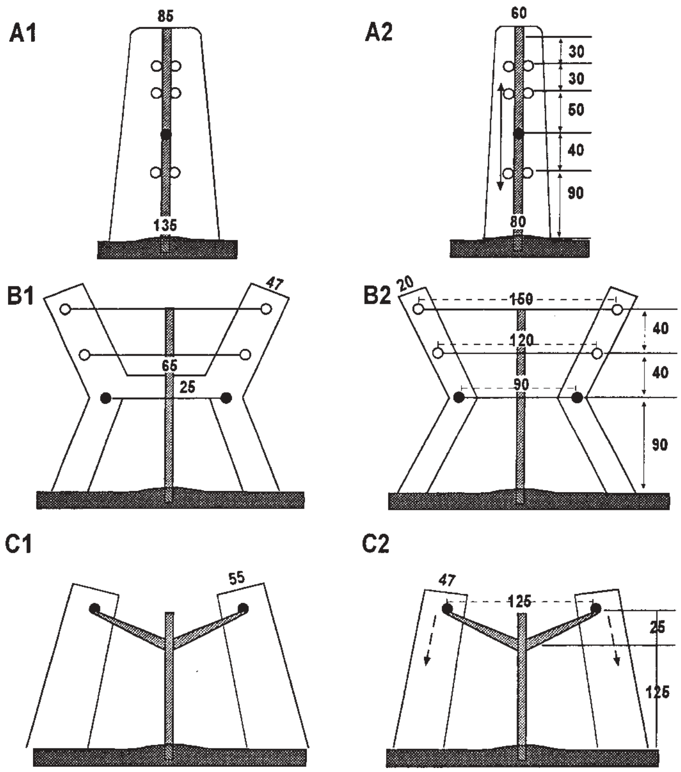

Figure 15 Cross-section graphs of three trellises used in the experiment. White and dark circles represent foliage and cordon wires, respectively. Arrows indicate shoot positioning direction. Dotted lines show the canopy contour. **A**, **B**, and **C** are vertical, lyre, and Geneva double-curtain trellises, respectively. The numbers 1 and 2 represent NSP and SP. Numbers shown within the figure represent centimeters.

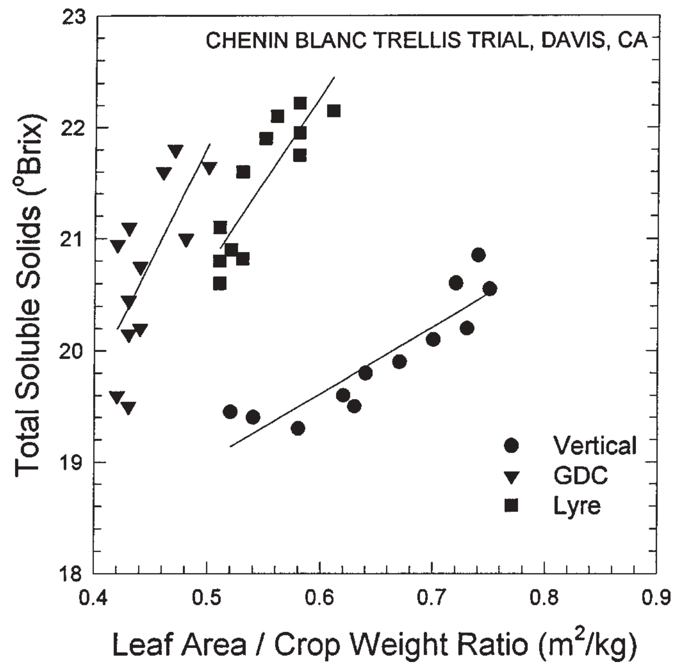

Figure 16 Regressions of leaf area/crop weight ratios versus total soluble solids of Chenin blanc berry juice at harvest for vines trained to vertical, Geneva double curtain, and lyre trellis systems.

Table 8 Vine growth, canopy density, crop yield, and fruit soluble solids of vertical-, lyre-, and GDC-trellised Chenin blanc grapevines, Davis, California.

	Trellis-training system			
Parameter	**Vertical**	**Lyre**	**GDC**	**Signif.**
Total shoots/vine	62.2 a[a]	68.1 a	77.1 b	0.007
Shoots/m canopy length	28.3 a	15.5 b	17.5 b	0.01
Leaf area (m^2)/m canopy length	9.9 a	5.0 b	3.4 c	0.01
Crop yield/vine (kg)	35.4 a	43.7 b	41.3 b	0.01
Pruning wt/vine (kg)	4.4 a	5.1 b	3.4 c	0.05
Pruning wt/canopy length (kg/m)	1.8 a	1.0 b	0.7 b	0.05
Crop yield/pruning wt ratio (kg/kg)	8.0 a	8.5 a	12.1 b	0.05
Leaf area/crop wt (m^2/kg)	0.68 a	0.55 b	0.40 c	0.01
Total soluble solids (B)	19.8 a	21.6 b	20.6 c	0.02

[a]Means followed by different letters in rows indicates significant differences at the indicated significance level.

Table 9 Sensory analysis of Chenin blanc wines by duo trio comparisons of trellising treatments (n = 24), 1990 vintage.

Treatment comparisons	**Correct responses**[a]
Vertical bilateral cordon vs. lyre	22**
Vertical bilateral cordon vs. GDC	23***
Lyre vs. GDC	12 ns

[a]**, ***, and ns indicate significance at $p < 0.01$, 0.001, and not significant, respectively.

current study, the leaf area/crop weight ratio required to mature fruit from vines trained to divided-canopy trellis systems generally ranged from 0.5 to 0.8 m^2/kg; whereas for single-canopy trellis systems, values of 0.8 to 1.4 m^2/kg were needed. This finding agrees with the data of Williams et al. (1987), which found that removing all the interior leaves of Thompson Seedless vines, representing 27% to 35% of the total vine leaf area, had no significant effect on berry weight and level of sugars in fruits. The leaf area/fruit ratio (m^2/kg) before defoliation was approximately 1.0 and after defoliation ranged from 0.5 to 0.65. Several studies have shown that divided canopy training systems, such as GDC and lyre, have considerably higher percentage of their leaf area at light saturation compared to single-canopy systems (Kliewer 1982, Kliewer et al. 1988, May et al. 1976, Shaulis et al. 1966), and therefore, a lower leaf area/fruit weight ratio to mature fruit would be expected, as demonstrated by the data presented above.

Conclusions

In a series of field experiments using canopy management and trellising treatments, a wide range of leaf area/crop weight and crop yield/pruning weight ratios were investigated to determine how much leaf area was required to fully ripen several grape cultivars. The results found that about 0.8 to 1.2 m^2 leaf area per kg fruit was needed to mature fruit trained to single-canopy trellis systems and 0.5 to 0.8 m^2/kg for vines trained to divided-canopy trellis systems. The corresponding crop yield/pruning weight ratios for SC and DC trellised vines were 4 to 10 and 5 to 10, respectively. The amount of leaf area (m^2) per m canopy length of SC and DC trained vines that had crop load values as indicated above generally ranging from 2 to 5 and 2 to 4, respectively. Vines that fell within the ranges of these indices were considered well balanced and capable of fully ripening their crop as well as producing high-quality wines.

Literature Cited

Amberg, H., and N.J. Shaulis. 1966. Techniques for controlled climate studies in Concord grape vines. *In* Proceedings of the VXIII International Horticultural Congress. International Society for Horticulture Science 1:588.

Bravdo, B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. 1984. Effect of crop level on growth, yield and wine quality of a high yielding Carignane vineyard. Am. J. Enol. Vitic. 35:247-252.

Bravdo, B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. 1985. Effect of crop level and crop load on growth, yield, must and wine composition and quality of Cabernet Sauvignon. Am. J. Enol. Vitic. 36:125-131.

Buttrose, M.S. 1966. The effect of reducing leaf area on the growth of roots, stems and berries of 'Gordo' grapes. Vitis 5:455-464.

Carbonneau, A., and P. Huglin. 1982. Adoptation of training systems to French regions. *In* Grape and Wine Centennial Symposium Proceedings. 18-21 June 1980, Davis, CA. A.D. Webb (Ed.), pp. 376-385. University of California, Davis.

Dokoozlian, N.K. 1990. Light quantity and light quality within *Vitis vinifera* L. grapevine canopies and their relative influence on berry growth and composition. Ph.D. dissertation, University of California, Davis.

Dokoozlian, N.K., and W.M. Kliewer. 1995. The light environment with grapevine canopies. I. Description and seasonal changes during fruit development. Am. J. Enol. Vitic. 46:209-218.

Dokoozlian, N.K., and W.M. Kliewer. 1995. The light environment with grapevine canopies. II. Influence of leaf area density on fruit zone light environment and some canopy assessment parameters. Am. J. Enol. Vitic. 46:219-226.

Gladstone, E.A. 1999. Interaction of canopy size and trellis/training system on grapevine canopy microclimate. MS thesis, University of California, Davis.

Johnson, R.A. 1988. The effect of trellising, row spacing, and pruning level on yield, yield components, and composition of Cabernet Sauvignon grapes. MS thesis, University of California, Davis.

Kaps, M.L., and G.A. Cahoon. 1992. Growth and fruiting of containers grown Seyval blanc grapevines modified by changes in crop level, leaf number and position, and light exposure. Am. J. Enol. Vitic. 43:191-198.

Kliewer, W.M. 1970. Effect of time and severity of defoliation on growth and composition of 'Thompson Seedless' grapes. Am. J. Enol. Vitic. 21:37-47.

Kliewer, W.M. 1982. Vineyard canopy management – A review. *In* Grape and Wine Centennial Symposium Proceedings. 18-21 June 1980, Davis, CA. A.D. Webb (Ed.), pp. 342-352. University of California, Davis.

Kliewer, W.M., and A.J. Antcliff. 1970. Influence of defoliation, leaf darkening, and cluster shading on the growth and composition of 'Sultana' grapes. Am. J. Enol. Vitic. 21:26-26.

Kliewer, W.M., and C.S. Ough. 1970. The effect of leaf area and crop level on the concentration of amino acids and total nitrogen in 'Thompson Seedless' grapes. Vitis 9:196-206.

Kliewer, W.M., J.J. Marois, et al. 1988. Relative effectiveness of leaf removal, shoot positioning and trellising for improving winegrape composition. *In* Proceedings of the Second International Symposium for Cool Climate Viticulture and Oenology. 11-15 Jan. 1988. R.E. Smart et al. (Eds.), pp. 123-126. New Zealand Society for Viticulture and Enology, Auckland.

Kliewer, W.M., and R.J. Weaver. 1971. Effect of crop level and leaf area on growth, composition and coloration of 'Tokay' grapes. Am. J. Enol. Vitic. 22:172-177.

Kliewer, W.M., J.A. Wolpert, and M. Benz. 2000. Trellis and vine spacing effects on growth, canopy microclimate, yield and fruit composition of Cabernet Sauvignon. Acta Hortic. 526:21-32.

May, P., N.J. Shaulis, and A.J. Antcliff. 1969. The effect of controlled defoliation in the Sultana vine. Am. J. Enol. 20:237-250.

May, P., P.R. Clingeleffer, P.B. Scholefield, and C.J. Brien. 1976. The response of the grape cultivar Crouchen (Australian Syn. Clare Riesling) to various trellis and pruning treatments. Austr. J. Agri. Res. 27:845-856.

Schuck, E. 1987. A comparison of productivity and fruit composition of six trellis-training systems and two pruning methods of 'Sauvignon Blanc' grown at Davis, CA. MS thesis, University of California, Davis.

Schultz, H.R. 1995. Grape canopy structure, light microclimate and photosynthesis. I. A two-dimensional model of the spatial distribution of surface area densities and leaf ages in two canopy systems. Vitis 34:211-215.

Shaulis, N.J. 1982. Responses of grapevines and grapes to spacing of and within canopies. *In* Grape and Wine Centennial Symposium Proceedings. 18-21 June 1980, Davis, CA. A.D. Webb (Ed.), pp. 353-360. University of California, Davis.

Shaulis, N.J., H. Amberg, and D. Crowe. 1966. Response of concord grapes to light exposure, and Geneva double curtain training. Proc. Am. Soc. Hortic. Sci. 89:268-280.

Shaulis, N., and P. May. 1971. Response of Sultana vines to training on a divided canopy and to shoot crowding. Am. J. Enol. Vitic. 22:215-222.

Smart, R.E. 1973. Sunlight interception by vineyards. Am. J. Enol. Vitic. 24:141-147.

Smart, R.E. 1982. Vine manipulation to improve wine grape quality. *In* Grape and Wine Centennial Symposium Proceedings. 18-21 June 1980, Davis, CA. A.D. Webb (Ed.), pp. 362-375. University of California, Davis.

Smart, R.E. 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. A review. Am. J. Enol. Vitic. 36:230-239.

Smart, R.E., J.K. Dick, et al. 1991. Canopy management to improve yield and quality: Principles and practices. S. Afr. J. Enol. Vitic. 11:3-17.

Smart, R.E., and M. Robinson. 1991. Sunlight into Wine. A Handbook for Winegrape Canopy Management. 88 pp. Winetitles, Adelaide, Australia.

Smart, R.E., N.J. Shaulis, and E.R. Lemon. 1982. The effect of Concord vineyard microclimate on yield. I. The effect of pruning, training and shoot positioning on radiation microclimate. Am. J. Enol. Vitic. 33:99-108.

Williams, L.E., P.J. Biscay, and R.J. Smith. 1987. Effect of interior canopy defoliation on berry composition and potassium distribution in Thompson Seedless grapevines. Am. J. Enol. Vitic. 38:287-292.

Winkler, A.J. 1930. The relationship of number of leaves to size and quality of tablegrapes. Proc. Am. Soc. Hortic. Sci. 27:158-160.

Winkler, A.J. 1954. Effects of overcropping. Am. J. Enol. 5:4-12.

Winkler, A.J. 1958. The relation of leaf area and climate to vine performance and grape quality. Am. J. Enol. 9:10-23.

Winkler, A.J., J.A. Cook, W.M. Kliewer, and L.A. Lider. 1994. General Viticulture. University of California Press, Berkeley .

Winkler, A J., and W.O. Williams. 1939. The heat required to bring Tokay grapes to maturity. Proc. Am. Soc. Hortic. Sci. 37:650-652.

Yang, W. 1991. Effects of trellising, shoot positioning, and leaf removal on canopy characteristics, microclimate, yield and fruit composition of Chenin blanc grapevines. MS thesis, University of California, Davis.