Effect of Crop Level and Crop Load on Growth, Yield, Must and Wine Composition, and Quality of Cabernet Sauvignon

B. BRAVDO[1], Y. HEPNER[2], C. LOINGER[3],
S. COHEN[4], and H. TABACMAN[5]

Three crop load treatments by cluster thinning immediately after bloom were applied to a Cabernet Sauvignon vineyard located at Luzit in the Adulam region of Israel during five consecutive years. The crop load values expressed as the grape yield to pruning weight ratio varied between 4 in the severely thinned treatment and 10 in the unthinned treatment. Wine quality as determined by tasting was significantly higher in the unthinned as compared to the severely thinned treatment in two out of the five experimental years. The five year averages of the wine quality score did not vary significantly. The pruning weight was negatively rank correlated with crop level and crop load, and positively with the harvest delay. Potassium leaf, must and wine content was negatively rank correlated with crop load, crop level, must malic acid and wine color, ash and tartaric acid content. Comparison of these results with those obtained earlier with Carignane lead the authors to suggest that crop load values above 10 have a negative effect on wine quality whereas no significant effect is apparent with values lower than 10.

The recent trend of rising grape yields, especially in irrigated vineyards grown in warm regions (16,23,26), gives prominence to the issue of the relationship between crop level and wine quality. Conflicting data have been reported concerning this relationship (3,4,6,8,10,11,14, 16,17,22,24,25,27,28,31). However, not always was the issue of vigor and capacity taken into consideration. Winkler *et al.* (30) demonstrated that fruit quality and yields both increased concomitantly with vine capacity due to regulation of pruning severity and fruit thinning. A number of defoliation experiments have shown that several maturation and quality parameters increased with leaf area per gram fruit up to a certain saturation level (13,14,15,19). About 10 to 14 cm^2/g fruit were required for reaching maximum berry weight and coloration, and juice concentration of proline, arginine, and nitrogen (14,15).

Buttrose (5) defined the term "overcropping" as a condition associated with berry/leaf number ratio. He also showed that berry growth and sugar accumulation was not delayed despite a three-fold increase in crop level when leaf area increased in parallel. The long term effects of crop level on growth, yield, and quality were reviewed in our previous paper (4) and will not be repeated here.

We have shown that the weight ratio of crop yield to winter pruning at ratio values above 10 was negatively correlated with wine quality of Carignane. Since pruning weight was found to correlate with leaf area (27) and both are known to determine the capacity (30), the use of yield/pruning weight ratio seems to follow the same logic as leaf area/fruit ratio and is even easier for field use. The question still before us is whether these ratio measures are correct only for a certain range of crop levels, or yields can continuously be increased without overcropping as long as leaf area/fruit ratio or yield/pruning weight ratio is in the range considered desirable. A second question is how, and to what extent, do the specific cultivars or scion-rootstock combinations differ in this respect. Such differences were already noted in a few studies (7,21,29).

This work was undertaken to study the relationships between crop level, crop load (grape yield/pruning weight ratio) and fruit and wine quality in a high yielding Cabernet Sauvignon vineyard and to compare the results with those obtained in another study with Carignane having different crop loads (3,4).

Materials and Methods

A crop load experiment was conducted at Luzit in the Adulam region of Israel during 1975 to 1980 in a virus free Cabernet Sauvignon on 110 R rootstock, vineyard planted in 1970, 1800 vines/ha (3.7 × 1.5 m) trained as a single cordon on a 80 cm high wire with one pair of parallel foliage wires, 30 cm apart, 120 cm above ground for keeping shoots in an upright position and irrigated by 4 L/hr drippers spaced 1.25 m apart, on a single lateral per row. One hundred fifty kg/ha N were applied through the irrigation system during the spring of each year in three applications and 300 kg/ha K were applied in 1978 only.

Three cluster thinning treatments were applied immediately after bloom as follows: Treatment 1 (UT), unthinned control, about 60 to 70 clusters per vine; Treatment 2 (MT), moderately thinned, 40 clusters per vine retained (in 1975 only 30 clusters per vine); Treatment 3 (ST), severely thinned, 20 clusters per vine retained. Each treatment consisted of 16 replicates of 10 vines each.

The treatments were arranged in a randomized block design as part of a bifactorial trial, the other factor was irrigation schedules which have already been reported (10,11). Interactions of crop load with irrigation will not be dealt with in this paper. Each plot was harvested when the fruit sugar content reached 22.5°Brix. Wine was made by the Israel Wine Institute using a sample of 30 kg fruit per replicate. Tasting procedures and chemical analyses of fruit, must, and wine were conducted as previously reported or cited (4,11). Potassium leaf content was analyzed on petioles + blades sampled opposite the cluster in August (20 leaves per replicate).

[1,2]The Hebrew University of Jerusalem Faculty of Agriculture, Department of Horticulture, Rehovot, P.O. Box 12, Israel; and [3,4,5]The Israel Wine Institute, Rehovot, P.O. Box 2329.

This research was supported by the Eugene Schöenberger Foundation, The University of Jerusalem. The authors wish to thank Mrs. Nehama Bar and Mrs. Shoshana Shalom for their skilled technical assistance.

Manuscript submitted for publication 2 July 1984.

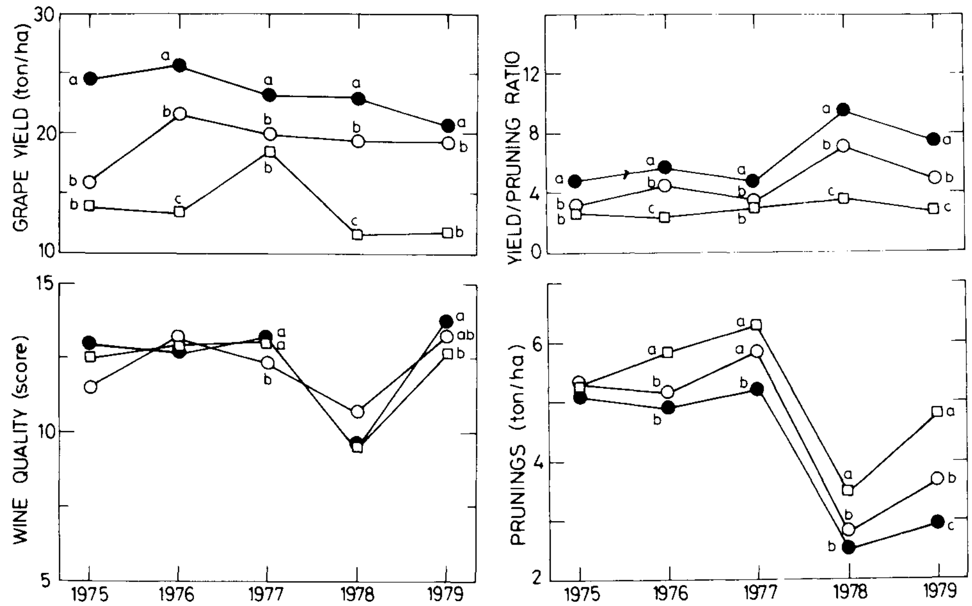

Fig. 1. Effect of crop load treatments (by cluster thinning) on wine quality, grape yield, pruning weight and yield/pruning weight ratio (annual average). Closed circles, open circles and open rectangles represent unthinned (UT), moderately thinned (MT) and severely thinned (ST) treatments, respectively. Treatments MT, and ST were thinned to 40 and 20 clusters, UT had normally 60-70 clusters per vine. Small letters indicate mean separation at p = 0.05 for each year.

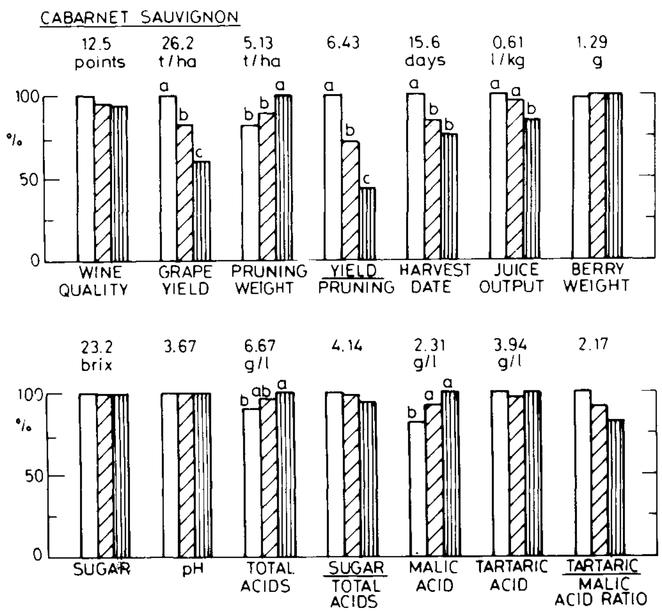

Fig. 2. Effect of crop load treatments (by cluster thinning) on wine quality and a few growth, crop, and must parameters (5-year averages). Open columns, vertical lines, and diagonal lines columns represent unthinned, moderately thinned, and severely thinned treatments, respectively. Yield/pruning is grape yield/pruning weight ratio. Harvest date is expressed as the number of days after the harvest of the first replicate which reached 22.5° Brix. Data are presented on a relative scale, with the greatest value assigned 100%. The greatest absolute values are indicated above each group of columns. Treatment details are given in **Materials and Methods.** Small letters indicate mean separation at p = 0.05 between treatments.

All data were subjected to analysis of variance followed by multiple range test, according to Student-Newman-Keuls.

Results and Discussion

Crop yield decreased gradually throughout the five experimental years (Fig. 1). The low yield of the MT treatment in 1975 was due to retaining 30 instead of the 40 bunches per vine in the following years. Yield differences between MT and the UT control treatments were significant throughout, while the yields of the ST treatment were significantly lower than MT only in two out of the five seasons. The general treatment means for the entire period (Fig. 2) were, however, all significantly different from each other. In a similar experiment with cv. Carignane (4,10), the yield reduction in the MT treatment was very slight because the larger berry weight and number of berries per bunch compensated for the reduced number of bunches per vine. In the present study with cv. Cabernet Sauvignon, only a partial compensation of crop weight was obtained. The number of berries per bunch was not affected by cluster thinning, and the compensation of the thinned treatments were due mainly to increased berry weight (Table 1).

The average berry weight for the entire experimental period was similar in all treatments (Fig. 2), but cumulative thinning effects induced a heavier berry weight in the last two years 1978, 1979 (Fig. 3).

The five year mean harvest date of the UT treatment was significantly later than those of the two other treatments (Fig. 2). This delay was significant only in 1977

Table 1. Effect of cluster thinning on yield, bunch and berry weight, and number of bunches per vine and per ha (Luzit 1978). UT, MT and ST are unthinned, medium thinned, and severely thinned, respectively. For further details see **Materials and Methods.**

	Yield		Bunch wt		Bunches/ha		Berries/bunch		Berry wt	
Treatment	t/ha	%	g	%	No.	%	No.	%	g	%
UT	23.1	100	178	100	130 330	100	169	100	1.05	100
MT	19.1	82.7	198	113.3	96 460	74	161	95.3	1.23	117
ST	11.8	51.5	202	113.5	58 410	44.8	160	94.7	1.26	120

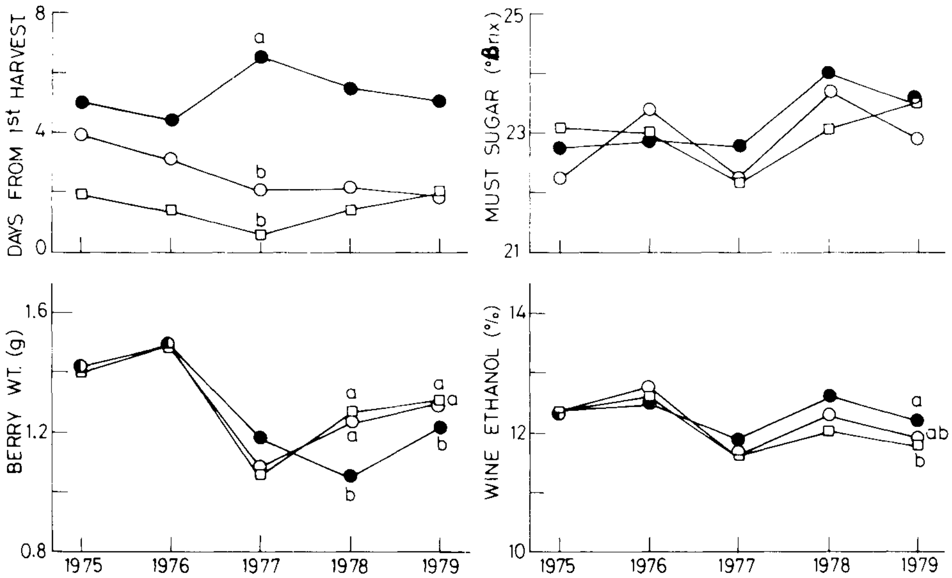

Fig. 3. Effect of crop load treatments (by cluster thinning) on harvest date, berry weight, must sugar, and wine ethanol (annual averages). Symbols and explanations as in Fig. 1. Small letters indicate mean separation at p = 0.05 for each year.

(Fig. 3), and in this year the final berry weight and sugar content per berry also tended to be the highest in the UT treatment (Fig. 3, 4). No differences in berry weight and sugar content between treatments were noted in 1976 (Fig. 3, 4) or in the means for the entire five experimental years (Fig. 2). The berry weight, sugar per berry and sugar concentration of the UT treatment tended to be relatively low throughout the 1976 and 1977 seasons (Fig. 4, 5). The advantage in UT berry weight and sugar per berry was attained in 1977 only during the delayed harvest time which enabled the grapes to reach the desired 22.5°Brix. Total acids percentage did not vary significantly among the treatments throughout the 1977 season, but was significantly lower at harvest in the UT treatment.

Quality tended to be slightly better in wines of the UT treatment than in wines from reduced crop (Fig. 2), and significant quality differences were observed in 1977 and 1979 (Fig. 1).

Pruning weight was lowest in the UT plots and increased with thinning (Fig. 1, 2). However, much greater and more significant differences were found between the yield/pruning weight ratio (crop load) of the various treatments for the entire experimental period (Fig. 2), indicating a positive relationship between crop level and crop load. The yield/pruning weight ratio (crop load) has been found to be negatively related to wine quality in cv. Carignane (4), where crop load values were above 10. No such relationship was found with the same cultivar when crop loads were below 10 (16). Calculated crop load ratios for the Carignane studied by Weaver *et.al.* (28) showed average values of 5.96 and 10.60 for the normal and overcropped treatments, respectively. Indications of damage to vines and wine quality by overcropping were only slight, and according to our experience such effects are to be expected at crop load values above 10. In the present study, yield/pruning weight ratio values varied from 4 to 9 in the control UT plots to about 3 in the ST plots (Fig. 1), with means of 6.43 and 4.50 for

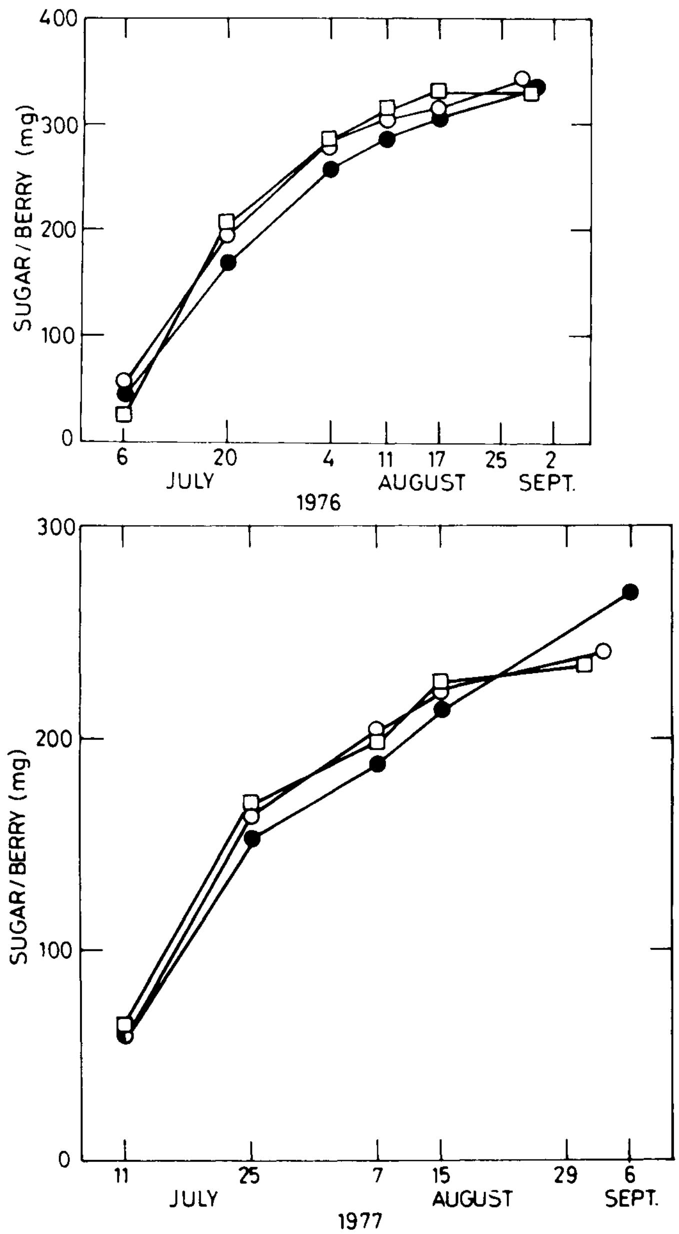

Fig. 4. Effect of crop load (by cluster thinning) on sugar content per berry in 1976 and 1977. Symbols and explanations as in Fig. 1. Small letters indicate mean separation at p = 0.05 for each date.

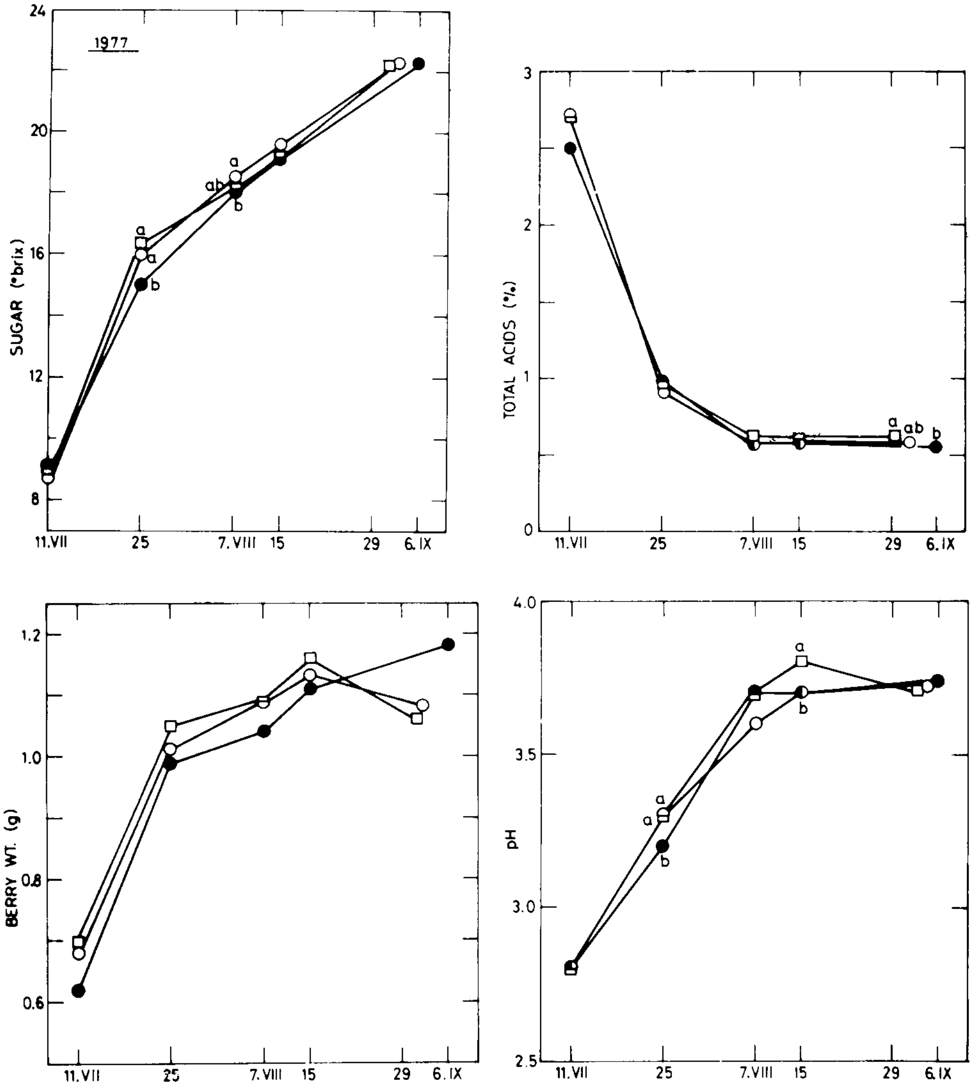

Fig. 5. Effect of crop load treatments (by cluster thinning) on berry weight and composition in 1977. Symbols and explanations as in Fig. 1. Small letters indicate mean separation at p = 0.05 for each date.

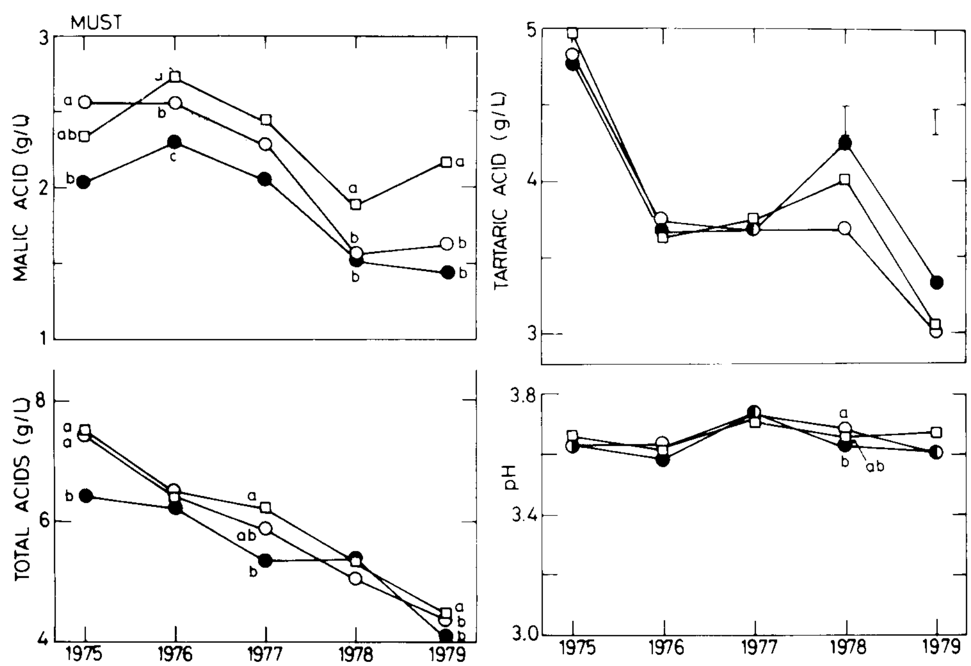

Fig. 6. Effect of crop load treatments on must acid content and pH. Symbols and explanations as in Fig. 1. Small letters indicate mean separation at p = 0.05 for each year.

the UT and MT treatments, respectively. These crop load values fall within the range where positive relationships with quality were sometimes observed (12,16,26) and are also consistent with the results of the present paper. In another study with Cabernet Sauvignon, higher yields and pruning weights were implemented by more sophisticated trellising, but neither the yield/pruning weight ratio nor the fruit quality was affected (25).

High crop loads delayed the date of harvest throughout the entire experimental period (Fig. 2, 3), similar to findings in other studies (3,10,27). The delayed ripening caused by high crop load had no quality effect on the Cabernet wines (Fig. 2), resembling Carignane results (4) where a comparison between the two thinned treatments (MT and ST) showed no effect on wine quality, even though harvest at full ripening was delayed in the MT treatment.

Harvest was successfully carried out with similar sugar contents in the musts of the various plots (Fig. 2, 3). The v/w juice output decreased with thinning severity (Fig. 2), probably because of the thicker skins of the heavy ST berries or possibly because of a greater number of seeds per berry.

During the two to three weeks preceding 1977 harvest, the berries in the UT treatment gained weight, but the thinned treatments lost weight by dehydration in spite of an absolute increase in their sugar content per berry (Table 2). It appears, therefore, that the delay in the ripening process in that season also delayed the loss of turgor under conditions of a heavy crop load.

Total must acidity decreased gradually during the experimental period and so did malic and tartaric acids (Fig. 6). Must pH levels were almost constant throughout the years and unaffected by the treatments (Fig. 6), probably because must potassium decreased parallel to the anions (Fig. 6, 7). Tartaric acid did not vary among the treatments until the last two years when levels in UT treatment musts tended to be higher (Fig. 6). Total acidity was mainly affected by malic acid contents which were low in the UT and high in the ST treatment musts throughout the experimental period (Fig. 6). This is also evident from the five year treatment means of must contents (Fig. 2) which show a remarkable impact of crop load on malate level and, consequently, a significant effect on total acids, but only a slight effect on tartarate (Fig. 2, 6). The tartaric/malic acids ratio (T/M) was influenced mostly by malate changes, but unlike the malic acid content, did not vary significantly among the treatments (Fig. 2). The T/M ratio of the UT treatment was 2.17 in this Cabernet study and 2.49 in a similar study with Carignane (4). Since all plots were harvested at the same sugar concentration and the pH means were unaffected by crop load treatments, the sugar × pH product, advocated as a good must quality parameter by some workers (2,30), was meaningless under the conditions of this study, and the sugar/total acidity ratio represented only fluctuations in acidity levels (Fig. 2).

Malic acid levels in must were depressed by increasing crop loads in a previous study with Carignane (4,10), where excessive load reduced wine quality. In the present study, must malic acid, but not wine quality, was reduced by high crop level and loads. It appears therefore that must malic acid content is closely related to crop load but

Table 2. Effect of cluster thinning treatments on TSS and water increments between 15 August and harvest (Luzit 1977). Treatment symbols as in Table 1. All plots were harvested at 22.5° Brix. For further details see **Materials and Methods.** All values were calculated from the treatment averages by converting percentage of TSS to g and assuming that all changes in berry weight were due to loss or gain of TSS and water.

Treatment	Wt increment per berry (g)		
	Water	TSS	Total
UT	0.3	0.4	0.70
MT	-0.79	0.29	-0.50
ST	-1.20	0.30	-0.90

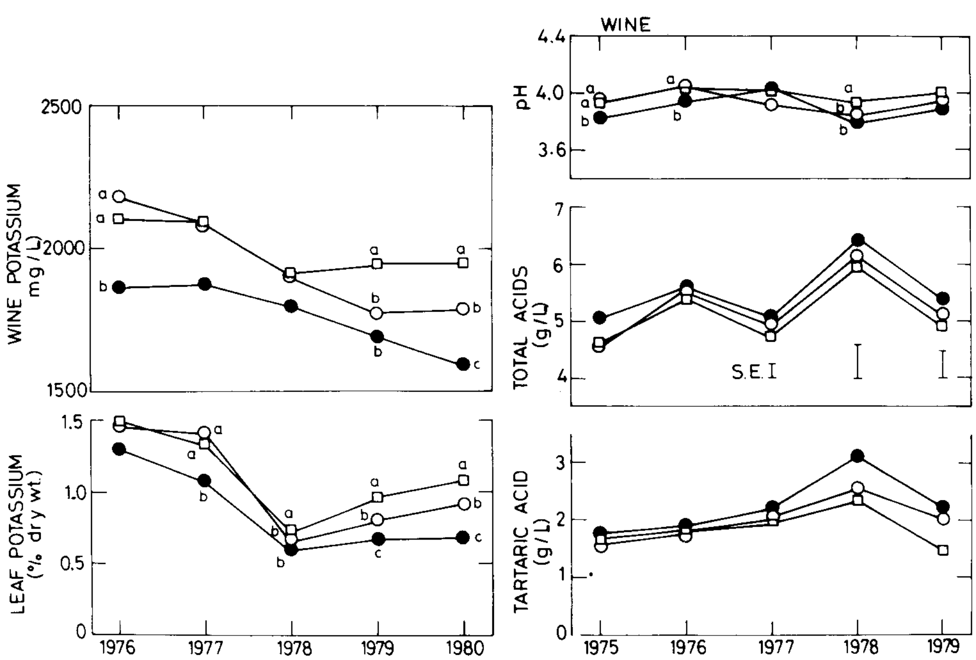

Fig. 7. Effect of crop load treatments (by cluster thinning) on potassium content of leaf and wine pH and acid content. Symbols and explanations as in Fig. 1. Small letters indicate mean separation at p = 0.05 between treatments.

has no direct influence on wine quality in our studies with Carignane and Cabernet Sauvignon (3,4,10). Cane starch, as tested in 1979 after five years of experiment, was not affected by crop load (Fig. 8). This may support our suggestion that no overcropping occurred at this range of crop loads. Previous studies have shown that cane and root starch was reduced by overcropping (27). Potassium content of leaves, must and wine dropped concomitantly with the increase in crop load (Fig. 7, 8). A similar drop due to crop load effect was also observed in our previous study with Carignane (4).

Leaf K content was found to decrease due to increasing yields even at low crop load ratios in many cultivars (1,13,20). On the other hand, Freeman *et al.* (9) did not find any consistent effect of crop load on petiole K content at bloom time and véraison in high yielding Carignane vines with crop load ratios of 5 to 8. In the present study, however, potassium was assayed before harvest, and therefore, the effect of crop load on K was more pronounced.

The total acid content of the must decreased with the increase in crop level and crop load (Fig. 6), whereas the opposite was true for the corresponding wines (Fig. 7, 9). This reversal effect was due mainly to the tartaric acid which counterbalanced the changes in lactic and malic acid contents (Fig. 9). The consistent positive correlation of the wine's tartaric acid with the crop load and crop level throughout the entire experimental period (Fig. 9) can be attributed to the negative relationship between K content of the must and wine on one hand and the crop load on the other. In another study, low K content of the wine resulted in less potassium bitartarate precipitation, and consequently, more free tartaric acid was retained in the wine (18). This relationship was also reflected in the negative rank correlation found between wine pH and crop load (Fig. 9). Fixed wine acids tended to vary parallel to tartaric acid content. Lactic acid content was lower in the UT treatment wines (Fig. 10), probably because the relatively high fixed acids in this treatment (Fig. 9) delayed the malolactic fermentation process.

Color quality was positively correlated with crop load (Fig. 10), corresponding with the similar tendency in wine quality (Fig. 2). Alkaline ash was negatively correlated with crop load since its main constituent is K. No significant differences were found in wine volatile acids, tartaric/lactic + malic acid ratio, color intensity, malic acid, tannin, total ash, total extract, and reduced extract. Reducing sugars (Fig. 9) were positively correlated with the crop load in spite of the uniform level of must sugar. Although the differences were small, a crop load effect on fermentation efficiency due to unknown factors may be involved.

Conclusions

1. The crop load (grape yield to pruning weight ratio) was found to be a better measure than crop level for evaluating the relationships between cropping and wine quality.

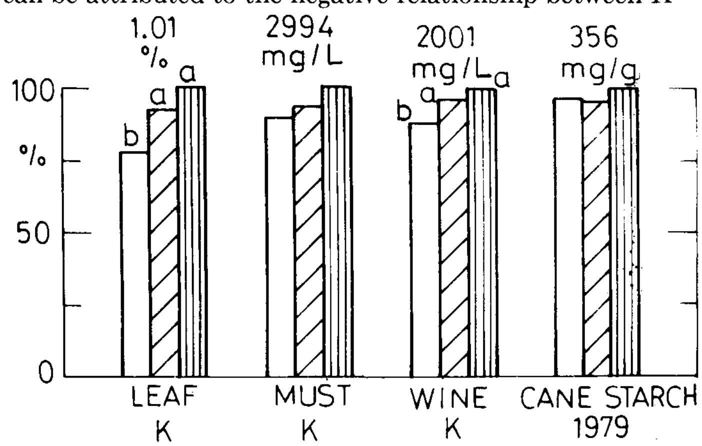

Fig. 8. Effect of crop load treatments (by cluster thinning) on leaf, must, wine K and cane starch (5-year averages). Symbols and explanations as in Fig. 2. Small letters indicate mean separation at p = 0.05 between treatments.

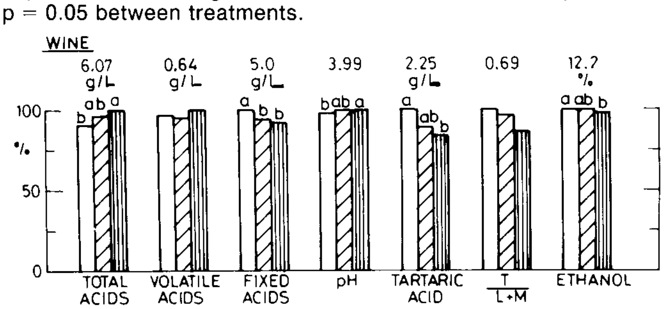

Fig. 9. Effect of crop load treatments (by cluster thinning) on wine pH, acids and ethanol content (5-year averages). Symbols and explanations as in Fig. 2. Small letters indicate mean separation at p = 0.05 between treatments.

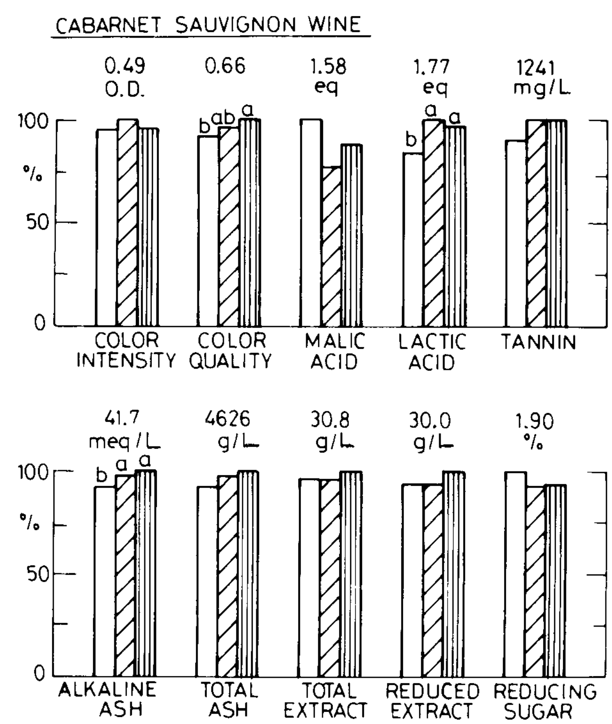

Fig. 10. Effect of crop load treatments (by cluster thinning) on wine color, acids, tannin, ash, extract, and sugar content. Symbols and explanations as in Fig. 2. Color intensity and color quality are the sum and ratio of optical density readings at 420 and 520 nm, respectively. Small letters indicate mean separation at p = 0.05 between treatments.

2. Crop levels of about 26 t/ha did not reduce wine quality as compared to 12 t/ha because the crop load values were favorable and ranged from 3 to 6.4 kg grapes to kg pruning weight. Data of individual plots in the present experiments, as well as other published data, show that crop loads of up to 10 are normally not subjected to reduction in wine quality due to overcropping. In another experiment with Carignane (4), we found reduction in wine quality as crop load increased from about 12 to 27 due to different degrees of cluster thinning.

3. Decreasing yields from 26 t/ha to 12 t/ha by cluster thinning in the present experiment were associated with advanced maturation, increased berry weight, leaf and wine K, must malic acid and pruning weight. However, the number of berries per bunch did not increase, and wine quality was not improved.

It may, therefore, be concluded that a reduction in the number of berries per bunch is an important characteristic of overcropping and that there are probably some additional parameters which are responsible for the reduction in wine quality when crop load exceeds a ratio of 10.

Literature Cited

1. Balasubrahmanyam, V. R., J. Elfert, and L. Diofasi. Nutrient reserves in grapevine canes as influenced by cropping levels. Vitis. 7:19-23 (1978).

2. Berg, H. W., and C. S. Ough. The relation of Balling to wine quality. Am. J. Enol. Vitic. 28:235-8 (1977).

3. Bravdo, B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. Effet de l'irrigation et de l'alimentation minerale sur la qualite du mout et des vins provenant des vignobles de Cabernet Sauvignon et de Carignan aux rendements eleves en Israel. XVIII Congres Internat. OIV Le Cap, S.A. (X/1983).

4. Bravdo, B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. Effect of crop level in a high yielding Carignane vineyard on growth, yield and wine quality. Am. J. Enol. Vitic. 35:247-52 (1984).

5. Buttrose, M. S. The effect of varying the berry number in Gordo grapevines with constant leaf area. Vitis. 7:299- 302 (1968).

6. Cawthon, D. L., and J. R. Morris. Yield and quality of 'Concord' grapes as affected by pruning severity, nodes per bearing unit, training system, shoot positioning and sampling date in Arkansas. J. Am. Soc. Hortic. Sci. 102:760-7 (1977).

7. Cook, J. A., and L. A. Lider. Mineral composition of bloomtime grape petiole in relation to rootstock and scion variety behavior. Am. Soc. Hortic. Sci. 84:243-54 (1963).

8. Fisher, K. H., O. A. Bradt, J. Wiebe, and V. A. Kirks. Cluster thinning 'de Chaunac' French hybrid grapes improves vine vigor and fruit quality in Ontario. J. Am. Soc. Hortic. Sci. 102:162-5 (1977).

9. Freeman, B. M., and W. M. Kliewer. Effect of irrigation, crop level and potassium fertilization on Carignane vines. II. Grape and wine quality. Am. J. Enol. Vitic. 34:197-207 (1982).

10. Hepner, Y. Effects of crop load and agrotechnical factors on the quality of grapes and wines. PhD Thesis, Hebrew University, Jerusalem (1983).

11. Hepner, Y., B. Bravdo, C. Loinger, S. Cohen, and H. Tabacman. Effect of drip irrigation schedules on growth, yield, must composition and wine quality of Cabernet Sauvignon. Am. J. Enol. Vitic. 36:77-85 (1985).

12. Kasimatis, A. N. Differential cropping levels of Zinfandel vines — a progress report on some effects on vine growth, fruit composition and wine quality. Internat. Symp. on Quality of Vintage, Proc. OIV, Capetown: 189-96 (1977).

13. Kliewer, W. M., and A. J. Antcliff. Influence of defoliation, leaf darkening and cluster shading on the growth and composition of Sultana grapes. Am. J. Enol. Vitic. 21:26-36 (1970).

14. Kliewer, W. M., and C. S. Ough. 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 (1970).

15. Kliewer, W. M., and R. J. Weaver. Effect of crop level and leaf area on the growth, composition and coloration of Tokay grapes. Am. J. Enol. Vitic. 22:172-7 (1971).

16. Kliewer, W. M., B. M. Freeman, and C. Hossom. Effect of irrigation, crop level and potassium fertilization on Carignane vines. I. Degree of water stress and effect on growth and yield. Am. J. Enol. Vitic. 34:186-96 (1983).

17. Loinger, C., and B. Safran. Interdependence entre le rendement, la maturation des rainsins et la qualite des vins. Ann. Technol. Agric. 20:225-40 (1971).

18. Mattick, L. R., N. J. Shaulis, and J. C. Moyer. The effect of potassium fertilization on the acid content of 'Concord' grape juice. Am. J. Enol. Vitic. 23:26-30 (1972).

19. May, P., N. J. Shaulis, and A. J. Antcliff. The effect of controlled defoliation in the Sultana vine. Am. J. Enol. Vitic. 20:237-50 (1969).

20. Morris, J. R., and D. L. Cawthon. Effect of irrigation, fruit load and potassium fertilization on yield, quality and petiole analysis of Concord grapes. Am. J. Enol. Vitic. 33:145-8 (1982).

21. Ough, C. S., L. A. Lider, and J. A. Cook. Rootstock-scion interactions concerning winemaking. I. Juice composition changes and effects on fermentation rate with St. George and 99-R rootstocks at two nitrogen fertilizer levels. Am. J. Enol. Vitic. 19:213-27 (1968).

22. Pool, R. M., C. Pratt, and H. D. Hubbard. Structure of base buds in relation to yield of grapes. Am. J. Enol. Vitic. 29:36-41 (1968).

23. Safran, B. Effects of cultivation practices on the quality of the vintage in hot regions. Int. Symp. on Quality of Vintage, Proc. OIV, Stellenbosch, South Africa:243-61 (1977).

24. Spayd, S. E., and J. R. Morris. Yield and quality of 'Concord' grapes as affected by irrigation, pruning severity and nitrogen. Arkansas Farm Research 27:9 (1968).

25. Steinhauer, R. E., and K. W. Bowers. Influence of trellis on yield and quality of Cabernet Sauvignon in Napa Valley. Am. J. Enol. Vitic. 30:236-40 (1979).

26. Van Zyl, J. L., and H. W. Weber. Irrigation of Chenin blanc in the Stellenbosch area within the framework of the climate-soil-water-plant continuum. Int. Symp. on Quality of Vintage. Proc. OIV Capetown: 331-50 (1977).

27. Weaver, R. J., and S. B. McCune. Effects of overcropping Alicante Bouschet grapevines in relation to carbohydrate nutrition and development of the vine. Proc. Am. Soc. Hortic. Sci. 75:341-53 (1960).

28. Weaver, R. J., S. B. McCune, and M. A. Amerine. Effect of level of crop on vine behavior and wine composition in Carignane and Grenache grapes. Am. J. Enol. Vitic. 12:175-84 (1961).

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

30. Winkler, A. J., J. A. Cook, W. M. Kliewer, and L. A. Lider. General Viticulture. 110 pp. University of California Press, Berkeley. (1974).

31. Wood, D. F., and N. E. Looney. Some cluster thinning and gibberellic acid effects on juice and wine quality of de Chaunac grapes. Canad. J. Plant. Sci. 57:643-6 (1977).