Factors Affecting Soluble Solids, Acid, pH, and Color in Grapes

D. I. JACKSON[1]

Vines were grown from two-node cuttings and induced to retain one bunch of grapes per plant. These plants were grown in a greenhouse and parameters, such as leaf number and area, berry number, °Brix, acid, pH, and color, were recorded. Correlations between pairs of variables were made and analyzed. Plants with low berry numbers grew more than those with high numbers. Low berry number, high leaf growth rate, and high leaf/fruit ratio are related to high sugar levels, but acid levels were low and pH levels high. These levels were not simply a response to advanced maturity. While soluble solids levels increased only until a certain leaf/fruit ratio was attained, pH and acid continued to change as the shoots grew. Under the warm conditions of this experiment, unacceptably high pH levels and low acid levels were recorded. The effect of extended shoot growth increasing pH and lowering acid was not mediated by shade and leaf/bunch exposure since shading was not permitted. The general hypothesis that low vigor vines produce higher quality can, therefore, be explained in part by a direct response of pH and acid to shoot growth.

Total soluble solids, acid, and pH levels are commonly used as indicators of ripeness for wine grapes. An appropriate balance between these can be a useful indicator of resultant quality of wine. Many factors can influence levels of these and other constituents of grapes, but within any one vineyard with any one cultivar, important criteria are considered to be water and nutrient availability and the pruning method adopted (12). It is considered that the leaf/fruit ratio will have a major influence on composition. Experimentally, 10 cm^2 of leaf area per gram of fruit seemed to be required to produce satisfactory ripeness (5). Most such trials investigate these factors under field conditions and manipulate crop levels by pruning and thinning. The danger in such trials is that interactions with the microclimate within the leaf canopy are difficult to exclude (10).

In this experiment, small test plants were produced and grown under more controlled environmental conditions. Detailed measurements of leaf number and area and berry number and weight were made to re-examine these and other criteria.

Materials and Methods

The grape cultivar Cabernet Sauvignon was grown from two-node dormant cuttings in August 1983. These were rooted in an outdoor hot bed providing 18°C at the root zone; the mean ambient temperatures were 8°C. They were then transferred to 1-L volume pots in standard potting compost and grown in a glasshouse with a temperature range of 16°C to 24°C. Light intensity was 41% of ambient.

Normally, vine cuttings will shed any inflorescences produced on a developing shoot; as a result, crops in the first year are not obtainable. A technique to enable the cutting to retain the inflorescence has been developed (6) and was adopted here (Fig. 1). It involves the removal of competing leaves prior to the first inflorescence assuming a terminal position; after this, leaves are permitted to grow.

Fifty-six plants were used in the study and were divided into four equal groups: Group 1 - no treatment applied; Group 2 - 50% of berries were removed on 21 December; Group 3 - 50% of berries were removed on 4 January; and Group 4 - 50% of berries were removed on 21 December and 50% of the remainder were removed on 4 January.

No other interference occurred, and plants were allowed to grow unchecked with adequate water being supplied at all times. Correlations were done within each

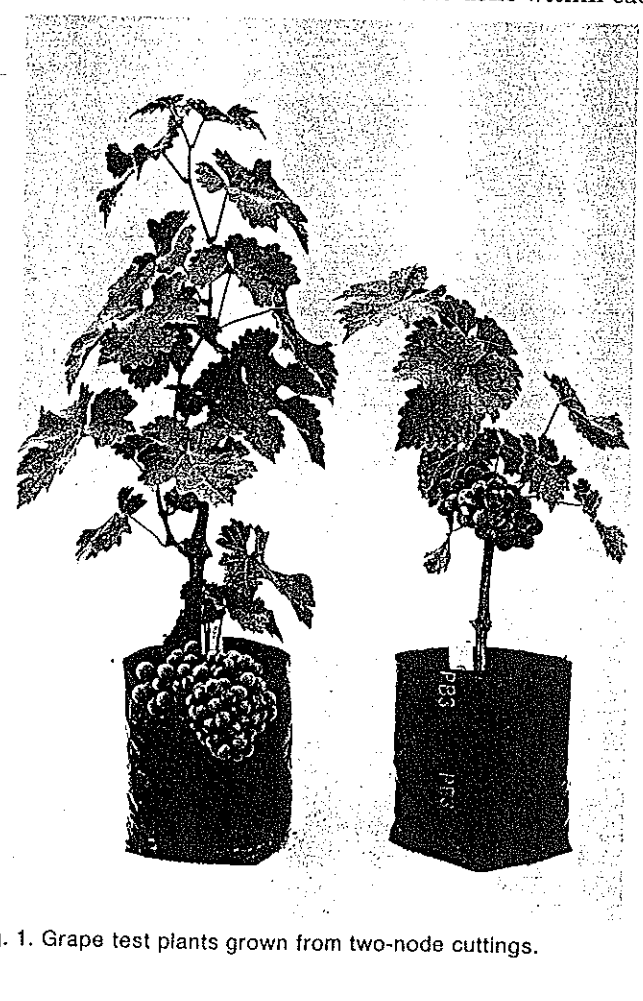

Fig. 1. Grape test plants grown from two-node cuttings.

[1]Department of Horticulture, Landscape, and Parks, Lincoln College, Canterbury, New Zealand.

The author thanks Alison Lister, Paul Hemmings, and Graeme Steans for discussion and statistical analysis.

This research conducted at Lincoln College, Canterbury, New Zealand.

Manuscript submitted for publication 30 May 1985.

Table 1. Parameters of vine growth and berry composition.

Parameter measured	*Mean*
No. of leaves, 30 Nov.	7.9
Leaf area, 30 Nov. (cm^2)[a]	232
Add'l. leaf no., 30 Nov. - 4 Jan.	4.1
Add'l. leaf area, 30 Nov. - 4 Jan. (cm^2)	217
Total leaf no., 4 Jan.	12.0
Total leaf area, 4 Jan. (cm^2)	449
Add'l. leaf no., 4 Jan. - 31 Jan.	2.3
Add'l. leaf area, 4 Jan. - 31 Jan. (cm^2)	139
Total leaf no., 31 Jan.	14.2
Total leaf area, 31 Jan. (cm^2)	588
Berry no., 30 Nov.	44.8
Berry no., 21 Dec.	34.3
Berry no., 4 Jan.	26.1
Color[b], 4 Jan.	1.06
Color, 18 Jan.	2.46
Color, 31 Jan.	2.96
Leaf no./berry no., 30 Nov.	0.18
Leaf area/berry no., 30 Nov.	5.18
Leaf no., 4. Jan./berry no., 21 Dec.	0.35
Leaf area, 4 Jan./berry no., 21 Dec.	13.1
Leaf no., 4 Jan./berry no., 4 Jan.	0.46
Leaf area, 4 Jan./berry no., 4 Jan.	17.2
Leaf no., 31 Jan./berry no., 4 Jan.	0.54
Leaf area, 31 Jan./berry no., 4 Jan.	22.5
°Brix, harvest[c]	19.6
Acid, harvest (g/L tartaric acid eq)[c]	5.6
pH, harvest	3.7
Wt./bunch at ripeness (g)[d]	19.7
Berry no. at ripeness[d]	26
Mean wt./berry (g)[d]	0.8
Leaf area, 31 Jan./fruit wt. at ripeness	29.8

[a]Leaf area of detached leaves, measured on leaf area meter, was found to have a straight-line relationship with leaf diameter. Leaf diameter was measured on the vine, and the area was computed from this relationship.

[b]Color was visually estimated on the basis of 0 = no color showing to 3 = all berries black.

[c]Total soluble solids (°Brix) were measured with a refractometer, acid equivalents by titration.

[d]Final measurements were made on individual plants 20 days after the color score of that plant was 3.

of the four groups using the parameters listed above which were measured or computed for each plant. Means are provided to give an overall idea of the magnitude of the parameters measured (Table 1).

Stage II lasted from approximately 10 December to 4 January, at which time color was appearing in some berries and after which the final growth phase (Stage III) began.

One problem when conducting trials of this nature is deciding when to harvest. There is no one recognized guide to maturity of grapes, and any criteria used is open to criticism. Grapes may be picked when, for example, a specific soluble solids, acid, or pH level has been attained. However, in addition to doubt of whether the choice was appropriate, there is a considerable cost in that the effect of treatments on that parameter is lost. The use of the color status of the bunch as a guide enabled the author to use all of the above factors in correlations. Choosing a set number of days after all berries were black ensured every bunch was reasonably mature and would suggest that changes in these parameters would be slowing down (12).

Results

Coefficients of linear correlation were d
all combinations of the 31 parameters sho
Table 2, the correlation coefficients are
those pairs which have physiological sign
four groups formed by berry-removal treat
been analyzed separately, are shown in sep
(Columns 1, 2, 3, and 4). Since the respons
and leaf number were virtually identical, o
the former only were included.

Responses to leaf area and leaf/
°Brix: Before Stage II (10 December),
relationship between °Brix and leaf area. I
that stage, leaves became more significa
however, be partly an indirect response to
since data (not shown in this paper) indic
31 November there was a significant in
production if berry number was small (R =

Leaf area was positively correlated and
negatively correlated with °Brix. A parall
found if leaf/fruit is considered. After 31
high leaf/fruit ratio is correlated significa
tively with °Brix.

In all cases above, significance was lost
much reduced if berry number was halve
(Columns 2, 3, and 4). This suggests that,
leaves to fruit is increased by artificial berr
area may become non-limiting.

Color: The color responses were very

Table 2. Correlation coefficients between factors in

Column Number+	1	2
Parameter		Bri
Leaf area, 30 Nov	-0.103	0.019
Extra leaf area, 30 Nov - 4 Jan	**0.688**	0.193
Total leaf area, 4 Jan	*0.640*	0.126
Extra leaf area, 4 Jan - 31 Jan	0.259	0.304
Total leaf area, 31 Jan	*0.630*	0.248
Berry number, 30 Nov	**-0.795**	-0.053
Berry number, 21 Dec	**-0.806**	-0.048
Berry number, 4 Jan	**-0.806**	-0.048
Color, 18 Jan	0.504	0.389
Wt/bunch, ripeness	**-0.826**	-0.152
Leaf area/berry no., 30 Nov	0.342	0.051
Leaf area/berry no., 21 Dec	*0.634*	0.123
Leaf area/berry no., 4 Jan	*0.634*	0.123
Leaf area/bunch wt., ripeness	**0.683**	0.270
Column Number+	1	2
Parameter		Color 18
Leaf area, 30 Nov	0.463	0.437
Extra leaf area, 30 Nov - 4 Jan	*0.643*	0.425
Total leaf area, 4 Jan	**0.825**	0.491
Extra leaf area, 4 Jan - 31 Jan	-0.070	0.218
Total leaf area, 31 Jan	*0.609*	0.489
Berry number, 30 Nov	**-0.753**	0.038
Berry number, 21 Dec	**-0.752**	0.036
Berry number, 4 Jan	**-0.752**	0.036
Color, 18 Jan		
Wt/bunch, ripeness	-0.464	0.087
Leaf area/berry no., 30 Nov	*0.611*	0.353
Leaf area/berry no., 21 Dec	**0.734**	0.414
Leaf area/berry no., 4 Jan	**0.734**	0.41
Leaf area/bunch wt., ripeness	**0.653**	0.40

Column Number+	1	2	3	4
Parameter	Acid g/L*			
Leaf area, 30 Nov	0.156	0.094	0.315	-0.011
Extra leaf area, 30 Nov - 4 Jan	-0.506	*-0.597*	-0.234	*-0.704*
Total leaf area, 4 Jan	-0.462	-0.463	-0.028	*-0.713*
Extra leaf area, 4 Jan - 31 Jan	*-0.575*	-0.042	-0.536	-0.354
Total leaf area, 31 Jan	**-0.715**	-0.321	-0.409	-0.569
Berry number, 30 Nov	0.473	*0.576*	0.561	0.202
Berry number, 21 Dec	0.471	0.562	-0.561	0.220
Berry number, 4 Jan	0.471	0.562	0.484	0.210
Color, 18 Jan	-0.139	0.028	0.208	**0.930**
Wt/bunch, ripeness	0.509	*0.666*	*0.650*	0.395
Leaf area/berry no., 30 Nov	-0.119	-0.461	-0.212	-0.364
Leaf area/berry no., 21 Dec	-0.259	*-0.623*	-0.249	*-0.679*
Leaf area/berry no., 4 Jan	-0.259	*-0.623*	0.216	*-0.649*
Leaf area/bunch wt., ripeness	*-0.545*	*-0.576*	*.570*	*0.694*

Column Number+	1	2	3	4
Parameter	pH*			
Leaf area, 30 Nov	0.433	-0.514	-0.379	-0.174
Extra leaf area, 30 Nov - 4 Jan	*0.645*	0.565	0.331	*0.637*
Total leaf area, 4 Jan	0.475	0.220	0.072	0.570
Extra leaf area, 4 Jan - 31 Jan	**0.748**	0.343	**0.718**	0.262
Total leaf area, 31 Jan	**0.829**	0.331	0.565	0.444
Berry number, 30 Nov	-0.487	*-0.633*	*-0.683*	-0.311
Berry number, 21 Dec	-0.509	*-0.656*	*-0.683*	-0.325
Berry number, 4 Jan	-0.509	*-0.656*	*-0.612*	-0.303
Color, 18 Jan	0.069	-0.075	0.000	**-0.975**
Wt/bunch, ripeness	*-0.569*	**-0.842**	**-0.832**	-0.492
Leaf area/berry no., 30 Nov	-0.080	0.209	0.285	0.170
Leaf area/berry no., 21 Dec	0.292	0.452	0.336	0.594
Leaf area/berry no., 4 Jan	0.292	0.452	0.306	0.559
Leaf area/bunch wt., ripeness	0.511	*0.647*	**-0.749**	*0.622*

Column Number+	1	2	3	4
Parameter	Weight per berry (g)*			
Leaf area, 30 Nov	0.130	0.484	0.528	0.314
Extra leaf area, 30 Nov - 4 Jan	0.298	0.258	*0.694*	0.453
Total leaf area, 4 Jan	0.349	0.403	**0.740**	0.483
Extra leaf area, 4 Jan - 31 Jan	-0.147	-0.338	0.414	-0.171
Total leaf area, 31 Jan	0.198	0.145	*0.668*	0.278
Berry number, 30 Nov	-0.265	-0.271	-0.311	**0.759**
Berry number, 21 Dec	-0.298	-0.282	-0.311	**-0.763**
Berry number, 4 Jan	-0.298	-0.282	-0.368	**-0.761**
Color, 18 Jan	0.447	0.246	-0.110	-0.136
Wt/bunch, ripeness	0.291	-0.004	-0.057	*-0.691*
Leaf area/berry no., 30 Nov	0.095	0.559	0.544	**0.891**
Leaf area/berry no., 21 Dec	0.389	0.476	*0.642*	**0.901**
Leaf area/berry no., 4 Jan	0.389	0.476	*0.667*	**0.899**
Leaf area/bunch wt., ripeness	-0.011	0.121	-0.339	*0.602*

\+ Columns 1 — Untouched
2 — Half berries removed 21 Dec.
3 — Half berries removed 4 Jan.
4 — Half berries removed 21 Dec. + 4 Jan.
* Light face - not significant
Italics - significant at 5%
Bold face - significant at 1%

responses already noted for °Brix. In other words, higher leaf production after Stage I and higher leaf/fruit ratios (in this case, before the end of Stage I) promote the early development of color.

Acid and pH: Acid and pH are not significantly correlated to leaf area before the end of Stage I; however, further leaf growth is negatively and often significantly related to acid levels and positively so to pH. Later leaf growth and area appears very strongly correlated, especially if bunches are not thinned, but less so if thinning has occurred. High leaf/fruit ratios are related to low acid and high pH. The former is significant especially if berries were thinned on 21 December.

Unlike °Brix, the relationship between leaves or leaves/fruit and acid or pH is not dramatically altered by thinning and is generally greater for leaves than the leaf/fruit ratios.

Analyses attempted to fit the data to a straight line, and plotting of most data indicated that such an approach was appropriate. In the case of °Brix data, however, it appeared to be linear to a certain point and then level off. Two such graphs are shown for unthinned plants (Fig. 2), where °Brix is related to leaf/fruit ratios. The leveling-off point occurs at approximately 10 cm^2 leaf area per gram fruit weight at 4 January and 14 cm^2 at harvest.

Unlike the graphs for sugar, those for pH and acid are clearly linear; there is no obvious cut-off point above which pH or acid is unaffected by leaf area changes (Fig. 3). (Correlation coefficients for graphs in Figures 2 and 3 are given in Table 2.)

Weight per berry: Individual berry weight tends to be higher if there is a higher leaf area, although only a few examples reach significant levels. There is a positive and usually significant relationship between leaf/fruit ratio and berry weight. This is very close ($R = 0.8$ to 0.9) if a considerable amount of berry thinning has occurred (*i.e.*, if the overall leaf/fruit ratios are high).

Response to berry numbers: A further analysis was undertaken to determine whether any of the three berry removal treatments affected the factors measured. The following parameters were analyzed: 1) extra leaf number (4-31 January); 2) extra leaf area (4-31 January); 3) leaf number (31 January); 4) leaf area (31 January); 5) berry weight; 6) °Brix; 7) acid level; and 8) pH.

Individual plants were treated as replicates. No treatment showed significant effects upon any of the eight factors, and consequently, results are not presented. Thus, although leaves and leaf/fruit ratios are correlated in different ways to °Brix, color, acid, pH, and berry weight, there is no evidence of a direct response to berry removal if this occurs after the middle of Stage II.

Results suggest that leaves and leaf/fruit ratios exert these key effects upon such parameters early in the period of berry development.

Berry numbers, alone or as part of the leaf/fruit ratio, correlate to the following factors (Table 2).

°Brix: Degrees Brix is decreased if berry numbers are high with high R values being established as early as the end of Stage I. Halving the numbers annuls the response; quartering them reverses it.

Once again, the plotted data suggest that in this case, the graph may not be linear (Fig. 4). This shows results for the unthinned vines and indicates that only as the berry number per vine increases above 40 does the decline commence.

Color: Color, like °Brix, is inversely related to berry

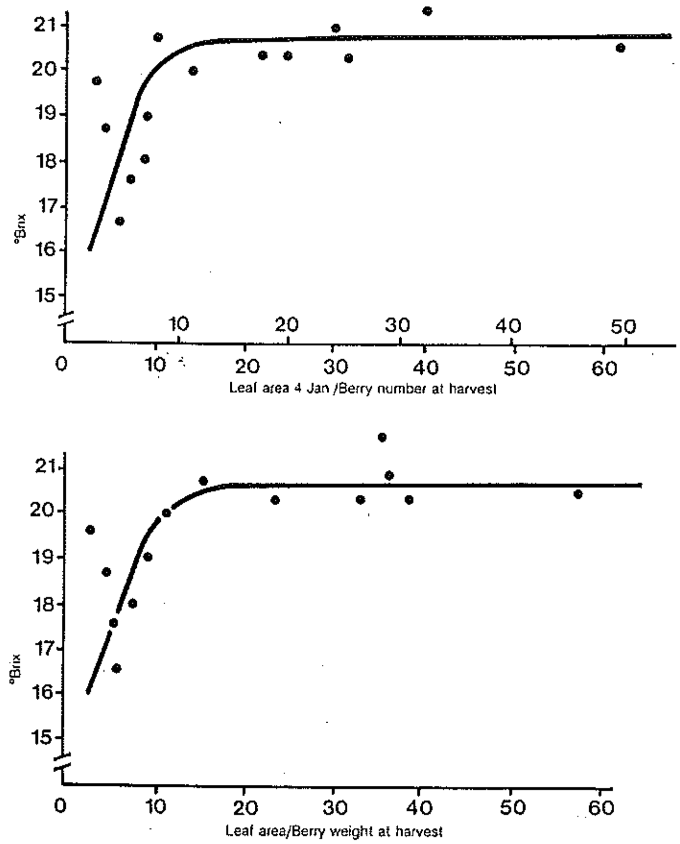

Fig. 2. Relationship between °Brix and leaf/fruit ratio at 4 January (above) and at harvest (below).

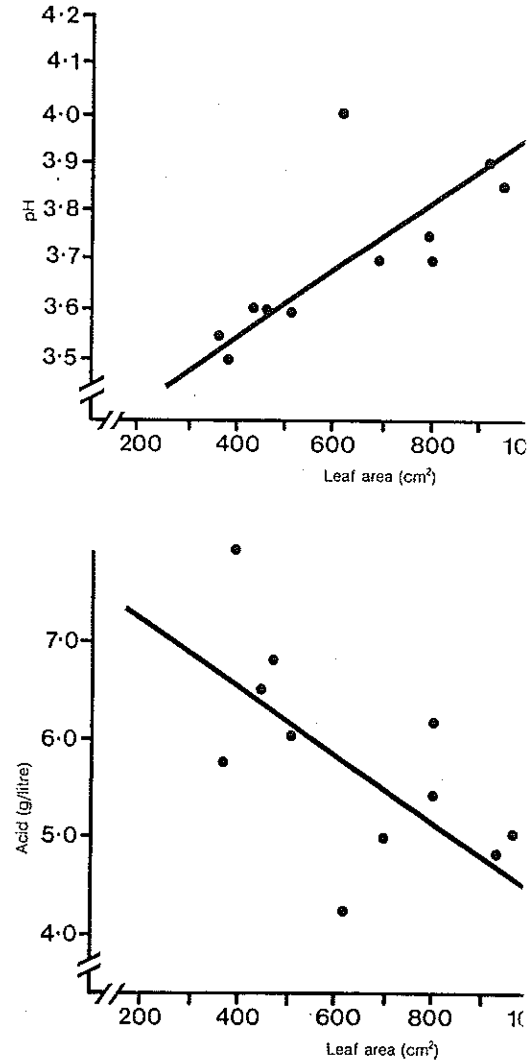

Fig. 3. Relationship between leaf area (31 Jan.) and between leaf area and acid (below).

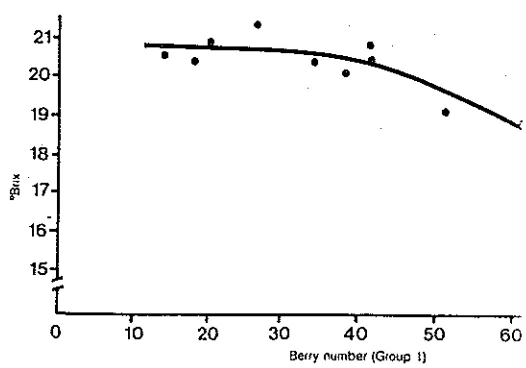

Fig. 4. Relationship between °Brix and berries p

number. Berry removal to half reduces the relationship; removal to a quarter reverses it.

Acid: Acid levels are positively related, occasionally significantly, to berry number.

pH: pH levels are negatively related to berry number.

Weight per berry: Weight per berry generally increases with lower berry numbers, and this becomes highly significant when berry numbers are quartered.

Color relations: The color figure was a measure of earliness of color development and not necessarily final color intensity. Harvest was at a set number of days (20 days) after the final berry in the bunch turned black. There was still a positive relationship between color and °Brix, which was significant when the berry number was quartered (Column 4).

Discussion

The technique of growing test plants in pots and evaluating responses of whole plants allows greater flexibility to manipulate the environment and the treatments in a more fully-controlled situation. These trials were exploratory, but some valuable data were produced.

Berries were picked 20 days after bunches were fully colored. The relationship between color at 18 January and final °Brix (Table 2) may not simply be due to earlier ripening since pH and acid did not show evidence of greater maturity; if anything, they were the reverse. Such responses suggest that results obtained, es °Brix, acid, and pH, are not simply measure of the berries harvested.

It has been known for some time that high cropping levels will reduce vegetative growth (12). The data with test plots confirms this — more berries, lower leaf growth. Heavy crops are also known to reduce or delay sugar levels (1), and once again, this has been confirmed (Fig. 4).

Changing berry number by thinning at Stage II of growth did not affect leaf production, °Brix, or any other parameter measured. Thus the responses, whether they act directly on berry composition or indirectly via effects on leaf production, obviously need to occur early in growth (probably before the end of Stage I).

Various authors have suggested that a critical leaf/fruit ratio is necessary for adequate ripening of grapes. This is possibly about 10 cm^2 per gram of fruit (5). The level probably depends on the effective illumination of the counted leaves; with a divided canopy with few interior leaves, Smart (7) found adequate ripening at 6.2 cm^2 per gram. By the beginning of Stage II in the present experiment, a leaf/fruit ratio of about 10 cm^2 per gram had been established as the point above which additional leaf area did not increase sugar (upper graph, Fig. 2). Since berry removal at this stage or later did not affect fruit composition, it is likely that the critical leaf area will be in the order of 10 cm^2 per gram rather than the 14 cm^2 per gram indicated in the lower graph of Figure 2.

It appears that the berry number established after set will determine the leaf growth rate and leaf/fruit ratio after the end of Stage I. The consequence is that a low berry number, a high leaf growth rate, and a high leaf/fruit ratio are related to high °Brix. While this may appear to be a bonus for the winemaker, these parameters were associated with undesirable pH and acid levels. The pH levels of up to 4.0 and acid levels of below 4.5 were recorded with low berry numbers, high leaf growth rate, and high leaf/fruit ratios.

Such results can be compared to field data obtained by Smart (5) with Shiraz in Australia which indicated that leaf area related positively with °Brix. He also found that leaf area per shoot, per vine, or per gram of fruit was negatively correlated with acid and positively so with pH, results similar to those presented in this paper. Hepner *et al.* (3) showed wine quality to be negatively related to pruning weight (capacity) and pH. The work of Jackson *et al.* (4) on outdoor vines which were trimmed to a constant volume and varied in crop weight provided further confirming evidence that low leaf/fruit ratios caused lower °Brix and lower pH.

Smart suggests in several papers (7,8,9) that shading of vine leaves induces unacceptably high pH levels and low acid levels and that in the field, this is normally a consequence of high vigor and dense canopies. He presents a model which pictures vigor influencing canopy microclimate which reduces fruit and foliage exposure, and this in turn influences fruit composition. From the present research, however, it appears that shoot vigor can have a direct influence on quality parameters, as leaf and fruit shading was not permitted in these experiments.

High pH and low acid are problems especially of warm climates (8). In cooler climates, acids are often too high, and high pH is uncommon. The special value of these results is the confirmation that a relatively low leaf/fruit ratio will ripen grapes and the finding that in warm conditions (in this case in a greenhouse), factors increasing shoot growth will have a direct effect in promoting low acid and high pH levels. Thus, it can be deduced that in vineyards where such conditions create quality problems, canopy management to restrict excessive growth will be beneficial.

Literature Cited

1. Bravdo, B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. Effect of crop level and crop load on growth, yield, must and wine composition, and quality of Cabernet Sauvignon. Am. J. Enol. Vitic. 36:125-35 (1985).

2. Freeman, B. M., T. H. Lee, and C. R. Turkington. Interaction of irrigation and pruning level on grape and wine quality of Shiraz vines. Am. J. Enol. Vitic. 31:125-35 (1980).

3. 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).

4. Jackson, D., G. Steans, and A. Collyns. Optimum bud numbers depend on variety. South. Hortic., Grapegrow. Winemaker 1:75-7 (1983).

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

6. Mullins, M. G., and K. Rajasekaren. Fruiting cuttings: revised method for producing test plants of grapevine cultivars. Am. J. Enol. Vitic. 32:35-40 (1981).

7. Smart, R. E. Vine manipulation to improve wine grape quality. Proc. Int. Symp. Grapes Wine. pp 362-75. University of California, Davis (1980).

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

9. Smart, R. E., J. B. Robinson, G. R. Due, and C. J. Brien. Canopy microclimate modification for the cultivar Shiraz. II. Effects on must and wine composition. Vitis 24:119-28 (1985).

10. Smart, R. E., N. J. Shaulis, and E. R. Lemon. The effect of Concord vineyard microclimate on yield. II. The inter-relationships between microclimate and yield expression. Am. J. Enol. Vitic. 33:109-16 (1982).

11. Somers, T. C. In search of quality for red wines. Food Technol. Aust. 27:49-56 (1975).

12. Winkler, A. J., J. A. Cook, W. M. Kliewer, and L. A. Lider. General Viticulture. 710 pp. University of California Press, Berkeley (1974).