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Shoot and Cluster Thinning Influence Vegetative Growth, Fruit Yield, and Wine Quality of 'Sauvignon blanc' Grapevines

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ABSTRACT. **Effects of two shoot densities (14 and 44 shoots/vine) and two crop levels (one and two fruit clusters per shoot) on yield, pruning weight, crop load, and juice and wine quality of field-grown 'Sauvignon blanc' grape (*Vitis vinifera* L.) were studied in a factorial experiment over 3 years. Main shoot length, lateral shoot length and number, shoot diameter, leaf area per shoot, and specific leaf weight were greater at the lower compared with the higher shoot density for all years whereas pruning weight was significantly increased only in the third year. Crop yield increased proportionally with the number of clusters, up to 44 clusters per vine, by both shoot and cluster thinning; a lower rate of yield increase was apparent when the number of clusters per vine was increased further, probably because of increasing source limitation. Berry maturation was delayed in the 44 shoots per vine treatment. Unchanged soluble solids, higher total acidity, and lower pH in the 44-shoot vine treatment in the third year indicated that the effect of cluster number on the must quality was not due to delayed maturation. No effect of cluster number per shoot on vegetative parameters was apparent. Berry size and number were affected by cluster thinning only in the 44 shoot/vine treatment. Both the number of shoots per vine and the number of clusters per shoot affected wine sensory attributes. Herbaceous aroma scores increased with increasing pruning weight. The wine sensory evaluation score decreased with increasing crop load. Total wine sensory scores decreased with decreasing leaf area to fruit weight ratio below ≈18 $cm^2 \cdot g^{-1}$, whereas a critical value of the crop to pruning weight ratio, for wine quality, was not apparent. Crop load expressed as crop to pruning weight ratio ($kg \cdot kg^{-1}$) was highly correlated with fruit weight to leaf area ratio ($g \cdot cm^{-2}$) ($r^2 = 0.86$), providing a biological rationale for the relevance of crop load and wine quality relations.**

Wine quality is affected by both cultural and climatic factors (Jackson and Lombard, 1993). The quality depends on the interactions among many factors, some of which are difficult to evaluate quantitatively. The study of the effects of cultural and climatic factors on fruit and wine quality is therefore complex and indirect, whereas directly observable effects comprise mainly changes in the chemical composition of the fruit caused by environmental and plant factors. Control of environmental factors in the root zone can be achieved by irrigation and fertilization (Bravdo and Proebsting, 1993), and the microclimate in the vicinity of the grape cluster can be affected by canopy management treatments such as shoot thinning, topping, and cluster thinning (Smart, 1985). All these treatments affect the reproductive to vegetative ratio and thereby the crop load.

Crop load is expressed either as the reciprocal of the yield per unit leaf area (Kaps and Cahoon, 1992; Kliewer, 1970; Kliewer and Antcliff, 1970; Kliewer and Weaver, 1971; May et al., 1969) or the ratio of yield to weight of pruning canes (Bravdo et al., 1984, 1985a, 1985b; Fisher et al., 1977; Jackson and Lombard, 1993). Pruning weight is well correlated with leaf area (Smart et al., 1985) and, therefore, may serve as a practical indicator for assimilate availability.

Crop level is determined primarily by the number of clusters per vine or per hectare whereas crop load is associated with the relationships between vegetative and reproductive weight (Bravdo and Hepner, 1987b; Jackson and Lombard, 1993).

In most cases, cluster weight has been found to increase as the number of clusters per grapevine decreased, because of both increased numbers of berries per cluster (Bravdo et al., 1984; Edson et al., 1993; Fisher et al., 1977; Freeman et al., 1979; Kliewer et al., 1983; Reynolds et al., 1994a, 1994b) and increased berry weight (Bravdo et al., 1984, 1985a; Edson et al., 1993; Fisher et al., 1977; Freeman and Kliewer, 1983; Kliewer and Weaver, 1971; Reynolds et al., 1994a, 1994b; Weaver and Pool, 1968). Crop yield sometimes (Edson et al., 1993), but not always (Clingeleffer and Krake, 1992; Miller et al., 1993) correlates with pruning weight. Parallel increases in crop level and pruning weight enable production to be increased without affecting crop load and thereby quality (Smart et al., 1985).

Pruning weight is unaffected by varying the number of shoots per vine (Freeman et al., 1979; Reynolds and Wardle, 1989; Reynolds et al., 1994b, 1994c), indicating that the vines can increase the vigor of the individual shoots to compensate for the reduction in shoot number imposed by shoot thinning. Pruning weight may be increased by reducing the number of clusters per vine, even at relatively low crop loads (Bravdo et al., 1984, 1985a; Fisher et al., 1977; Kliewer and Weaver, 1971; Kliewer et al., 1983; Reynolds et al., 1986, 1994a, 1994b, 1994c; Weaver and McCune, 1960).

The complex interactions among factors involved in production and quality of wine grapes account for some of the conflicting findings regarding optimal crop load and shoot density (Bravdo et al., 1984, 1985a, 1985b; Freeman and Kliewer, 1983; Freeman et al., 1980; Kliewer and Weaver, 1971; Reynolds et al., 1994a; Sinton et al., 1978; Edson et al., 1993). Therefore, the objective of the present research was to evaluate quantitatively the effects

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of shoot and cluster density on vegetative growth, fruit yield, and crop quality of a high-yielding *Vitis vinifera* 'Sauvignon blanc' vineyard.

Materials and Methods

Experimental vineyard. An experiment (cluster density per shoot × shoot density) was conducted in a vineyard located on the Golan Heights, Israel, 880 m above sea level and 50 km east of the Mediterranean Sea. The region is semiarid with no summer rain. Average midday air temperature, relative humidity, and wind speed in midsummer are 29 °C, 35%, and 3 $m \cdot s^{-1}$, respectively. The experiment was conducted with 12-year-old drip-irrigated 'Sauvignon blanc' grafted onto '216-3C' rootstock in a commercial vineyard, on a shallow, Basaltic brown Mediterranean clay soil (39% clay, 47% silt, 14% fine sand in soil fraction). The vine spacing was 3 × 1.5 m in north–south oriented rows, and a vertical shoot positioned trellis was used for the training system.

Irrigation and fertilization. The irrigation rate was increased gradually from 0.5 $mm \cdot d^{-1}$ at 2 weeks after budbreak to 2.5 $mm \cdot d^{-1}$ at veraison. Average postveraison irrigation rates of 1.54, 2.97 and 2.63 $mm \cdot d^{-1}$ were applied in 1992, 1993, and 1994, respectively, equivalent to 0.20, 0.38, and 0.34, respectively, of average Class A pan evaporation. The vineyard was fertigated with N, P, and K at 77, 15, and 57 $kg \cdot ha^{-1}$, respectively, in 1992; N, P and K at 46, 9, and 33 $kg \cdot ha^{-1}$, respectively, in 1993; and N at 60 $kg \cdot ha^{-1}$ in 1994 in accordance with petiole mineral nutrient analyses.

Treatments. Canopy size was controlled by shoot thinning to 14 or 44 shoots/vine. The crop level, within each shoot density, was controlled by inflorescence thinning to one or two clusters/shoot. The study was conducted as a 2 × 2 factorial experiment. There were nine vines in each treatment, and all treatments were replicated five times in randomized complete blocks. The vines were spur-pruned in the winter to allow the maximum number of buds per vine to enable selection of 44 vital shoots/vine. The shoots were thinned in the early spring (at a shoot length of ≈20 cm) to two shoots/spur and 14 or 44 shoots/vine, evenly distributed along the cordons. In the first year, a maximum of only 30 shoots/vine were available. The shoots were thinned to one or two clusters per shoot, 2 weeks before bloom. Additional thinning of newly formed shoots and leaf removal opposite the clusters were performed several times during May and June. No shoot topping and secondary shoot removal were done during the experimental period.

Canopy measurements. Primary shoot length was measured on eight representative shoots per replication. Pruning weight per vine was measured every winter. Three (in 1992) or four (in 1993) vines per replication were selected for detailed measurements of the shoots. The number of laterals per shoot and the cumulative lengths of the lateral shoots were measured. The main shoot diameter at the first node was also measured.

The relationship between shoot length and shoot leaf area was determined 2 weeks before harvest in 1993. Three shoots were randomly selected in each replication in all treatments, and lengths of the main shoot and of each lateral (secondary) shoot was measured. Average main-shoot lengths were 122.3, 166.8, and 228.2 cm in the short, medium, and long shoots, respectively. The leaves were removed and leaf areas were measured with a leaf area meter (Delta-T Devices, Ltd., Cambridge, United Kingdom). Linear regressions between shoot leaf area and shoot length were performed for each of the short, average, and long shoots, separately. These relationships were used for the calculation of shoot and vine leaf area for each replication.

Specific leaf weight ($g \cdot cm^{-2}$) was measured on three randomly selected leaves from each replication (10^{th} leaf from the bottom, mature and similar age). Twenty leaf discs (16 mm in diameter) were taken from each leaf and oven dried, and specific leaf dry weight was calculated.

Measurements at harvest. All treatments were harvested on the same date (19 Sept. 1992 and 3 Sept. 1993), whereas in 1994, treatments were harvested separately when soluble solids reached 21%. The yield and the number of fruit clusters per vine were determined for each vine and cluster weight was calculated. Five clusters per replication were selected randomly from the five inner vines, and the number of berries and weight were determined. Juice was prepared from five clusters per replication and soluble solids, pH, potassium (K), and titratable acidity (total acidity) calculated as tartaric acid was determined.

Wine preparation and sensory evaluation. Microvinification was performed at the Israeli Wine Institute, Rehovot on 25 kg grape samples per replication. A panel of wine experts from the Golan Heights Winery evaluated the wine quality as follows. In 1993 a scale of 0 (poor) to 4 (excellent) was used to evaluate the appearance (color intensity and quality), aroma (flavor by nose), taste (flavor by mouth), and harmony (mouth and nose interaction) and multiplied by the weighing factors 12%, 24%, 40%, 24%, respectively, summed and adjusted to a 0 to 20 scale by multiplication by 0.2. In 1994, the aroma and the taste were split equally into fruity and herbaceous flavor using the same calculation method.

Statistical analysis. All data were subjected to analysis of variance (ANOVA) procedures and means separated by Duncan's multiple range test using SAS PROC GLM (SAS Inst., Inc., Cary N.C.). Regression analysis was performed by Sigmaplot V. 4.0 (SPSS, Chicago).

Results

Shoot size, pruning weight, and leaf area. Primary shoot length was higher in the low shoot treatment in all 3 years (Table 1). Cumulative secondary shoot length, number of lateral shoots (data not presented), and shoot diameter (data not presented) increased in the low shoot vines (Table 1). Pruning weight was not affected by varying the number of shoots per vine during the 1992 and 1993 seasons (Table 2), whereas in 1994 the pruning weight of the 14-shoot vines was greater than that of the 44-shoot vines. There were no significant interactions between shoots per vine and clusters per shoot for these variables. Vine leaf area was significantly greater for the high shoot per vine and one cluster per shoot treatment compared with the other treatments (Table 1).

Crop yield and crop load. Crop yield to pruning weight and crop yield to leaf area ratios were highly correlated (Fig. 1). The yield per vine was linearly related to the number of clusters, up to 45 clusters/vine, and leveled off at ≈80 clusters/vine (Fig. 2). Both shoot and cluster thinning reduced crop yield per vine (Table 2, Fig. 2). Yield per shoot increased gradually in the 14-shoot vines during the three experimental years and exceeded that of the 44-shoot vines (data not presented).

Cluster weight was lower in the high–shoot-number vines and increased as the number of clusters per shoot decreased from two to one (Table 3). Berry weight was not affected by the number of shoots per vine and increased slightly in 1992 only due to cluster thinning (Table 3). There were no significant interactions be-

Table 1. Primary shoot length, cumulative secondary shoot length per primary shoot at harvest, vine leaf area, and specific leaf weight as a function of the number of shoots per vine (shoot density) and clusters per shoot (cluster density).

		Mean primary shoot length (cm)			Cumulative secondary shoot length/ primary shoot (cm)		Vine leaf area (m^2)	Specific leaf wt ($g\cdot m^{-2}$)
Shoots/vine[z]	Clusters/shoot	1992	1993	1994	1992	1993	1993	1992
Low		201 a[y]	252 a	229 a	77 a	170 a	---	72 a
High		142 b	192 b	164 b	14 b	12 b	---	63 b
	1	158 a	224 a	200 a	49 a	96 a	---	70 a
	2	184 a	221 a	194 a	42 a	86 a	---	65 a
Low	1	185 ab	252 a	232 a	84 a	181 a	10.9 b	76 a
Low	2	217 a	253 a	226 a	71 a	158 a	11.3 b	68 ab
High	1	132 c	195 b	174 b	13 b	14 b	14.0 a	64 ab
High	2	152 bc	188 b	155 b	14 b	10 b	11.2 b	62 b

[z]Low = 14 shoot/vine; high = 30 shoots/vine in 1992 and 44 shoots/vine in 1993–94. Main effects are shown when the interactions were nonsignificant.

[y]Mean separation (n = 5) within columns for a treatment by Duncan's multiple range test, $P = 0.05$.

Table 2. Vine crop yield, pruning weight per vine, and crop load as functions of the number of shoots per vine (shoot density) and clusters per shoot (cluster density).

		Vine crop load (kg/vine)			Pruning wt/vine (kg/vine)			Vine crop yield (kg yield/kg pruning)		
Shoots/vine[z]	Clusters/shoot	1992	1993	1994	1992	1993	1994	1992	1993	1994
Low		3.6 b[y]	---	5.9 b	1.7 a	2.0 a	2.2 a	2.4 b	2.4 b	3.1 b
High		7.7 a	---	12.3 a	1.6 a	1.8 a	1.8 b	5.4 a	7.1 a	7.6 a
	1	4.5 b	---	7.2 b	1.6 a	2.0 a	2.1 a	3.3 a	3.8 b	4.1 b
	2	6.8 a	---	10.8 a	1.7 a	1.9 a	1.9 a	4.6 a	5.7 a	6.5 a
Low	1	2.7 c	3.1 d	4.1 d	1.6 a	2.0 a	2.3 a	2.1 c	1.7 c	2.0 d
Low	2	4.5 bc	5.8 c	7.8 c	1.7 a	2.0 a	2.1 ab	2.8 bc	3.1 c	4.1 c
High	1	6.4 b	10.0 b	10.6 b	1.6 a	1.9 a	1.8 bc	4.5 ab	5.8 b	6.3 b
High	2	9.1 a	13.4 a	14.5 a	1.6 a	1.76 a	1.70 c	6.3 a	8.3 a	8.9 a

[z]Low = 14 shoot/vine; high = 30 shoots/vine in 1992 and 44 shoots/vine in 1993–94. Main effects are shown when the interactions were nonsignificant.

[y]Mean separation (n = 5) within columns for a treatment by Duncan's multiple range test, $P = 0.05$.

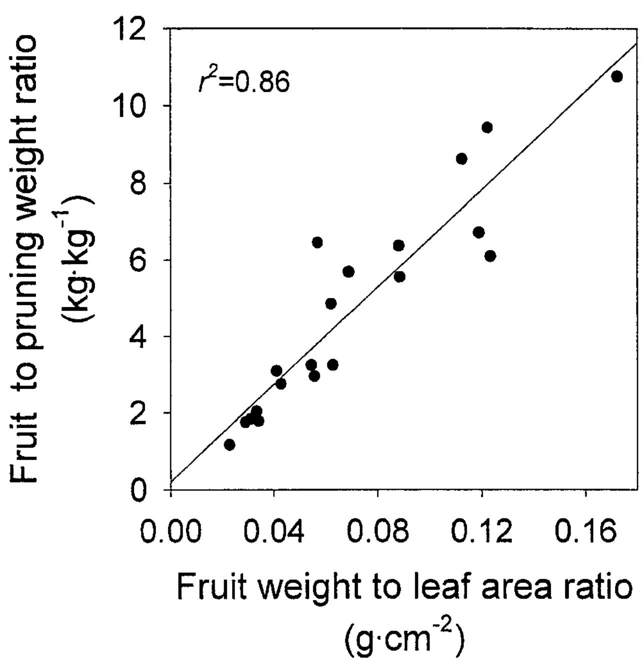

Fig. 1. Crop load in all treatments in 1993 as a function of the fruit weight to leaf area ratio. Y = 0.21 + 63.46 • X ($P = 0.001$).

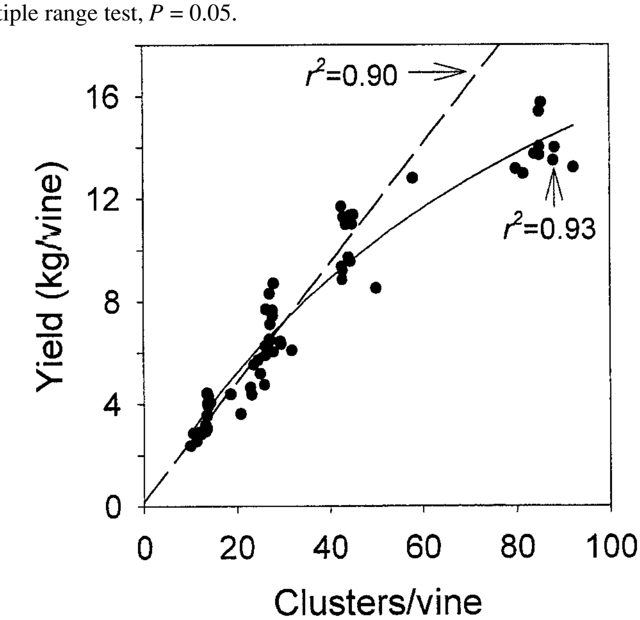

Fig. 2. Crop yield as a function of the number of clusters per vine in all treatments (1992–94), each point represents one replicate. A hyperbola was fitted to all data points (solid line) [y = 30.59•X/(97.48+X); $P = 0.001$] and a linear regression line was fitted where the number of clusters per vine was <45 (dashed line) (y = 0.19 + 0.23 • X; $P = 0.001$).

Table 3. Cluster and berry weight as a function of the number of shoots per vine (shoot density) and clusters per shoot (cluster density).

		Cluster wt (g)			Berry wt (g)		
Shoots/vine[z]	Clusters/shoot	1992	1993	1994	1992	1993	1994
Low		230 a[y]	226 a	290 a	1.88 a	1.56 a	1.70 a
High		230 a	193 b	211 b	1.91 a	1.60 a	1.75 a
	1	243 a	231 a	269 a	1.93 a	1.59 a	1.71 a
	2	217 a	188 b	236 b	1.87 b	1.57 a	1.73 a
Low	1	248 a	234 a	295 a	1.89 ab	1.59 a	1.68 a
Low	2	213 a	218 a	285 a	1.87 b	1.52 a	1.72 a
High	1	239 a	229 a	242 b	1.96 a	1.59 a	1.74 a
High	2	221 a	158 b	169 c	1.86 b	1.61 a	1.75 a

[z]Low = 14 shoot/vine; high = 30 shoots/vine in 1992 and 44 shoots/vine in 1993–94. Main effects are shown when the interactions were nonsignificant.
[y]Mean separation (n = 5) within columns for a treatment by Duncan's multiple range test, $P = 0.05$.

Table 4. Juice soluble solids, titratable acidity, and pH as a function of the number of shoots per vine (shoot density) and clusters per shoot (cluster density).

		Soluble soilds (%)			Titratable acid ($mg{\cdot}L^{-1}$)			pH		
Shoots/vine[z]	Clusters/shoot	1992	1993	1994	1992	1993	1994	1992	1993	1994
Low		---	---	---	7.0 b[y]	5.9 b	---	3.65 a	3.28 a	---
High		---	---	---	7.5 a	7.1 a	---	3.56 b	3.16 b	---
	1	---	---	---	7.0 b	6.2 b	---	3.63 a	3.24 a	---
	2	---	---	---	7.5 a	6.7 a	---	3.58 b	3.20 a	---
Low	1	22.6 a	21.8 a	20.5 a	6.8 b	5.8 c	7.1 a	3.65 a	3.29 a	3.25 ab
Low	2	22.5 a	22.5 a	20.4 a	7.1 b	6.0 c	7.1 a	3.64 a	3.27 a	3.25 ab
High	1	21.6 a	21.7 a	20.4 a	7.1 b	6.7 b	6.3 a	3.61 a	3.19 b	3.21 b
High	2	19.5 b	19.0 b	21.0 a	7.9 a	7.5 a	5.1 b	3.51 b	3.13 b	3.29 a

[z]Low = 14 shoot/vine; high = 30 shoots/vine in 1992 and 44 shoots/vine in 1993–94. Main effects are shown when the interactions were nonsignificant.
[y]Mean separation (n = 5) within columns for a treatment by Duncan's multiple range test, $P = 0.05$.

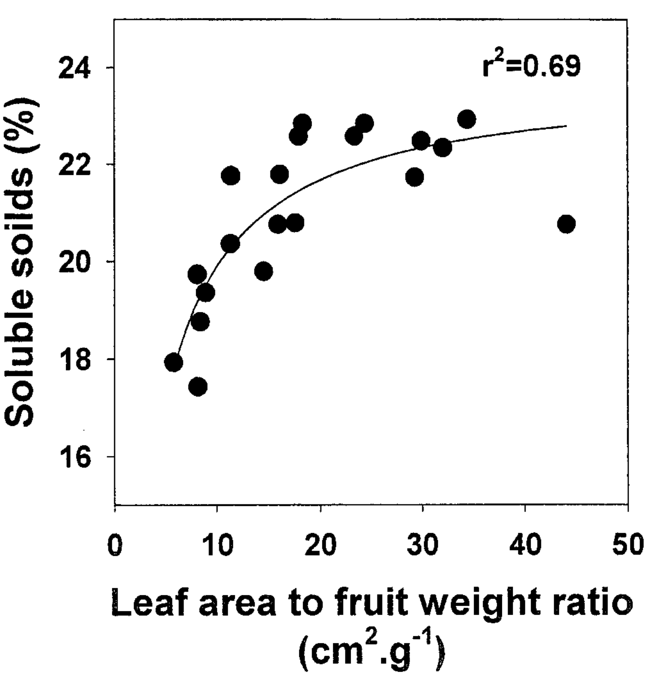

Fig. 3. Soluble solids in all treatments in 1993 as a function of the leaf area to fruit weight ratio. A hyperbola was fitted to the data [$y = 23.8 \bullet X/(1.97 + X)$; $P = 0.0001$].

tween shoots per vine and clusters per shoot for berry weight. The vine crop load (crop yield per pruning weight) decreased due to cluster thinning per shoot in 1993 and 1994 (Table 2), and due to intensive shoot thinning in all 3 years (Table 2). Leaf area to fruit weight ratio increased in 1993 due to both shoot and cluster thinning (data not presented).

Juice composition. Soluble solids increased in 1992 and 1993 due to cluster thinning in the high shoot density (Table 4). Soluble solids content also increased with increasing leaf area per gram of fruit (Fig. 3). No consistent effect of the treatments on titratable acidity content was apparent in the three experimental years (Table 4). Juice pH increased due to intensive shoot thinning in 1992 and 1993, and decreased due to cluster thinning in 1992 (Table 4). Juice K content increased due to intensive shoot thinning and cluster thinning in 1994 (data not presented), in parallel to the decrease in crop level and load (Table 2). In most years, cluster thinning was more effective in the 44 shoots than in the 14 shoot per/vine treatment in regard to cluster weight (Table 3) and soluble solids (Table 4).

Wine sensory evaluation. An increase in fruity and herbaceous taste aroma, harmony, and total scores in both 1993 (data not presented) and 1994 (Table 5), were associated with a decrease in the crop load (Fig. 4). The leaf area to fruit weight ratio affected positively both the soluble solids and the wine sensory evaluation scores, up to a ratio of ≈18 and then started to level off (Fig. 5).

Table 5. Wine sensory evaluation in 1994.

Shoots/vine[z]	Clusters/shoot	Fruity taste	Herbaceous taste	Fruity smell	Herbaceous smell	Harmony	Total score
Low		10.4 a[y]	11.6 a	5.8 a	7.2 a	18.9 a	12.9 a
High		8.1 b	8.7 b	4.0 b	4.4 b	16.6 b	10.3 b
	1	10.3 a	11.2 a	5.8 a	6.2 a	18.7 a	12.4 a
	2	8.2 b	9.0 a	4.7 a	5.4 b	16.9 b	10.8 b
Low	1	10.4 a	11.6 a	5.8 a	7.2 a	18.9 a	12.9 a
Low	2	8.1 b	8.7 b	4.0 b	4.4 b	16.6 b	10.3 b
High	1	10.3 a	11.2 a	5.8 a	6.2 a	18.7 a	12.4 a
High	2	8.2 b	9.0 a	4.7 a	5.4 b	16.9 b	10.8 b

[z]Low = 14 shoot/vine; high = 30 shoots/vine in 1992 and 44 shoots/vine in 1993–94. Main effects are shown when the interactions were nonsignificant.
[y]Mean separation (n = 5) within columns for a treatment by Duncan's multiple range test, $P = 0.05$.

Discussion

Effect of thinning on yield, pruning weight, and crop load. Reduction from 44 to 14 shoots/vine significantly affected the vigor as well as the crop load of the vines. Typical vigor enhancement characteristics such as longer shoots, and increases in the number and length of laterals, shoot diameter, and specific leaf weight resulted from reduction in the numbers of vegetative and fruit sinks. Reductions of both sinks allowed greater allocation of assimilates and reserves to each of the remaining clusters and vegetative growing points.

The overall balance between the losses attributable to shoot removal and the gains made by the remaining shoots resulted in a cumulative net increase in vegetative growth, expressed as pruning weight. A similar finding was reported by Reynolds et al., 1994a, 1994b). Kliewer et al. (2000) found that reducing the in-row spacing of 'Cabernet Sauvignon' vines from 2 and 3 m to 1 m resulted in a smaller number of shoots per vine, whereas shoot density per meter row was almost unchanged; nevertheless, the yields per hectare were higher and crop load and maturity parameters were hardly changed. However, crop loads and crop levels in that experiment were moderate and did not vary greatly, therefore, only limited conclusions can be drawn regarding the interaction between crop load and shoot density. In the present study, the lack of effect of the number of clusters per shoot on any of the vegetative parameters measured indicates there was no significant sink competition between clusters and vegetative growth at the single-shoot level, regardless of the number of shoots per vine. On the contrary, decreasing the number of clusters per vine by shoot thinning resulted in increases in all vegetative parameters measured indicating an increase in the relative sink strength. Interestingly, shoot thinning increased leaf area per shoot to an extent that the effect on the whole vine leaf area was small and insignificant, probably due to a compensation effect. The absence of cluster per shoot thinning effect might also be interpreted as an autonomic behavior of individual shoots and lack of transfer of assimilates among them. The decrease in crop load by cluster thinning within each of the two shoot density treatments did not affect the vegetative parameters, whereas reducing crop load by shoot thinning significantly affected most vegetative, cluster, and maturity parameters. It may well be that

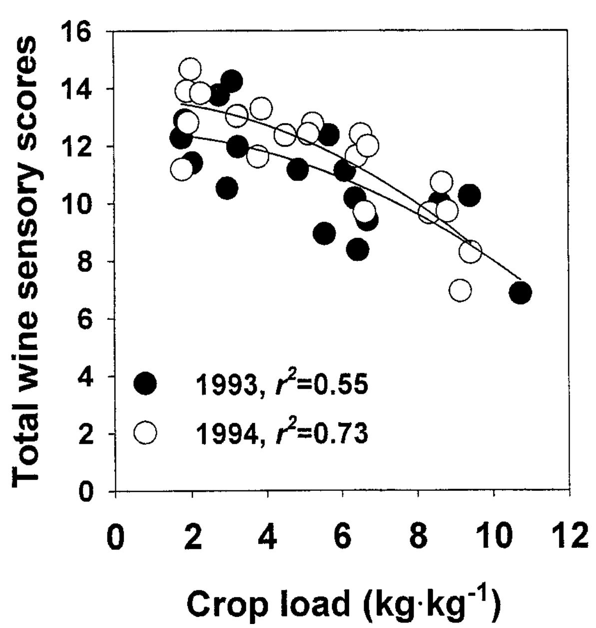

Fig. 4. Total wine sensory scores of all treatments as a function of the crop load in 1993 and 1994. A second order polynomial line was fitted to the data (1993: $y = 12.50 - 0.05 \cdot X^2$; P=0.0005, 1994: $y = 13.62 - 0.06 \cdot X^2$; $P = 0.0001$).

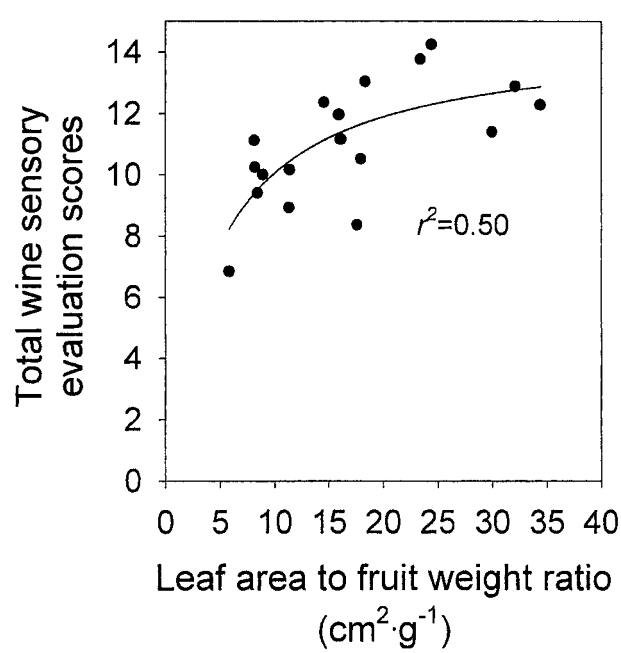

Fig. 5. Total wine scores of all treatments in 1993 as a function of the leaf area to fruit weight ratio. A hyperbola was fitted to the data [$y = 14.54 \cdot X/(4.45 + X)$; $P = 0.001$].

the effect of shoot density on maturity parameters was related in part to shading effect (Smart, 1985). Therefore, it seems that both crop load and the shading caused by the increased shoot density were responsible for these effects.

The increase in cluster weight caused by cluster thinning in the high-shoot-density treatment only indicates an effect of the whole vine crop load, which appears to be more important than the shading effect, since cluster thinning by itself does not have a direct effect on the shading. Furthermore, the number of clusters per shoot did not affect the cluster and berry weights of the 14-shoots/vine treatment, probably because the cluster weights of these vines were not subjected to source limitation, and even the vines with two clusters per shoot could have reached their potential size. The reduction in cluster weight in 1993 and 1994 was due mostly to a decrease in the number of berries per cluster, since berry weight was not significantly affected by the number of clusters per shoot and the calculated number of berries per cluster was significantly increased by cluster thinning in the 44-shoots/vine treatment. No effect on berry number was apparent in 1992 since it is known that the number of berries is determined 1 year before the time that the thinning treatment was applied (Winkler et al., 1974).

Concomitant reductions in berry weight and number because of increased shoot density and, consequently, crop load were reported by Reynolds et al. (1994a, 1994b, 1994c) who imposed crop load values of 6 to 22.3 $kg \cdot kg^{-1}$, compared with 1.7 to 10.5 $kg \cdot kg^{-1}$ in the present experiment. A reduction in the number of berries per cluster has been suggested to be a sensitive indicator of overcropping in 'Carignan' and 'Cabernet Sauvignon' grapes, having crop load values ranging between 3 and 19.3 $kg \cdot kg^{-1}$ (Bravdo et al., 1984, 1985a, 1985b).

The linear increase in yield with cluster number up to 45 clusters per vine, observed in the present study indicates lack of source limitation. The decrease in the rate of yield increase above 45 clusters/vine was probably associated with limited availability of assimilates to each cluster.

Effect of thinning on juice composition and wine sensory evaluation. Soluble solids, titratable acidity, pH, and K content were affected significantly by cluster thinning only in the 44-shoots/vine treatments, characterized by high crop load. Most of the effects indicated delayed ripening—a typical response to increasing crop load (Bravdo and Hepner, 1987a; Jackson and Lombard, 1993).

The overall wine sensory evaluation show a tendency for quality to decrease as crop load increased. Cluster thinning in the 44-shoots/vine treatment caused an increase in the total score in 1993 and increases in all sensory parameters in 1994.

The increases in herbaceous taste and aroma scores with pruning weight indicate an effect of vine vigor on wine taste and aroma. The reduction in total wine score at ratios of leaf area to fruit load below ≈18 $cm^2 \cdot g^{-1}$ (Fig. 5) is consistent with results of Kliewer and Weaver (1971) who found a reduction in a few fruit quality parameters. It is also consistent with many other findings showing optimal wine quality over a certain range of crop load values, above which it starts to decline (Bravdo and Hepner, 1987b; Bravdo et al., 1984, 1985a, 1985b; Kasimatis, 1977; Spayd et al., 1993).

Use of crop load as an indicator for overcropping. The strong correlation between the reciprocal of the ratio of leaf area to fruit weight and the ratio of fruit weight to pruning weight provides a biological rationale for the relationship between crop load and wine quality (Bravdo et al., 1984, 1985a). A decrease in 'Cabernet Sauvignon' and 'Carignan' wine quality has been reported for crop loads higher than 10 (Bravdo et al., 1985a, 1985b). Similar results were reported by Kliewer and Dokoozlian (2000) for 'Cabernet Sauvignon' in a detailed study consisting of six training systems, three in row spacings, and two rootstocks as well as with two white-wine cultivars, 'Chenin blanc' and 'Thompson Seedless'. These authors concluded that the optimal crop load range for quality is 4 to 10 crop yield to pruning weight ratio or the corresponding 5 to 12 $cm^2 \cdot g^{-1}$ of leaf area to fruit weight ratio. These values coincide well with results herein and may explain the relatively small variation in quality compared to the wide range of crop yield. Reynolds et al. (1994a, 1994b, 1994c) concluded that wine quality did not decrease with increasing crop load (yield to pruning weight ratio) in the range of 6.4 to 19.7, although their data show clearly significant effects of high crop load on a few sensory attributes and aroma compounds. The ratios of fruit weight to pruning weight and of fruit weight to leaf area that we calculated from the data of Reynolds et al. (1994a) were not correlated. In addition, the ratios of leaf area to fruit weight were >22, and at these levels, soluble solids no longer respond to increasing leaf area to fruit weight ratio (Kliewer and Dokoozlian, 2000; Kliewer and Weaver, 1971). Moreover, these authors also found a high correlation between crop yield and pruning weight as well as leaf area to crop weight ratios as we report. It seems that once the ratios of fruit weight to pruning weight and of fruit weight to leaf area are correlated, the use of crop load as an overcropping indicator is justified. Crop load values associated with overcropping seem to be well in agreement with several studies (Bravdo and Hepner, 1987b; Jackson and Lombard, 1993; Kliewer and Dokoozlian, 2000). In the present study, reduction in wine sensory evaluation was apparent when yield increased from 23.5 to 32.2 $t \cdot ha^{-1}$, crop load increased from 6.3 to 8.9 $kg \cdot kg^{-1}$, and leaf area to fruit weight ratio decreased from 14.2 to 7.9 $cm^2 \cdot g^{-1}$. This reduction in wine quality was relatively small and may be attributed to an interaction with light penetration, although a specific effect of extremely high yields exceeding 30 $t \cdot ha^{-1}$ cannot be ruled out (Jackson and Lombard, 1993). The values related to undercropping are less clear. Kliewer and Dokoozlian (2000) concluded that negative undercropping effects occur below 4 to 5 crop/pruning weight or above 12 $cm^2 \cdot g^{-1}$ leaf area/crop weight ratios, while we demonstrate that high wine quality was still achieved when crop/pruning weight ratio was as low as 2. Winkler et al (1974) showed that high vigor and low capacity cause reduction in fruit quality, however, the absence of quantitative measures does not allow comparisons with the present results. No effect of crop yield/pruning weight ratios as low as 2.5 on wine quality was found in our previous work on 'Cabernet Sauvignon' (Bravdo et al., 1985a).

It may be concluded that the crop load is a more reliable measure for fruit and wine quality than crop level. The range for optimal quality is well defined, although some variations are possible due to varying environmental conditions, particularly solar light intensity and spectral composition.

Literature Cited

Bravdo, B. and Y. Hepner. 1987a. Irrigation management and fertigation to optimize grape composition and vine performance. Acta Hort. 206:49–67.

Bravdo, B. and Y. Hepner. 1987b. Water management and effect on fruit quality in grapevines, p. 150–158. In: T. Lee (ed.). Proc. 6th Austral. Wine Ind. Technol. Conf.

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. Amer. J. Enol. Viticult. 35:247–252.

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

Bravdo, B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. 1985b. Effect of irrigation and crop level on growth, yield and wine quality of Cabernet Sauvignon. Amer. J. Enol. Viticult. 36:132–139.

Bravdo, B. and E.L. Proebsting. 1993. Use of drip irrigation in orchards. HortTechnology 3:44–49.

Clingeleffer P.R. and L.R. Krake. 1992. Responses of Cabernet franc grapevines to minimal pruning and virus infection. Amer. J. Enol. Viticult. 43:31–37.

Edson, C.E., G.S. Howell, and J.A. Flore. 1993. Influence of crop load on photosynthesis and dry matter partitioning of Seyval grapevines. I. Single leaf and whole vine response pre- and post-harvest. Amer. J. Enol. Viticult. 44:139–147.

Fisher, K.H., O.H. Bradt, J. Wiebe, and V.A. Dirks. 1977. Cluster-thinning 'de Chaunac' french hybrid grapes improves vine vigor and fruit quality in Ontario. J. Amer. Soc. Hort. Sci. 102:162–165.

Freeman, B.M. and W.M. Kliewer. 1983. Effect of irrigation, crop level and potassium fertilization on Carignane vines. II. Grape and wine quality. Amer. J. Enol. Viticult. 34:197–207.

Freeman, B.M., T.H. Lee, and C.R. Turkington. 1979. Interactions of irrigation and pruning level on growth and yield of Shiraz vines. Amer. J. Enol. Viticult. 30:218–223.

Freeman, B.M., T.H. Lee, and C.R. Turkington. 1980. Interaction of irrigation and pruning level on grape and wine quality of Shiraz vines. Amer. J. Enol. Viticult. 31:124–135.

Jackson, D.I. and P.B. Lombard. 1993. Environmental and management practices affecting grape composition and wine quality—A review. Amer. J. Enol. Viticult. 44:409–430.

Kaps, M.L. and G.A. Cahoon, 1992. Growth and fruiting of container-grown Syvil blanc grapevines modified by changes in crop level, leaf number and position, and light exposure. Amer. J. Enol. Viticult. 21:37–47.

Kasimatis A.N. 1977. Differential cropping levels of zinfandel vines—A progress report on some effects on vine growth, fruit composition, and wine quality. Proc. IV Intl. Symp. on Quality of Vintage. p. 189–96.

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

Kliewer, W.M. and A.J. Antcliff. 1970. Influence of defoliation, leaf darkening, and cluster shading on the growth and composition of Sultana grapes. Amer. J. Enol. Viticult. 21:26–36.

Kliewer, W.M. and N.K. Dokoozlian. 2000. Leaf area /crop weight ratios of grapevines: Influence on fruit composition and wine quality. Proc. Amer. Soc. Enol. and Viticult. 50th Anniv. Annu. Mtg. p. 285–295.

Kliewer, W.M., B.M. Freeman, and C. Hossom. 1983. Effect of irrigation, crop level and potassium fertilization on Carrignane vines. I. Degree of water stress and effect of growth and yield. Amer. J. Enol. Viticult. 34:186–196.

Kliewer, W.M. and R.J. Weaver. 1971. Effect of crop level and leaf area on growth, composition and coloration of 'Tokay' grapes. Amer. J. Enol. Viticult. 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 Hort. 526:21–31.

May, P., N.J. Shaulis, and A.J. Antcliff. 1969. Effect of controlled defoliation in the Sultana vines. Amer. J. Enol. Viticult. 20:237–250.

Miller, D.P., G.S. Howell, and R.K. Striegler. 1993. Reproductive and vegetative response of mature grapevines subjected to differential cropping stresses. Amer. J. Enol. Viticult. 44:435–440.

Reynolds, A.G., C.G. Edwards, D.A. Wardle, D.R. Webster, and M. Dever. 1994a. Shoot density affects 'Riesling' grapevines. I. Vine performance. J. Amer. Soc. Hort. Sci. 119:874–880.

Reynolds, A.G., C.G. Edwards, D.A. Wardle, D.R. Webster, and M. Dever. 1994b. Shoot density affects 'Riesling' grapevines. II. Wine composition and sensory response. J. Amer. Soc. Hort. Sci. 119:881–892.

Reynolds, A.G., R.M. Pool, and L.R. Mattick. 1986. Effect of shoot density and crop control on growth, yield, fruit composition, and wine quality of 'Seyval blanc' grapes. J. Amer. Soc. Hort. Sci. 111:55–63.

Reynolds, A.G. and D.A. Wardle. 1989. Impact of various canopy manipulation techniques on growth, yield, fruit composition, and wine quality of Gewurztraminer. Amer. J. Enol. Viticult. 40:121–129.

Reynolds, A.G., D.A. Wardle, and M. Dever. 1994c. Shoot density effects on Riesling grapevines: Interactions with cordon age. Amer. J. Enol. Viticult. 45:435–443.

Sinton, T.H., C.S. Ough, J.J. Kissler, and A.N. Kasimatis. 1978. Grape juice indicators for prediction of potential wine quality. I. Relationship between crop level, juice and wine composition, and wine sensory ratings and scores. Amer. J. Enol. Viticult. 29:267–271.

Smart R.E. 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality: A review. Amer. J. Enol. Viticult. 36:230–239.

Smart, R.E., J.B. Robinson, G.R. Due, and C.J. Brien. 1985. Canopy microclimate modification for the cultivar Shiraz. I. Definition of canopy microclimate. Vitis 24:17–31.

Spayd, S.E., R.L. Wample, R.G. Stevens, R.G. Evans, and A.K. Kawakami. 1993. Nitrogen fertilization of White Riesling in Washington: Effects on petiole nutrient concentration, yield, yield components, and vegetative growth. Amer. J. Enol. Viticult. 44:378–386.

Weaver, R.J. and S.B. McCune. 1960. Effect of overcropping Alicante Bouschet grapevines in relation to carbohydrate nutrition and development of the vine. Proc. Amer. Soc. Hort. Sci. 75:341–353.

Weaver, R.J. and R.M. Pool. 1968. Effect of various levels of cropping on *Vitis vinifera* grapevines. Amer. J. Enol. Viticult. 19:185–193.

Winkler, A.J., J.A. Cook, W.M. Kliewer, and L.A. Lider. 1974. General viticulture. Univ. Calif. Press, Berkeley.