EFFECT OF CROP LEVEL AND LEAF AREA ON GROWTH, COMPOSITION, AND COLORATION OF 'TOKAY' GRAPES

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ABSTRACT

The effect of leaf area per unit weight of fruits on growth, composition, and coloration of 'Tokay' grapes was investigated on vines in which the crop level was adjusted by pruning or by pruning and cluster thinning. Significant ($P<0.001$) curvilinear equations were obtained for relationships between leaf area per unit weight of fruits and fruit maturity (°Brix), berry weight, fruit coloration, and level of proline in berry juice. Correlation coefficients ranged from 0.76 to 0.92. Regression analysis indicated that fruit maturity, berry weight, fruit coloration, and proline concentration in berry juice were maximum when the ratio of square centimeters of leaf surface to gram of fruits was between 11 and 14. Severe overcropping occurred on unpruned and unthinned vines, and on vines pruned but not cluster thinned (3.8 and 5.0 cm^2 leaf area per g fruits, respectively). This was reflected in significant reductions in pruning weights, total leaf area per vine, berry and cluster weights, total soluble solids, fruit coloration, and concentrations of proline and arginine in berry juice, compared with those for vines that were pruned and thinned to 18 clusters per vine (12.6 cm^2 leaf area/g fruits).

A grapevine has the capacity to produce a given weight of fruits and to bring that fruit to normal maturity with a given number of degree-days of heat characteristic for the cultivar and the climatic region (15). The capacity of a vine is largely determined by its total leaf area and by the percentage of the total leaf surface that is at light saturation or above, provided other factors are not limiting growth and the initiation of fruit primordia. In recent investigations (6, 7) with 'Thompson Seedless', about 10 cm^2 of leaf area per g of fruits were required to mature the crop to 23° Brix. Also, concentrations of proline, arginine, and total nitrogen in the juice of 'Thompson Seedless' berries were maximum when the ratio of leaf area to crop weight was 10 to 14 cm^2 per g of fruits (7). Berry size, coloration, bud fruitfulness, shoot growth, and carbohydrate reserves are reduced, and fruit maturation delayed, when grapevines are overcropped (2, 10, 11, 14).

The present investigation was made to determine the leaf area needed to support a unit weight of 'Tokay' fruits for maximum berry weight and coloration and a high level of soluble solids 20 °Brix).

MATERIALS AND METHODS

Used in this investigation were 12-year-old own-rooted vines of *Vitis vinifera* L., 'Tokay', on A x R rootstock in an irrigated vineyard at the University of California, Davis. The vines were cordon-trained and spur-pruned to three buds. The three crop levels were controlled by vine pruning and cluster thinning. The treatments were: 1) vines not pruned and clusters not thinned (NP-NT); 2) vines pruned but clusters not thinned (P-NT); and 3) vines pruned and clusters thinned (P-T). Each treatment was replicated five times in randomized blocks, four vines per block. The vines (P-NT and P-T) were pruned in March, 1970, and cluster thinned (P-T) at bloom (May 28). Each retained cluster was further thinned to about six basal laterals. The respective average numbers of clusters per vine for NP-NT, P-NT, and P-T treatments were 120, 31.8, and 18.7. The average number of berries per vine and per cluster are given in table 1.

Three to five berries were randomly sampled from each cluster on P-T and P-NT vines, and from about half the clusters on NP-NT vines, at weekly intervals during the ripening period, beginning

TABLE 1

Effect of Pruning and Cluster Thinning on Growth, Yield, and Composition of 'Tokay' Grapes[a, b]

	Treatment			
	Not pruned, not thinned	**Pruned, not thinned**	**Pruned, thinned**	**LSD at 5% level**
No. of clusters per vine	120.0	31.8	18.7	—
No. of berries per cluster	76	133	94	—
No of berries per vine	9120	4229	1758	—
Weight per berry (g)	2.95	5.58	6.50	0.24
Weight per cluster (g)	222 (0.49)	744 (1.64)	612 (1.35)	76
Crop weight (kg/vine)	26.7 (58.9)	23.3 (51.3)	11.0 (24.3)	3.8
Leaf area per vine (cm^2)	10.06	10.92	12.60	1.5
Leaf area per g fruit (cm^2/g)	3.85	5.00	12.10	1.2
Leaf area per berry (cm^2/berry)	11.35	27.90	82.20	—
Total soluble solids of must (°B)	13.2	16.8	20.3	0.5
Total soluble solids per vine (kg)	3.51	3.89	2.34	0.55
Total soluble solids per m^2 of leaf surface (kg)	0.347	0.358	0.186	0.031
Fruit coloration (% of maximum color)	15	43	100	—
Pruning weight (kg)	0.36 (0.8)	1.45 (3.2)	1.82 (4.0)	0.26

[a] Data are the means of 5 replicates of 4 vines each. The crop was harvested September 24.

[b] Figures in parentheses are in pounds.

August 12. The berries in each treatment were counted, weighed, macerated in a mortar, and then squeezed through two layers of cheesecloth. The expressed juice was immediately analyzed for total soluble solids (degree Brix, °B) with a refractometer, and for total titratable acidity by titration with 0.1 N NaOH to a phenolphthalein end point. The pH of the juice was measured with an expanded-scale pH meter, using a glass electrode. A 1 or 2-ml portion of the juice was diluted with an appropriate amount of distilled water and assayed for malate (3), proline, and arginine as described previously (4).

To determine fruit coloration, a 5-mm disc of skin was taken from the apical region of 20 berries from each sample. The discs were placed in a screw-cap culture tube containing 20 ml of 95% ethanol, acidified to contain 1% HCl. The tubes were tightly capped and then placed in a boiling-water bath for 2 minutes. Afterwards, the discs were incubated in the ethanolic solution in the dark for about 2 hours, occasionally being stirred with a vortex mixer. The optical densities of the skin extracts were read at 530 mμ. Results were calculated as optical density of pigments per cm^2 of skin in 20 ml ethanol.

On September 24 the crop was harvested and weighed, and the clusters per vine were counted. On September 28 and 29, the fresh and dry weights of all leaf blades per vine, from all vines, were determined for estimating total leaf area. The dry weight and area of 100 leaves, sampled from all parts of the vines in all treatments, were determined at the time the leaf blades were removed from the vines. A value of 8.77 mg dry weight per square centimeter of leaf removed was used in calculating total leaf area per vine.

RESULTS

Fruit growth and crop yield: At each sampling date the average weight of individual berries was 90 to 110% greater from P-NT vines than from NP-NT vines, and about 20% greater from P-T vines than from P-NT vines (Figure 1A).

The average crop weight of NP-NT vines was 26.7 kg, approximately 15% greater than the yield of P-NT vines and 140% greater than that of P-T vines (Table 1). The differences in crop weight mainly reflected differences in the number of clusters per vine. Fruit set, as judged by average number of berries per cluster, was about 43% less on NP-NT vines than on P-NT vines.

Vine growth: Pruning weights were respectively 20 and 80% less for P-NT and NP-NT vines than for P-T vines (Table 1). Total leaf area per vine was significantly less ($P<0.05$) on NP-NT and P-NT vines than on P-T vines. The average area per leaf blade for NP-NT vines was less than half that

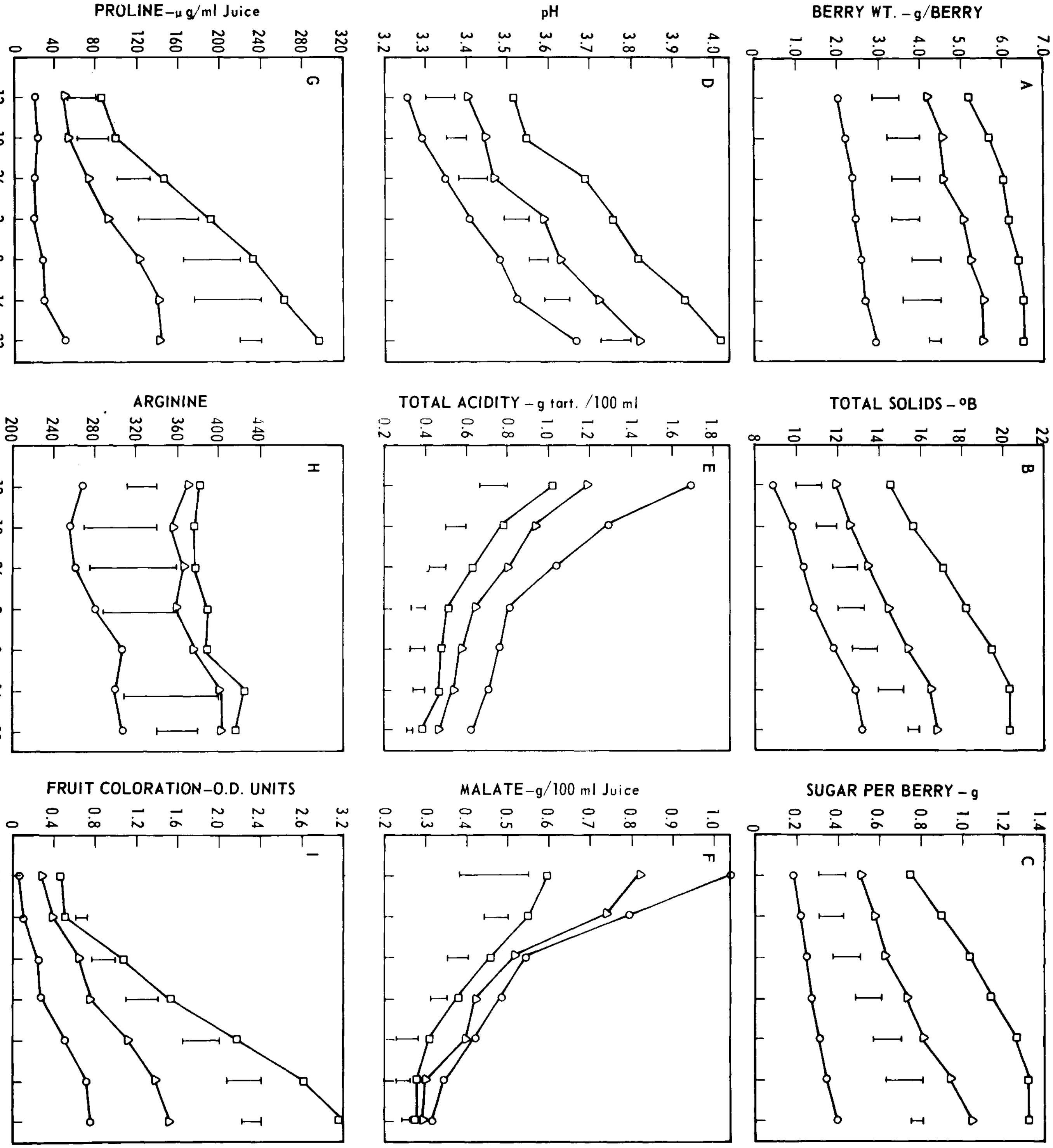

Figure 1. Effect of reducing the crop load by pruning or pruning and cluster-thinning on berry weight, fruit composition, and fruit coloration of 'Tokay' grapes. Squares indicate vines pruned and thinned to 18 clusters; triangles, vines pruned but not cluster-thinned; and circles, vines not pruned or cluster-thinned.

for P-NT and P-T vines. As expected, shoot growth on NP-NT vines was extremely poor, reflecting the overcropped condition.

Fruit composition: The large crop on the NP-NT and P-NT vines relative to leaf area, resulted in berries with considerably less ($P<0.01$) total soluble solids at each sampling date than on P-T vines (Figure 1B, 1C, Table 1). The NP-NT an P-NT berries never reached a level of sugar acceptable for table fruits, whereas grapes on P-T vines were harvestable for the fresh market by September 2 (Brix/acid ratio 35:1). Total sugar (soluble solids) in all fruits, both per vine and per square meter of leaf surface, was slightly greater for P-NT vines than for NP-NT vines, even though there were more than twice as many berries per vine in the latter treatment (Table 1).

The pH was highest and the levels of total acidity and malate lowest in berries from vines with the least crop load (P-T) at each sampling date (Figure 1D, E, F). The concentration of proline was greatest in juice of berries from P-T vines and lowest in juice from NP-NT vines (Figure 1G). The rate of increase in the concentration of proline with fruit maturity was inversely related to crop load. The level of arginine in berries was significantly greater ($P<0.05$) from P-T and P-NT vines than from NP-NT vines (Figure 1H). However, the concentration of arginine, unlike that of proline, did not increase greatly during the final stages of fruit maturation.

The coloration of P-T fruits was significantly greater ($P<0.01$) than that of P-NT and NP-NT fruits at each sampling date. At harvest (September 24), the level of anthocyanin in berries was more than six-times as great from P-T vines as from NP-NT vines, and over 2 times as great as from P-NT vines (Figure 1I, Table 1). Initiation of anthocyanin formation was considerably earlier in P-T grapes than in the other treatments, and rate of increase in color was markedly greater (Figure 1I).

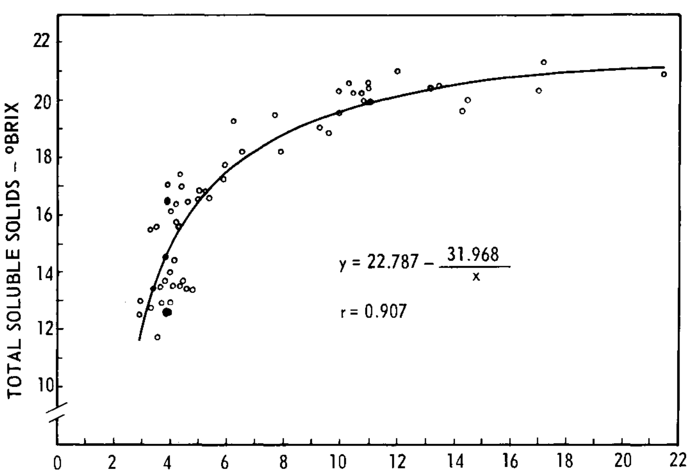

Figure 2. Regression of total soluble solids (°Brix) of 'Tokay' berry juice at harvest (September 24) on leaf area per unit crop weight (cm^2/g).

Relationship of leaf area per unit weight of fruits to berry weight, fruit maturity, level of proline, and fruit coloration: The respective average leaf areas per g of fruits for P-T, P-NT, and NP-NT vines were 12.10, 5.00, and 3.85 cm^2/g, equivalent to 82.20, 27.90 and 11.35 cm^2 per berry. Figure 2 shows the relation between total soluble solids of fruits at harvest and leaf area per unit weight of fruits for all vines, irrespective of treatment. A significant curvi-

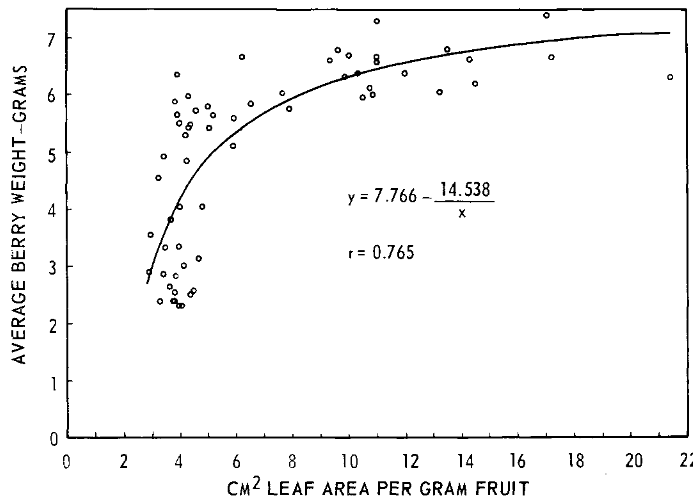

Figure 3. Regression of average berry weight (g) of 'Tokay' fruits at harvest (September 24) on leaf area per unit crop weight (cm^2/g).

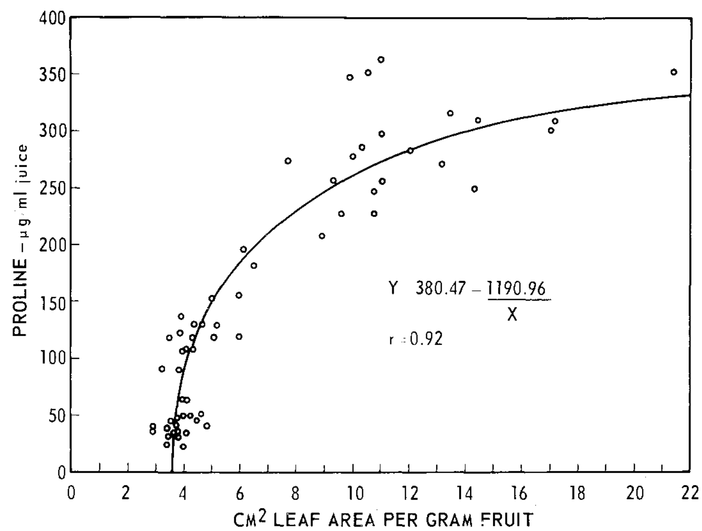

Figure 4. Regression of concentration of proline ($\mu g/ml$ juice) in 'Tokay' fruits at harvest (September 24) on leaf area per unit crop weight (cm^2/g).

linear regression ($P<0.001$) fitted the equation $Y = 22.787 - 31.968/x$, in which Y = °Brix and X = cm^2 leaf area per gram of fruits, with a correlation coefficient of 0.907. The data in figure 2 indicate that differences between treatments were due to variations in leaf area unit fruit weight, and that, under the conditions of the experiment, about 11 to 12 cm^2 leaf area per gram of fruits were required to mature the crop (20°B).

Differences in berry weight, concentration of proline in berry juice, and fruit coloration were also due to variations in leaf area per unit weight of fruits, irrespective of treatment (Figures 3, 4, 5). The relation between average berry weight per vine at harvest (September 24) and cm^2 of leaf area per g of fruits, for all vines, is described by the regres-

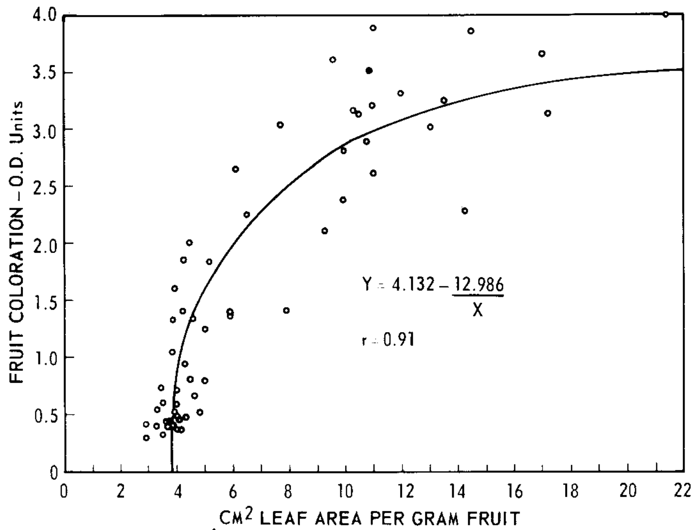

Figure 5. Regression of fruit coloration (optical density units/ cm^2 skin tissue/20 ml ethanol) of 'Tokay' fruits at harvest (September 24) on leaf area per unit crop weight (cm^2/g).

sion equation Y = 7.766-14.538/X, in which Y = average berry weight (g) and X = cm^2 leaf surface/ g fruits (Figure 3). A correlation coefficient of 0.765 was obtained. About 11 cm^2 of leaf surface per g fruits were required to produce berries with an average weight of 6.5 g.

There was a highly significant ($P<0.001$) relation between the concentration of proline in juice of berries at harvest and leaf area per unit weight of fruits. The relation is described by the curvilinear equation Y = 380.47-1190.96/X, in which Y = concentration of proline ($\mu g/ml$) and X = cm^2 leaf area per gram fruits (Figure 4). About 14 cm^2 leaf surface per g of fruits were required to produce berries with a proline concentration of 300 $\mu g/ml$, the average amount of proline in fruits from P-T vines at harvest.

The relation between leaf area per unit weight of fruits and fruit coloration at harvest is shown in figure 5. A significant curvilinear regression ($P<0.001$) followed the equation Y = 4.132-12.986/ X, in which Y = coloration of fruits (optical density units/cm^2 skin tissue per 20 ml ethanol and X = cm^2 leaf area/g fruits. Fruit coloration was maximum when cm^2 leaf area per g of fruits was about 14.

DISCUSSION

Winkler (14, 15) has stressed the importance of maintaining enough leaf area per unit weight of fruits to produce grapes of high quality for table use, and for raisin and wine production. He has described a method for determining whether a vine is over- or undercropped, based on fruit composition and number of degree-days of heat to bring the crop to maturity. The data in figures 2 and 3 show that about 11 to 12 cm^2 of leaf area per g of fruits were required to produce mature 'Tokay' fruits (20 °Brix) with an average weight of 6.5 g per berry. This is equivalent to 72 to 78 cm^2 per berry, or 6,768 to 7,332 cm^2 per average cluster on vines pruned and thinned. The average area per leaf on P-T vines was estimated to be about 280 cm^2. Therefore, about 24 to 26 leaves per cluster were required to mature the fruits. The respective average leaf areas per gram of fruits for P-NT and NP-NT vines were 5.0 and 3.8 cm^2/g. The corresponding fruit maturities and berry weights at harvest were 16.8 and 13.2°B and 5.58 and 2.95 g, indicating that these vines were severely overcropped. The heat summation between bloom and harvest (fruits with a Brix/acid ratio of 35:1) for P-T vines was 2,150 degree-days, which is within the normal number of heat units necessary for maturing 'Tokay' fruits (2,250 degree days), as determined by Winkler (13). Fruits on NP-NT and P-NT vines had not reached commercial maturity by September 24, at which time the number of degree days of heat had already reached 2,644.

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. (8) reported that about 7 cm^2 of leaf area per gram of fruits were required to ripen 'Thompson Seedless' berries, whereas Kliewer and Antcliff (6) and Kliewer (7), using the same cultivar, found that about 10 cm^2 of leaf surface were necessary. Winkler (12), using girdled shoots of 'Muscat of Alexandria', reported that 12 to 16 cm^2 leaf area per gram of fruits were needed for full maturation of a cluster. Buttrose (2), using the same cultivar, indicated that 17 cm^2 per g of fruits were needed for unhindered development of all parts of 1-year-old vines grown in pots. Amberg and Shaulis (1) indicated a requirement of 15 cm^2/g fruit for the cultivar 'Concord' grown under New York conditions.

Further evidence that the NP-NT and P-NT 'Tokay' vines were overcropped is the slow rate of fruit maturation, poor fruit coloration, small pruning weight, high Brix/acid ratio at a given fruit maturity, and the relatively low concentration of proline in the berry juice (Figure 1). Earlier work showed that the level of proline in grape berries is closely related to fruit maturity (7) and may be a useful indicator of wine quality (9). Furthermore, wood maturity in NP-NT vines was extremely poor, as judged by severe dieback of canes after the first winter frost, and by the very light pruning weight (Table 1). The concentrations of proline and of anthocyanins in 'Tokay' fruits reached maximum levels when leaf area per unit weight of fruits was about 14 cm^2/g (Figures 4, 5). This is about the same ratio of leaf area to fruit weight required for maximum berry weight and total soluble solids. Our data are in agreement with those from earlier work by Kliewer and Ough (7), who found that 10 to 14

cm^2 leaf area per gram of fruits were required for maximum concentrations of proline, arginine, and total nitrogen in 'Thompson Seedless' berries grown at Davis.

The ratios of leaf area to fruit weight mentioned in the previous three paragraphs were, in all instances, for only one season's crop. To evaluate the extent that carbohydrate reserves in roots, canes, and trunk are utilized in fruit maturation, and the effect of seasonal climatic conditions, vines need to be studied in several consecutive years. Kliewer and Antcliff (6) found that as much as 40% of the total sugar in the fruits may come from storage parts of the vine. The amount of leaf area needed to support a unit weight of fruits will, of course, be influenced by such factors as cultivar and clone, vine age, trellising system, temperature and light conditions, day length, soil, plant nutrients, and general cultural practices. The long-term effect of several of these factors on the amount of leaf area needed to support a unit weight of fruit is presently being investigated.

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