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Yield and Quality of 'Niagara' Grapes as Affected by Pruning Severity, Nodes per Bearing Unit, Training System, and Shoot Positioning

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Abstract. **A 4-year study was conducted on 'Niagara' grapes (*Vitis labrusca* L.) to examine the effects of 3 pruning severities (based on nodes retained), 3 levels of nodes/bearing unit (3, 6, and 9), 2 training systems [Geneva Double Curtain (GDC) and Bilateral Cordon (BC)], and 2 canopy management treatments (shoots positioned and shoots not positioned) on yield and fruit quality. Leaving heavy fruit loads suppressed yields in the 4th and final year of this study as a result of reduced node fruitfulness. The 3 node spurs were not as productive as the 6 and 9 node canes. GDC training produced higher yields than BC training in the 3 high yielding years of the study while maintaining vine vigor. Shoot positioning was more beneficial in increasing yields on the BC training system than on the GDC training system, because of the crowded conditions of the canes on the BC system. The effects of these variables on fruit quality were small, but the heavy fruit loads did result in fruit with a reduced percentage of soluble solids and pH, increased acidity and light color (increased CDM 'L' values). Shoot positioning reduced fruit pH, slightly increased acidity, and produced darker color (decreased CDM 'L' values). Under Arkansas growing conditions, if harvest is delayed beyond 14% soluble solids, it is possible that unacceptable fruit pH and acidity levels will exist.**

'Niagara' is the major grape cultivar used for white grape juice in the United States, and is a major wine grape cultivar in the Eastern United States and Canada. However, very little research has been reported on the yield and quality of the 'Niagara' grape (8, 19, 28, 29, 30, 31). Early research in Arkansas by Vaile (28) reported low yields for 'Niagara', ranging from 4.4 to 5.9 MT/ha on 4-cane Kniffin trained vines. Another study by Reynolds and Vaile (19) showed that hot-pressed juice of 'Niagara' had a soluble solids range from 15.1% to 17.6%, an acid range from 0.71% to 0.97%, and a pH range from 3.42 to 3.68.

Early research in Oklahoma by Webster and Cross (29) reported no quality differences between 'Niagara' grapes grown on a vertical trellis system compared to the Munson trellis system. The percentage of soluble solids of 'Niagara' grapes in this study ranged from 9.7% to 11.1%, and the titratable acidity ranged from 0.55% to 0.61%. In another Oklahoma study, total sugar levels of 'Niagara' were reported to be only 11.3%, with titratable acidity of 0.64% (30). Neither Oklahoma studies reported yield. In a 2-year study in Canada by Zubeckis (31), 'Niagara' grapes averaged about 5.5 and 12 kg/vine and, by the final sampling dates, had Brix readings of 16.2° and 16.5°, acidity (as percentage of tartaric) of 0.53 and 0.80, and pH values of 3.25 and 3.30, respectively. Crowther (8) sampled 20 different wine grape cultivars in Canada, starting 3 to 4 weeks before expected commercial harvest to determine the proper harvest maturity. 'Niagara' showed a wide range in the percentage of soluble solids, acidity, and pH among the 3 years of the study. In 1959, the percentage of soluble solids increased to above 17%, but, in 1960, the percentage of soluble solids never increased above 10%. The titratable acidity and pH also varied among years, but not to the extent reported for the percentage of soluble solids. Yields were not reported in this study.

In contrast to the limited research reported in 'Niagara' grapes, extensive research has been conducted with 'Concord' on the influence of pruning severity (3, 4, 6, 9, 10, 11, 12, 13, 14, 15, 16, 20, 23, 24, 26, 27), nodes per bearing unit (3, 15, 17, 18, 21) training systems (1, 2, 3, 5, 6, 7, 14, 15, 22, 23, 25), and shoot positioning (3, 15, 22, 24, 26) on yield and quality. Therefore, this factorial study was established to examine the effects of these variables on the yield and composition of 'Niagara' grapes.

Materials and Methods

This study was conducted in a vineyard of 'Niagara' on their own roots at the Arkansas Agr. Expt. Sta., Fayetteville. The vineyard was established in 1974, using a vine spacing of 2.4 m within rows and 3.1 m between rows. The vines were trained to bilateral cordons (BC) or Geneva Double Curtain (GDC). All flower clusters were removed from the vines during 1975 and 1976. The pruning and shoot positioning treatments were initiated in Feb. 1977. Treatments (in a factorial design) consisted of: 1) 3 pruning severities: 30 + 10, 50 + 10, and 70 + 10 (30, 50, or 70 nodes retained for the 1st 454 g of dormant cane prunings and 10 additional nodes retained for each additional 454 g of cane prunings removed); 2) 3 levels of nodes/bearing unit: 3, 6, or 9 nodes; 3) 2 training systems: BC or GDC; and 4) 2 canopy positioning treatments, not positioned (NP) (shoots allowed to grow at random) or shoot positioned (SP) (shoots manually positioned vertically toward the vineyard floor). Shoot positioning usually was required 3 times a year at about 2 week intervals beginning at berry shatter.

The dormant pruning weights from the 1976 growing season were used to adjust node number of each vine for the initial year of the study. The pruning weights of the vines in 1976 were extremely uniform and averaged 1.51 kg/vine on GDC trained plots and 1.47 kg/vine on BC plots. All treatments were imposed upon the same plots each year. Each plot consisted of 2 vines, and all treatments were replicated 4 times. Individual vine yields and cane pruning weights were determined. Three fruit samples were taken each year, starting when the 50 + 10,

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bilateral cordon, nonpositioned, 6-node cane plots had developed between 10% and 11% soluble solids and continuing at 7–10 day intervals. The last fruit samples were collected at harvest each year (23 Aug. and 5, 8, and 9 Sept. successively from 1977–1980). Fruit samples, consisting of 3 whole basal clusters from each plot, were frozen in polyethylene bags for subsequent analysis.

For analysis, samples were thawed overnight at 2°C, and the number of berries per cluster and berry weight were determined. Fruit were mixed for 15 sec in a blender, and the percentage of soluble solids was determined on a Bausch and Lomb Abbe Refractometer. Samples then were heated for 1 hr at 85°, allowed to cool to about 40°, and the pulp was separated from the juice by squeezing through 2 layers of grade 50 cheesecloth. Color quality of the juice was determined using a Gardner Color Difference Meter (CDM) that had been standardized to a white plate (L = 92.4, a = −1.0, b = 1.0). A 5 ml portion of juice was diluted to 125 ml with deionized water, the pH was determined, and the sample was titrated to pH 8.4 with 0.1 N NaOH. Titratable acidity is reported as the percentage of tartaric acid.

For statistical analysis, all data for each year and for all years together were subjected to factorial analysis of variance. Duncan's multiple range test at the 5% level was used to separate means of the main effects, and Least Significant Difference (LSD) was used to separate means of the significant interactions. Linear regression analysis was used to examine the relationship of pH, acidity, and color to the development of soluble solids.

Results and Discussion

Since few interactions were significant (Table 1) only those significant and relevant interactions are presented along with the main effect means. Yield, node fruitfulness, and vine vigor data are presented for all 4 years and for the 4-year means. However, due to only slight variations among years on quality, only data for the final year and for the 4-year means are presented.

Yield, node fruitfulness, vine vigor

Effect of pruning severity. In the 2nd year of the study, the pruning severities of 50 + 10 and 70 + 10 increased yield in comparison with 30 + 10. However, during the final year of the study, the pruning severity of 70 + 10 was associated with lowered yields (Table 2). The 4-year means for yield showed no significant difference between pruning severities. Light pruning levels resulted in a reduction of node fruitfulness [yield (g)/node] during the entire study, which might explain why light pruning did not increase yield consistently (Table 2). There was a tendency for the 70 + 10 pruning severity to reduce vine size during the entire study, but this reduction was significant in only 1 year and for the 4-year mean (Table 2).

Effect of nodes/bearing unit. There was a trend for the 3 node spurs to produce slightly lower yields than the 6 and 9 node canes for the final 3 years of the study, and this difference was significant for the 4-year mean (Table 3). Increasing the nodes/bearing unit had no effect on yield/node during the 1st year, but the 3 node spurs had reduced node productivity during the 2nd and 4th years. Nine-node canes reduced vine size, and the 4-year means showed that with each increase in nodes/bearing unit, there was a reduction in pruning weight.

Effect of training system. GDC training produced higher yields than BC for the 4-year mean and in all years except for the lowest yielding year (Table 4). GDC training increased yield/node in the final 2 years and for the 4-year mean. There was no effect of training system on pruning weight. Thus, the GDC system increased yields without decreasing vine vigor.

Table 1. F-value significance for effects at final sample date of pruning severity, nodes/bearing unit, training system and shoot positioning.

Effect	Yield (MT/ha)	Yield (g/node)	Pruning wt	Soluble solids	pH	Acidity	CDM 'L'
PS[z]	NS[y]	***	**	***	NS	*	*
N	NS	NS	***	***	***	***	*
TS	***	**	NS	***	NS	***	NS
SP	*	**	***	NS	***	***	*
PS × N	NS	NS	NS	NS	NS	NS	NS
PS × TS	NS	*	NS	NS	NS	NS	NS
N × TS	NS	NS	NS	NS	NS	NS	NS
PS × N × TS	*	***	**	NS	NS	NS	NS
PS × SP	NS	NS	NS	NS	NS	NS	NS
N × SP	NS	NS	**	NS	***	NS	NS
PS × N × SP	NS	NS	NS	NS	*	NS	NS
TS × SP	*	NS	*	NS	NS	NS	*
PS × TS × SP	NS	NS	NS	NS	NS	NS	NS
N × TS × SP	NS	*	*	NS	NS	NS	NS

[z]PS = pruning severity, N = nodes/bearing unit, TS = training system, SP = shoot positioning.
[y]Not significant (NS), and significant at 5%(*), 1%(**), and 0.1%(***).

Table 2. Main effect of pruning severity on yield, yield/node and pruning weight of 'Niagara' grapevines for 4 years.

Pruning severity	Year 1977	1978	1979	1980	4-year mean
	Yield (MT/ha)				
30 + 10	24.0 a[z]	11.1 b	22.9 a	16.8 a	18.7 a
50 + 10	25.1 a	13.9 a	22.6 a	15.6 ab	19.3 a
70 + 10	25.5 a	14.5 a	24.6 a	13.9 b	19.6 a
	Yield (g)/node				
30 + 10	440 a	205 a	346 a	252 a	311 a
50 + 10	331 b	168 b	254 b	189 b	235 b
70 + 10	285 b	141 c	243 b	169 c	209 c
	Pruning weight (kg/vine)				
30 + 10	1.36 a	1.59 a	1.57 a	1.32 a	1.43 a
50 + 10	1.30 a	1.46 a	1.46 a	1.33 a	1.39 a
70 + 10	1.25 a	1.30 a	1.13 b	1.18 a	1.21 b

[z]Means within pruning severity and year separated by Duncan's multiple range test, 5% level.

Table 3. Main effects of nodes/bearing unit on yield, yield/node and pruning weight of 'Niagara' grapevines for 4 years.

Nodes/bearing unit	Year 1977	1978	1979	1980	4-year mean
	Yield (MT/ha)				
3	24.7 a[z]	11.8 b	22.8 a	14.7 a	18.5 b
6	25.2 a	13.6 ab	24.3 a	16.5 a	19.9 a
9	24.7 a	14.1 a	23.0 a	15.2 a	19.2 a
	Yield (g)/node				
3	357 a	152 b	269 a	189 b	241 a
6	360 a	172 ab	285 a	210 a	257 a
9	339 a	190 a	290 a	210 a	257 a
	Pruning weight (kg/vine)				
3	1.43 a	1.65 a	1.63 a	1.43 a	1.53 a
6	1.29 ab	1.57 a	1.41 a	1.28 ab	1.39 b
9	1.19 b	1.12 b	1.02 b	1.13 b	1.12 c

[z]Means within nodes/bearing unit and year separated by Duncan's multiple range test, 5% level.

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Table 4. Main effect of training system on the yield, yield/node and pruning weight of 'Niagara' grapevines for 4 years.

Training system	Year 1977	1978	1979	1980	4-year mean
			Yield (MT/ha)		
BC[y]	22.5 b[z]	12.9 a	21.1 b	14.0 b	17.6 b
GDC	27.2 a	13.4 a	25.7 a	17.0 a	20.8 a
			Yield (g)/node		
BC	347 a	166 a	262 b	194 b	242 b
GDC	257 a	176 a	299 a	212 a	261 a
			Pruning weight (kg/vine)		
BC	1.38 a	1.43 a	1.44 a	1.30 a	1.39 a
GDC	1.22 a	1.47 a	1.27 a	1.25 a	1.30 a

[z]Means within training system and year separated by Duncan's multiple range test, 5% level.
[y]BC = bilateral cordon, GDC = Geneva Double Curtain.

Table 5. Main effect of shoot positioning on the yield, yield/node and pruning weight of 'Niagara' grapevines for 4 years.

Shoot positioning	Year 1977	1978	1979	1980	4-year mean
			Yield (MT/ha)		
Not positioned	23.9 a[z]	11.9 b	23.3 a	15.3 a	18.6 b
Positioned	25.8 a	14.4 a	23.5 a	15.6 a	19.8 a
			Yield (g)/Node		
Not positioned	331 b	157 b	250 b	189 b	242 b
Positioned	372 a	186 a	312 a	217 a	262 a
			Pruning weight (kg/vine)		
Not positioned	1.28 a	1.92 a	1.82 a	1.39 a	1.60 a
Positioned	1.32 a	0.98 b	0.89 b	1.17 b	1.09 b

[z]Means within training system and year separated by Duncan's multiple range tests, 5% level.

Effect of shoot positioning. Shoot positioning tended to increase yields each year of the study, but yields were increased significantly only during the 2nd year and for the 4-year mean (Table 5). Shoot positioning consistently increased the yield/node and decreased pruning weights during the final 3 years of the study and for the 4-year mean.

Interactive effects. The interaction of training system × shoot positioning was significant for the 4-year means for both yield and pruning weight (Fig. 1). Shoot positioning improved yields only on BC trained vines (Fig. 1), probably due to the crowded condition and excessive shading that existed when large numbers of spurs or canes were left on the 2.4 m bearing surface of the BC trained vines, as compared to 4.8 m bearing surface for the GDC trained vines. When 'Niagara' grapes are produced on a GDC training system, there would be no advantage of shoot positioning the vines if they are no larger than those in this study (about 1.5 kg pruning weight per vine). More vigorous vines probably would respond to shoot positioning on the GDC system. Pruning weight difference between shoot positioned and nonpositioned vines was greater with the BC system than with the GDC system (Fig. 1). This difference again could be explained by the crowded condition of fruiting units on the BC trained vines, or by the fact that BC vines responded to shoot positioning with fruitfulness and yield increases. The increased yield would tend to decrease vine size.

A significant 3-way interaction of training system × pruning severity × nodes bearing unit showed that the 3-node spurs on

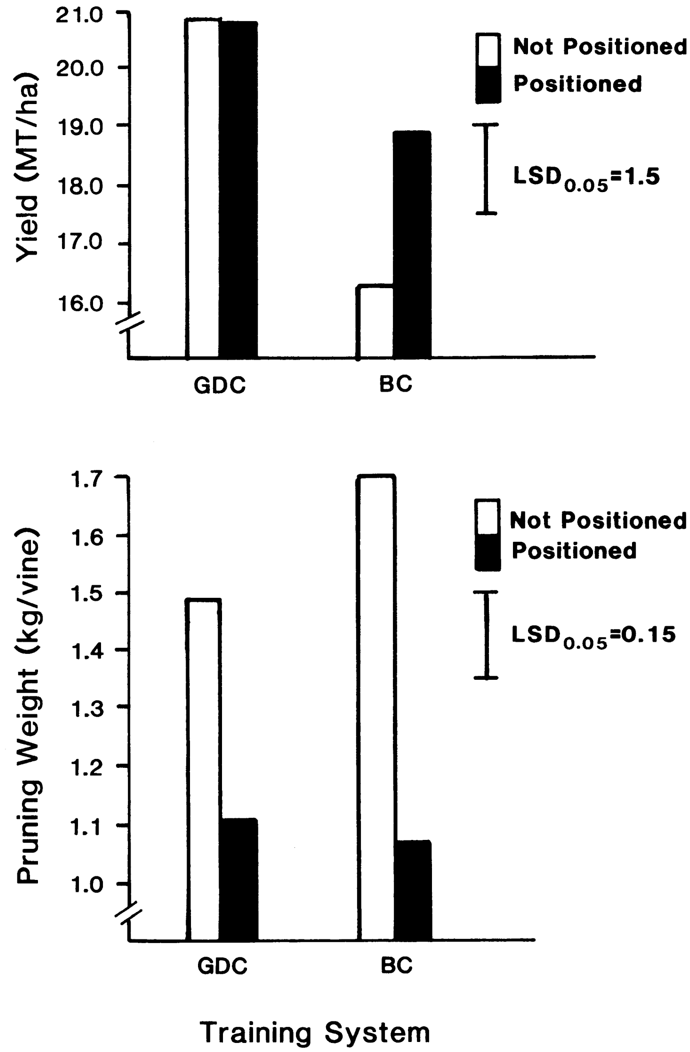

Fig. 1. Interactive effects of training system × shoot positioning on the yield and pruning weight of 'Niagara' grapes (4-year means).

the GDC training system were as productive as the 6- and 9-node canes under all pruning severities. However, the 3-node canes on the BC training system pruned to 30 + 10 or 50 + 10 were not as productive as the 6- and 9-node canes, either in total yield or yield/node (data not shown).

Fruit quality

Effect of pruning severity. Pruning severity did not have a significant effect on the percentage of soluble solids, pH, or acidity of the fruit on the final year (Table 6). However, the 4-year means showed that decreasing pruning severity to 50 + 10 or 70 + 10 reduced the percentage of soluble solids slightly (Table 7). The 70 + 10 pruning severity also increased fruit acidity and reduced pH more than the 30 + 10 treatment for the 4-year means. The 30 + 10 pruning severity produced slightly darker colored fruit (reduced CDM 'L' values) both for the final year and the 4-year means (Tables 6 and 7). On the basis of 4-year means the quality attributes of fruit from the 30 + 10 treatment indicate that these fruit were slightly more mature than those from the other pruning severities, but this difference was not evident in data of the final year of the study.

Effect of nodes/bearing unit. The 3 node spurs produced fruit with a higher percentage of soluble solids, slightly higher pH, and slightly lower acidity than the 6 and 9 node canes for the

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Table 6. Main effects of pruning severity, nodes/bearing unit, training system and shoot positioning on quality of 'Niagara' grapes at harvest, 1980.

Main effect	Soluble solids (%)	pH	Acidity (% tartaric)	CDM 'L'
Pruning severity				
30 + 10	13.8 a[z]	3.60 a	0.68 a	30.4 b
50 + 10	13.1 a	3.65 a	0.68 a	31.6 a
70 + 10	13.4 a	3.62 a	0.69 a	32.3 a
Nodes/bearing unit				
3	14.3 a	3.65 a	0.65 b	31.0 a
6	13.4 b	3.62 ab	0.68 b	31.0 a
9	12.5 c	3.59 b	0.72 a	32.3 a
Training system				
BC	13.8 a	3.65 a	0.67 b	30.8 b
GDC	13.1 b	3.60 b	0.70 a	32.1 a
Shoot positioning				
Not Positioned	13.4 a	3.66 a	0.66 b	31.9 a
Positioned	13.4 a	3.59 b	0.71 a	30.9 a

[z]Means within main effect separated by Duncan's multiple range test, 5% level.

Table 7. Main effects of pruning severity, nodes/bearing unit, training system and shoot positioning on quality of 'Niagara' grapes, 4-year mean.

Main effect	Soluble solids (%)	pH	Acidity (% tartaric)	CDM 'L'
Pruning severity				
30 + 10	14.4 a[z]	3.61 a	0.68 b	30.7 b
50 + 10	13.9 b	3.61 a	0.69 ab	31.3 a
70 + 10	13.7 b	3.57 b	0.70 a	31.5 a
Nodes/bearing unit				
3	14.6 a	3.63 a	0.67 b	31.0 b
6	13.9 b	3.58 b	0.69 a	30.9 b
9	13.6 b	3.58 b	0.71 a	31.6 a
Training system				
BC	14.3 a	3.61 a	0.68 b	31.0 a
GDC	13.7 b	3.59 a	0.70 a	31.3 a
Shoot positioning				
Not positioned	14.0 a	3.63 a	0.68 b	31.4 a
Positioned	14.1 a	3.56 b	0.70 a	30.9 b

[z]Means within main effect separated by Duncan's multiple range test, 5% level.

4-year means (Table 7). These trends in quality also were present the final year of the study (Table 6). The 9 node canes produced fruit that was slightly lighter in color (higher CDM 'L') than fruit from 3 node spurs and 6 node canes for the 4-year means (Table 7), but this slight difference in color was not significant the final year of the study (Table 6).

Effect of training system. BC training produced fruit with a higher percentage of soluble solids and lower acidity than did GDC during the final year of the study and for the 4-year means (Table 6 and 7), which was probably due to yield differences (Table 4). Training system did not affect fruit pH or color for the 4-year mean, but the pH was lower and the fruit was lighter in color (higher CDM 'L') on the GDC trained vines as compared to the BC trained vines the final year of the study (Table 6).

Effect of shoot positioning. Shoot positioning had no effect on the percentage of soluble solids of the fruit, but decreased pH and increased acidity for the final year of the study as well as for the 4-year means. The shoot positioned fruit were slightly darker in color than the nonpositioned fruit as indicated by the slightly lower CDM 'L' values for the 4-year means (Table 7).

Interactive effects. The significant interactive effects of training system × shoot positioning for the 4-year mean indicate that shoot positioning lowered the CDM 'L' values (darker colored fruit) only on BC trained vines (Fig. 2), indicating that shading of the fruit was more of a problem in the BC vines. The few other interactions that were significant (Table 1) were irrelevant to the interpretation of the results.

Changes in pH and acidity. Linear regression analyses across all years and all experimental variables show the relationship to acidity and pH to soluble solids (Fig. 3). The correlation between acidity and the percentage of soluble solids ($r = 0.66$) was slightly better than pH and the percentage of soluble solids ($r = 0.59$), although both correlations were highly significant. These data indicate that acidity declines rapidly and pH increases rapidly under Arkansas growing conditions if harvest is delayed until the percentage of soluble solids reaches the 16% range. In general, a percentage of soluble solids level of approximately 14% would be about maximum in order to have an acceptable pH and acidity range.

The rates of change in fruit acidity were related to the de-

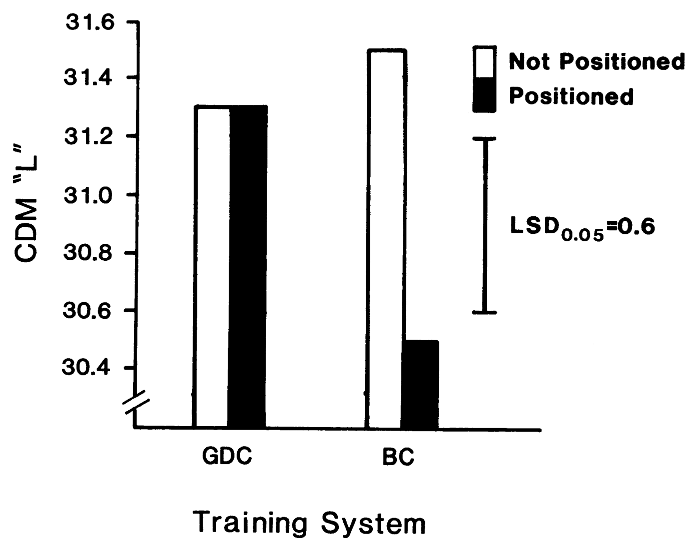

Fig. 2. Interactive effects of training system × shoot positioning on the CDM 'L' values of 'Niagara' grapes (4-year mean).

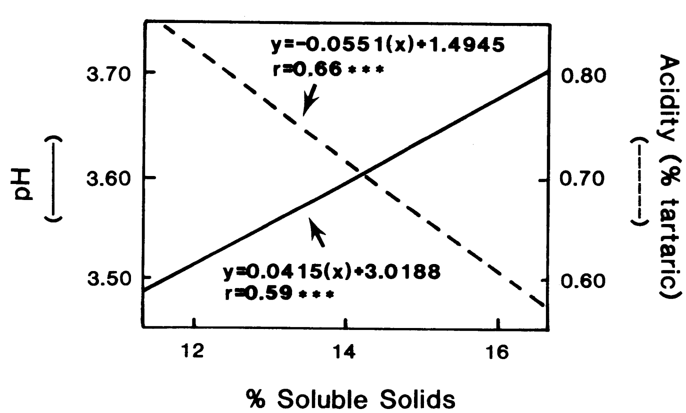

Fig. 3. Relationship between the percentage of soluble solids, pH and acidity of 'Niagara' grapes for 4 years.

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velopment of soluble solids for each of the experimental variables for the final year of the study (Fig. 4 and 5). As soluble solids increased, the acidity of fruit from the 30 + 10 pruning severity dropped faster than that of fruit from the other 2 pruning treatments (Fig. 4). Fruit from the 9 node canes maintained higher acidity than the 3 node spurs or the 6 node canes at all levels of soluble solids (Fig. 4). The fruit from the GDC training system and the fruit from the shoot positioned vines had increased acidity at any given level of soluble solids (Fig. 5).

Conclusions

Heavy fruit loads did not suppress yields until the 4th year of the study, but did result in a consistent reduction in node fruitfulness. There was a tendency for the 70 + 10 pruning severity to reduce vine vigor. The 3 node spurs were not as productive as the 6 and 9 node canes. The 9 node canes produced lower pruning weights than the 3 or 6 node treatments. During the 3 high yielding years of the study GDC training produced higher yields than BC, but there was no effect of training system on pruning weight. This suggests that the GDC system was more efficient in maintaining vine vigor than the BC system while producing higher yields. Shoot positioning increased yields by increasing the node fruitfulness. Shoot positioning was more effective in increasing yield of BC trained vines as compared to GDC trained vines, and this was probably due to the shading effect on the BC trained vines.

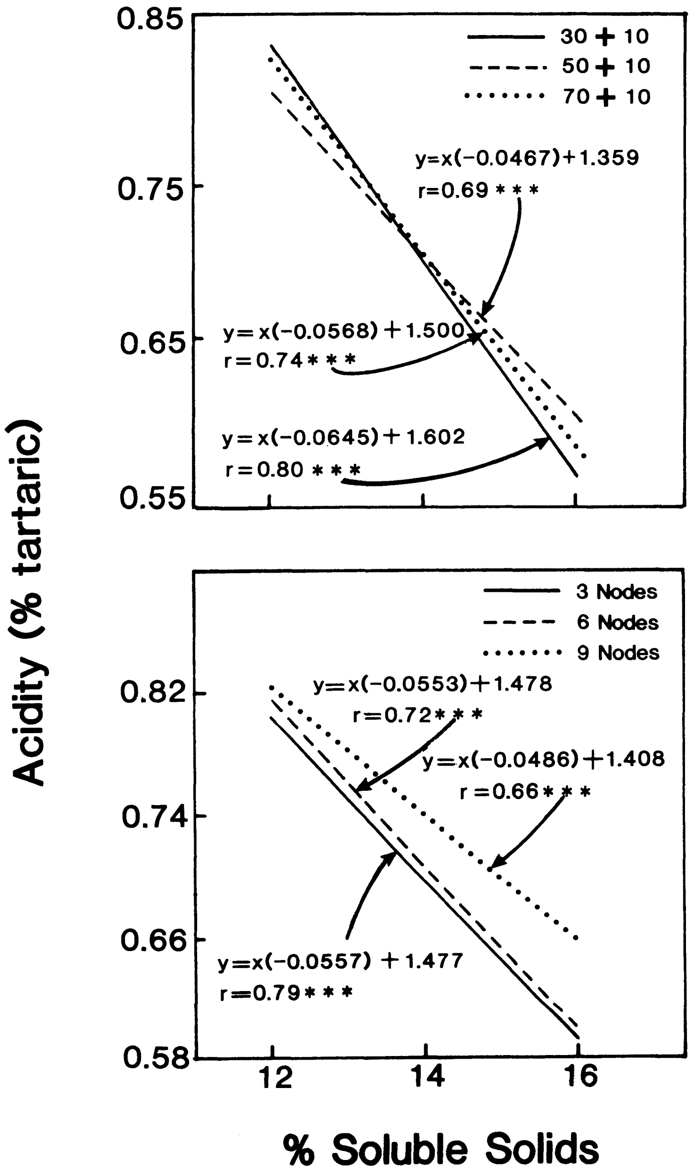

Fig. 4. The relationship of juice acidity to development of the percentage of soluble solids in 'Niagara' grapes as affected by pruning severity and nodes/bearing unit during the final year (1980).

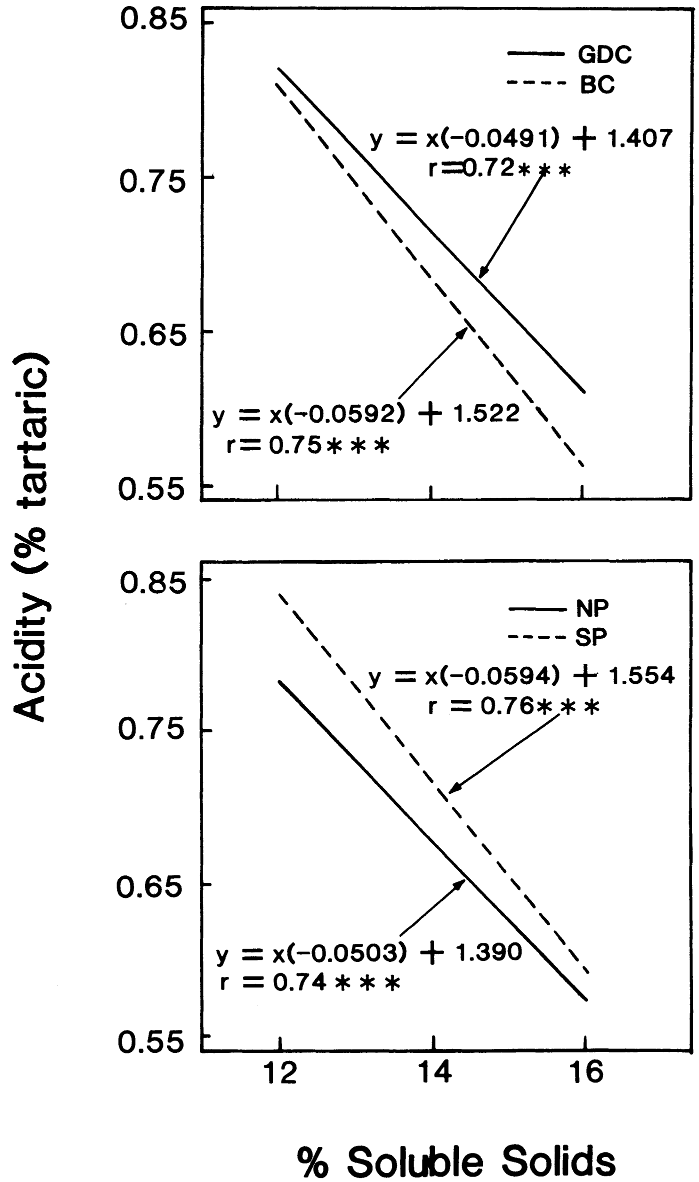

Fig. 5. The relationship of juice acidity to development of the percentage of soluble solids in 'Niagara' grapes as affected by training system and shoot positioning during the final year (1980).

None of the variables had a great effect on quality. However, the heavier fruit loads resulted in fruit with a slightly lower percentage of soluble solids, lower pH, higher acidity, and lighter color. The BC training system produced fruit with a higher percentage of soluble solids and slightly lower acidity than the GDC training system, probably as a result of low yields on the BC system. Shoot positioning the vines resulted in fruit with lower pH, slightly higher acidity, and darker color. Shoot positioning improved color to a greater extent on BC trained vines than on GDC trained vines.

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