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*'Niagara' (*Vitis labruscana *Bailey) vines were evaluated for 4 years, from 2000 to 2003 in a commercial vineyard in Scottdale, MI. Vines were trained as Hudson River Umbrella (HRU), umbrella Kniffen (UK), and Hybrid (HYB) and pruned for 4 years at four pruning levels (20, 40, 80, or 120 nodes/vine) and minimally pruned or hedge pruned mechanically. Node levels above 80 nodes decreased several yield components, such as cluster and berry weight. Reduction in yield and sugar components was obtained with pruning levels above 80 nodes per vine and related to a decrease in cluster and berry weight as well as a decrease in bud fruitfulness (productivity index). As number of nodes retained increased, vine size, cluster weight, berry weight, percent soluble solids, and pH decreased, while yield, cluster number, and leaf area at veraison increased. Yield components, vine size, and productivity were optimum at 20 and 40 nodes retained, but these node levels produce unacceptable low yields for economically viable juice grape production in Michigan. Therefore, retaining 80 fixed nodes produced sustainable production, without compromising vine health or long-term vineyard sustainability. There were no differences between HRU, UK, and HYB on vegetative or reproductive parameters or on fruit composition. Thus, the choice of training system—HRU, UK, or HYB—should be based on specific grower and vineyard needs.*

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KEYWORDS juice grape, head trained, cordon trained, mechanical edging, minimal pruning

INTRODUCTION

Concord and Niagara (*Vitis labruscana* Bailey) are the most widely cultivated grape cultivars in Michigan, where they account for 64% and 24% of the total area dedicated to grapes, respectively (USDA-NASS, 2012). In 2010, 49% of the United States hectares of 'Niagara' grapes were in Michigan due to a National Grape Cooperative program that subsidized part of the planting costs for Michigan juice grape growers. From 1996 to 2001, due to this program, the hectares of 'Niagara' grapes increased by about 800 ha (+73%) reaching a plateau of 1422 ha in 2006 (USDA-NASS, 2012). Unfortunately, the cost of juice grape production is increasing and currently juice grape prices are below the break-even point for several Michigan growers. In general, grape grower's revenues are maximized when high yields above the minimum acceptable juice soluble solids are obtained every year (Bates and Morris, 2009). However, under cool climate conditions, the interaction between grapevine and environment often limits yield and balance between vegetative and reproductive growth is essential to sustain high production and fruit quality without compromising the health of the vine. High yield per vine of ripe fruit, without compromising vine health, is a goal in viticulture and vine balance is a pivotal tool to achieve quality production, sustainable over many years at a cost that returns a net profit to the growers (Howell, 2001). Smart and Robinson (1991) described vine balance as an equilibrium between vegetative growth and fruit load that would encourage high fruit quality. In the early 1900s, Ravaz (1911) described vine balance as an annual assessment of the mass ratio of fruit to vegetative growth that has since become known as the Ravaz Index (RI). Smart and Robinson (1991) suggested a 5:1 to 10:1 ratio as optimal for moderate vigor vines. *Vitis labruscana* Bailey (Bailey, 1917), being more vigorous, would fall at the higher end of the RI suggested for wine cultivars (Kliewer and Dokoozlian, 2005). Over-cropped vines tend to decrease yield after several years because of reduced bud fruitfulness (Miller et al., 1993; Morris et al., 1984) and reduced fruitfulness can be related to poor light penetration into the canopy and/or vine photoassimilate production and allocation (Koblet et al., 1994; Petrie et al., 2000). Over-cropped vines also exhibit source limitation by delayed fruit maturity and/or reduced percent soluble solids (Morris et al., 1984; Shaulis et al. 1966; Winkler, 1954). In contrast, vines severely pruned can become out of balance resulting in excessive carbohydrate partitioning into vegetative growth. Shaulis et al. (1966) and Miller et al. (1993) found that severe pruning caused under-cropping, which resulted in excessive vegetative growth, leading to within-canopy shading, reducing cluster size and number, compromising cold hardiness, and delaying fruit maturity.

The objective of this work was to investigate the differences between training systems and how they affect yield, vegetative growth, and fruit composition in 'Niagara' grapevines grown for juice grape production. Further, we evaluated the effect of node number per vine on yield, vegetative growth, fruit composition, and vine balance.

MATERIAL AND METHODS

Plant Material

The experiments were conducted in Scottdale, southwest Michigan, 8 km east of Lake Michigan (N 42.08, W 86.35; elevation: 220 m). Treatments were established in May 1999, and measurements were taken for 5 years (1999 to 2003). The vineyard was established in 1974 (2.4 × 3.0 m within and between rows, respectively) on a well-drained Coupee silt loam (NRSC, 2005) with a soil depth in excess of 2 m and a surface soil pH of 5.7 and 1.5% of organic matter. Vines were own-rooted and trained initially to a Four-Arm Kniffen with double trunks and pruned to 70–80 nodes. Trellis height was 1.8 m. Recommended crop protection practices were followed and the pest management program was based on scouting, experience, and weather conditions (Wise et al., 2008). A combination of fungicides and insecticides used for control were rotated to avoid resistance. Post-bloom nitrogen (66 kg $\times$ ha^{-1}) was applied as calcium nitrate or ammonium nitrate every year. In December of each year 333 kg $\times$ ha^{-1} of potassium was also applied. No irrigation or summer vine canopy management was provided. Pertinent temperature data were recorded by an automated weather station located on the site 200 m from the experimental vineyard.

Experimental Design and Treatments

Training and pruning treatments were arranged in a 3 × 4 randomized block split-plot design, with training systems as main plots. The main factors consisted of three single-curtain training systems—Hudson River Umbrella (HRU), Umbrella Kniffen (UK), and Hybrid (HYB)—common training systems for Niagara grapevines in Michigan (Howell et al., 1991). HRU is a high (1.8 m) cordon system with 8-node canes for fruiting and 2-node spurs for renewal (Koblet et al., 1994). UK is a high (1.8 m) head-trained system with 15–20 node canes and two to four 2-node renewal spurs at the head (Shaulis and Lemon, 1982). HYB is a high cordon system that also retains one to three long canes arising at the head, often replaced when damaged by mechanical harvesters. Sub-plots consisted of four randomized pruning categories (20, 40, 80, or 120 nodes per vine at dormant pruning).

In addition, a randomized block design experiment with two high node treatments, minimally-pruned (MP) and hedged (HGD), and trained to HRU, was included to investigate simulated mechanical pruning approaches in high cordon trained vines (1.8 m). The MP treatment was established by hand-trimming growth at 76 cm below the cordon wire. The HGD treatment was simulated by hand-removing all growth beyond a 15-cm radius around the cordon wire. Each training system treatment (HRU, UK, HYB) consisted of 12 vines, replicated 4 times and the subplot factor (pruning categories: 20, 40, 80, 120) consisted of 3 vines replicated 4 times for each training system. The minimally-pruned treatments (MP and HGD) consisted of three vines replicated four times. In case of missing data, averages of vine replicates were used and error degrees of freedom in the ANOVA penalized as described in Cochran and Cox (1992).

Node Numbers and Vine Size

The vines were hand pruned in mid-December during the 5 years of data collection and nodes retained were counted at the time of winter pruning. Winter cold and spring freeze damage was assessed at node level, and viability or mortality was noted for each vine and each bud and these data were used to calculate the viable buds remaining on the vines (live nodes or nodes retained). The weight of dormant cane prunings from each vine was used as an index of vegetative seasonal growth. However, pruning weights on hedged and minimally pruned vines cannot be compared with traditionally pruned vines for the purpose of estimating vine size; therefore, leaf area per vine was used.

Leaf Area Measurements

Leaf area was estimated at three phenological stages during the growing season: (1) bloom (LA-bloom), (2) 650 (base 10°C) growing degree-days (LA-650), and (3) veraison (LA-Ver). LA-bloom was estimated by measuring the length of three tagged shoots per vine in the vineyard. Fifteen shoots representing different lengths also were collected weekly from guard vines from bud break to veraison and taken to the laboratory for leaf area measurements using a LI-3100 area meter (Li-Cor, Inc., Lincoln, NE, USA). The linear relationship was used to estimate leaf area on tagged shoots ($y = 21.18 \times -133.79$, $R^2 = 0.86$). Leaf area per shoot was multiplied by the shoot number to obtain leaf area per vine. LA-650 and LA-Ver were estimated by the measured surface area of the vine's canopy and multiplied by 1.5 photosynthetic leaf layers (Smart and Robinson, 1991). The treatment comparison analysis was based on LA-Ver because the amount of leaf area from veraison to harvest was deemed crucial to the maturation of fruit as well as to carbohydrate accumulation and partition to the storage organs (Edson et al., 1995).

Yield Measurements

Yield was measured at harvest on a weight per vine basis, and cluster number per vine counted. Samples of 50 random berries per replicate were also collected and weighed at harvest for each treatment and mean berry weight per vine calculated. These yield and berry weight values were used to calculate cluster weight and berries per cluster, respectively. Calculation of the fruitfulness parameter (yield/nodes retained) was used to determine the amount of fruit an average node produced. The Ravaz Index (RI) was used to describe the ratio of reproductive to vegetative growth (yield/vine size) that occurred over the season thereby providing a post-season assessment of vine balance (Howell, 2001).

Fruit Composition Measurements

Chemical composition of fruit was analyzed on the 50-count berry sample per replicate taken on the day of harvest and frozen for later analysis. Prior to analysis, berries were thawed at 24°C for 24 h. Grape juice soluble solids (°Brix) were measured using a NAR IT Atago (Kirkland, WA, USA) refractometer and pH was measured using a 370 Thermo Orion (Beverly, MA, USA) pH meter. An automatic titrator, coupled to an autosampler and control unit (Titroline 96, Schott, Germany) was used to determine titratable acidity.

Statistical Analysis

Basic statistics, analysis of variance, and correlation analysis were performed using PROC MIXED in SAS (version 9.1.3; SAS Institute Inc., Cary, NC, USA) and Sigma Plot (version 10; SPSS, Chicago, IL, USA). Results were tested for homogeneity of variance and subjected to three-way (training system × node number × year) analysis of the variance (ANOVA). The effects of training system and training system × pruning category interactions were not significant ($P < 0.05$) during the 5 experimental years for economically important parameters: vine size, yield per vine, and soluble solids. Therefore, treatments comparison was performed using the LSD test. Selected parameters were subjected to correlation analysis, and linear and polynomial curves were fitted using the best-fit analysis in the dynamic fit wizard option package of Sigma Plot. Correlations were performed combining individual vine data for each parameter collected during the 5 experimental years. By combining 5 years of data, precision was increased allowing for greater discrimination of vine response to treatment (Cochran and Cox, 1992).

RESULTS AND DICUSSION

The 5-year average GDD (base 50°F) accumulation for the period 1 Apr. to 31 Oct. during the 5 experimental years was 2806 GDD (Fig. 1). The

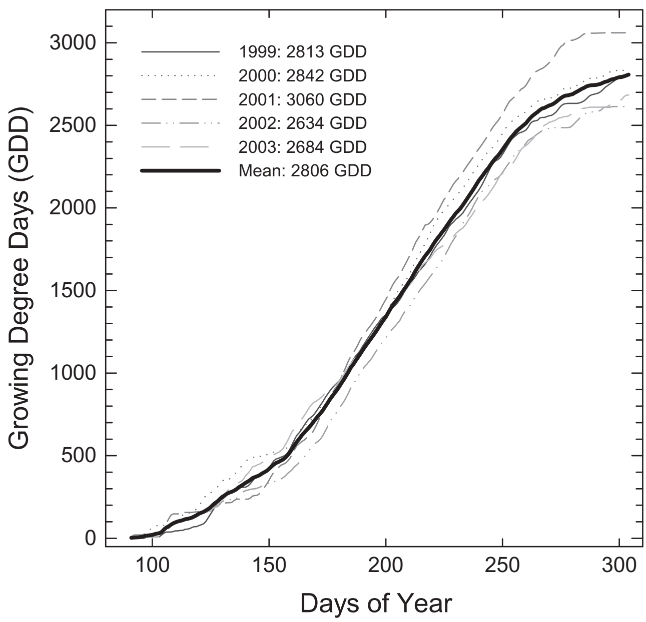

FIGURE 1 Growing degree days (GDD) accumulation (base 50°F) in Scottdale (MI) from 1 Apr. to 31 Oct. during the 5 experimental years (1999–2003) calculated as described by Baskerville and Emin (1969).

individual seasonal GDD accumulation indicated variation from the 5-year average (mean 2806 GDD, sd 166 and cv 6%). The warmest growing season was 2001 (+253 GDD from the 5-year average) and the coolest 2002 (−173 GDD from the 5-year average). The season length (from bloom to the first fall frost) was less variable then the seasonal heat accumulation from 1999 to 2003. The season length was 152 ± 6.5 d during the 5 experimental years and not significantly correlated to the GDD accumulation ($y = -14.76x + 3804.8$, $r^2 = 0.31$).

There were no differences between HRU, UK, and HYB in the 5-year average of seasonal measurements (Table 1). Single season data revealed soluble solids in 2000 and 2001 to be the only difference among the training systems in 5 years (data not shown). Alternatively, the remaining years did not follow similar trends and therefore treatment differences cannot be concluded. The difference between soluble solids was ±0.1 (Table 2), which was not considered viticulturally meaningful since the acceptable range of soluble solids for 'Niagara' juice production is between 12 to 14 °Brix (Howell et al., 1982). All of the training systems reached this range. Therefore, these training systems were not considered to produce differences in seasonal vegetative growth and fruit maturation. This finding is supported by other reports as well (Howell et al., 1991).

TABLE 1 Training System Treatments: Reproductive, Vegetative Measurements, and Calculations of Niagara Grapevines Averaged over 5 Years (1999–2003) and over All Node Numbers Retained at Pruning (20, 40, 80, and 120)

	Training system			
Measured or calculated	UK	HRU	HYB	*P*-value
Nodes retained[u]	55	54	55	ns
Vine size (kg)[v]	1.03	1.10	0.99	ns
Yield (kg/vine)	11.20	10.43	11.29	ns
Yield (t/ha)	6.73	6.27	6.76	ns
Clusters/vine	116	105	108	ns
Cluster weight (g)	108	108	109	ns
Berries/cluster	30	30	30	ns
Ravaz Index[w]	24	24	26	—
Fruitfulness (kg/node)[x]	0.24	0.23	0.25	ns
Leaf area ver. (m^2)[y]	10.0	10.7	10.5	ns
LA/fruit (cm^2/g)[z]	9.01	10.22	9.31	ns

[z]LA/fruit = leaf area per gram of fruit expresses a ratio of vegetative to reproductive growth. In Michigan ~11–14 cm^2/g is optimum (Miller et al., 1993).
[y]Leaf area ver. = leaf area at veraison was used to estimate a component of vegetative growth. The amount of leaf area at veraison is important because at this stage the vine is the most source limited.
[x]Fruitfulness = yield [kg]/nodes retained.
[w]Ravaz Index = yield [kg]/post-season vine size (1-year old pruning weight) [kg].
[v]Vine size = weight of dormant cane pruning per vine.
[u]Nodes retained = number of nodes per vine established during dormant pruning.

TABLE 2 Training System Treatments: Fruit Composition Measurements of Niagara Grapevines Averaged over 5 Years (1999–2003) and over All Node Numbers Retained at Pruning (20, 40, 80, and 120)

	Training system			
Parameter	UK	HRU	HYB	*P*-value
Berry weight (g)	3.58	3.59	3.60	ns
Soluble solids (°Brix)	14.6	14.5	14.6	ns
Soluble solids/vine	1.55	1.45	1.57	ns
pH	3.31	3.35	3.33	ns
Titratable acidity (g/L)	6.40	6.42	6.39	ns

Unlike the comparison of training systems, node levels impacted all measured parameters when analyzed by mean separation (Table 3). The higher level of significance associated with this treatment variable was anticipated because vines are highly responsive to pruning severity (Howell et al., 1991; Morris et al., 1984; Shaulis et al., 1966). In general, as number of nodes increased, yield increased and soluble solids and vine size decreased (Table 4). Correlation analysis showed that the yield increased as nodes retained increased, but the polynomial curve ($y = -0.0013x^2 + 0.2706x + 1.1331$) suggests that the yield increase plateaus beyond 80 nodes retained

TABLE 3 Comparison of Reproductive and Vegetative Measurements and Calculations of Niagara Grapevines Subjected to Different Node Level Treatments per Vine Averaged over 5 Years (1999–2003) and over Three Training System Treatments (HRU, UK, and HYB)

	Node level				Minimally pruned	
Measured or calculated	20	40	80	120	HGD	MP
Nodes retained[u]	19f[t]	38e	70d	92c	99b	117a
Vine size (kg)[v]	1.45a	1.30b	0.80c	0.62d	—	—
Yield (kg/vine)	6.14d	8.95c	13.73b	15.07ab	15.42a	14.59ab
Yield (t/ha)	3.96d	5.38c	8.25b	9.06ab	9.27a	8.77ab
Cluster/vine	57d	93c	134b	155a	155a	166a
Cluster weight (g)	113a	109a	108a	104a	105a	99a
Ravaz Index[w]	5.93	11.28	30.11	50.80	—	—
Fruitfulness (kg/node)[x]	0.34a	0.23b	0.20bc	0.17cd	0.18cd	0.15d
Leaf area ver. (m^2)[y]	9.0b	10.3ab	11.0ab	11.2ab	10.8ab	12.1a
LA/fruit (cm^2/g)[z]	20.3a	15.7b	10.8c	10.2c	10.0c	11.6c

[z]LA/fruit = leaf area per gram of fruit expresses a ratio of vegetative to reproductive growth. In Michigan ~11–14 cm^2/g is optimum (Miller et al., 1993).
[y]Leaf area ver. = leaf area at veraison was used to estimate a component of vegetative growth. The amount of leaf area at veraison is important because at this stage the vine is most source limited.
[x]Fruitfulness = yield [kg]/nodes retained.
[w]Ravaz Index = yield [kg]/post-season vine size [kg].
[v]Vine size = weight of dormant cane pruning per vine.
[u]Nodes retained = number of nodes per vine established during dormant pruning.
[t]Means in a row followed by the same letters are not significantly different by LSD test.

TABLE 4 Comparison of Basic Fruit Composition Measurements of Niagara Grapevines Subjected to Different Node Level Treatments per Vine Averaged over 5 Years (1999–2003) and over Three Training System Treatments (HRU, UK, and HYB)

	Node level				Minimally pruned	
Parameter	20	40	80	120	HGD	MP
Berry weight (g)	3.7a[x]	3.7a	3.6b	3.4cd	3.5bc	3.3d
Soluble solids (°Brix)	15.6a	15.0b	13.8c	13.8c	13.5c	13.7c
Soluble solids/Vine	0.94d	1.32c	1.84b	1.99ab	2.01a	1.93ab
pH	3.35ab	3.38a	3.31bc	3.29c	3.27c	3.27c
Titratable acidity (g/L)	6.4a	6.5a	6.4a	6.3a	6.4a	6.2a

[x]Means in a row followed by the same letters are not significantly different by LSD test.

TABLE 5 Correlation Values of Measured and Calculated Parameters (1999–2003) vs. Number of Nodes Retained

Measured or calculated[z]	Correlation coefficients (r)[y]	Coefficient significance
Vine size (kg)	0.98[L]	***
Yield (kg/vine)	0.99[P]	***
Yield (t/ha)	0.99[P]	***
Clusters/vine	0.88[L]	**
Cluster weight (g)	0.82[L]	ns
Berry weight (g)	0.90[L]	**
Soluble solids (°Brix)	0.98[P]	***
Soluble solids/vine	0.90[P]	***
pH	0.92[L]	*
Titratable acidity (g/L)	0.82[L]	ns
Fruitfulness (kg/node)	0.92[P]	***
Leaf area ver. (m^2)	0.83[L]	**
LA/fruit (cm^2/g)	0.88[P]	*

[z]See Table 1 for details.
[y]Coefficient significance: *, **, ***, ns indicate significance at $p > 0.5$, 0.01, 0.001, and not significant, respectively. Coefficients for linear (L) or polynomial (P) best fit analysis of measured or calculated parameters (averaged over 5 experimental years) against number of nodes retained.

(Table 5). The three highest node levels (120, H and MP) did not produce different yields by correlation analysis or mean separation (Tables 3 and 5). Yield limits have been reported in other studies where reduced fruitfulness, influenced by both berries per cluster and berry weight, contributed to the limited yield (Miller et al., 1993; Morris et al., 1984). In this experiment fruitfulness decreased from 0.34 to 0.17 kg/node in 20 and 120 nodes retained, respectively (Table 3). A 50% fruitfulness reduction in combination with reduced cluster weight and berry weight contributed to significant yield loss as number of nodes retained increased. Retaining more than 80 nodes per vine produced a 29% average increase of cluster number over the 20- and 40-node treatments but also produced a 67% decrease of cluster weight, which compromised the potential yield increase. Nevertheless, the yield increase was the result of more clusters per vine as nodes retained increased. Consequently, the positive linear relationship (Table 5) between nodes retained and cluster number per vine ($y = 21.49x + 51.48$) did not result in larger yields probably due to the negative relationship between number of nodes and cluster weight ($y = -2.57x + 115.29$). The decrease in cluster and berry weight was primarily responsible for limiting the yield as node level increased. Internal canopy shading in less severely pruned vines, like 120, H, and MP, may also contribute to a yield loss due to reduced fruitfulness, which decreased as node numbers increased (Table 3). While not estimated in this study, leaf layer number was easily perceived visually for the 120, MP, and H treatments and was commonly four layers or more, suggesting the presence of internal canopy shading (Koblet et al., 1994; Petrie et al., 2000). Vines with node levels above 80 did not have higher bud fruitfulness, and the fruitfulness curve leveled off as the relationship between nodes retained and bud fruitfulness diminished.

Soluble solids decreased from 15.6 to 13.8 °Brix as the nodes retained increased from 20 to 120, respectively (Table 4). The two minimally pruned treatments, simulating mechanically pruned vines, reported low soluble sugar levels in this experiment (≈13.6 °Brix) not statistically different from the 80- and 120-node level treatments. pH and titrable acidity (TA) showed no relationship to yield. Moreover, the relationship between Brix and yield plateaued at ≈80 nodes retained ($y = 0.003x^2 - 0.0599 + 16.734$), suggesting the strong influence of yield on fruit soluble solids over 80 nodes retained per vine (Table 5). However, sugar accumulation indexed as soluble solids at all node levels retained was above or within processor standards, 12–14 °Brix. It appears possible that the vines with higher soluble solids (20 and 40 nodes retained) ripened fruit earlier in the season. Overall, HGD, MP, and 120-node vines were able to produce the most soluble solids per vine (Table 4) over all of the pruning systems. Soluble solids per vine were calculated as °Brix (%) multiplied by yield per vine (kg). Therefore, the high yield in the high node number treatments, coupled with °Brix within the desired composition range (12–14 °Brix), resulted in higher soluble solids per vine.

Vine size decreased as nodes retained increased (Table 3) as already extensively reported in the literature (Howell et al., 1991; Morris et al., 1984). In this study vine size (indexed as 1-year-old winter pruning weight) decreased ≈60% from 1.45 to 0.62 kg/vine in 20 and 120 nodes retained, respectively. Vine size was not used to express the vegetative growth of MP and HGD vines (Clingeleffer and Krake, 1992) and leaf area (LA) per vine was more appropriate. Correlation analysis (Table 5) showed LA at veraison increased linearly as nodes/vine increased ($y = 0.025x + 8.914$). However, leaf area did not increase significantly. It must be remembered that this measurement does not represent the total foliar canopy beyond 1.5 layers. Four to five leaf layers have been observed in 'Niagara' vines possessing high node numbers. However, the LA/fruit ratio was significantly decreased as the number of nodes retained with the winter pruning increased; above 80 nodes a ≈50% reduction in leaf area per gram of fruit was observed (Table 3). Nevertheless, this reduction was still in the optimum range of ~11–14 cm^2/g suggested for juice grape in Michigan (Miller et al., 1993).

CONCLUSION

Great Lakes viticultural regions must consider the impact of their cool climate on any cultural practices to achieve vine balance and highest sustainable yields (Howell, 2001; Jackson and Schuster, 2001). Cool climate conditions impact viticulture in several ways: winter freeze injury and spring frost damages, limited length of growing season, low sunlight intensity, and limited post-harvest time with foliage as a recovery period (early fall frost). Michigan's climate is characterized by a short growing season (150 to 175 frost-free days) with cool-climate conditions (1600 ± 300 GDD base 10°C or 2880 ± 540 GDD base 50°F) and yield and fruit quality are often limited by low winter temperatures, spring freeze (frost-free day May 15), early fall frost, with high humidity and rainfall during harvest season (Howell and Sabbatini, 2008). Seasonal weather conditions, analyzed as GDD, varied significantly during the 5 experimental years and despite this significant difference in heat accumulation, the growing seasons did not influence vine growth, yield, and fruit composition as much as did pruning strategy. There was no significant year effect, indicating that pruning strategies had a major impact on the response more than external environmental conditions. In fact, HRU, UK, and HYB vines produced similar vegetative and reproductive growth during the 5 years of the study (Tables 1 and 2) and those results could help juice grape growers in making training system decisions based on the "best fit" for their operation. UK training requires arching and tying of long canes for each vine, increasing time and labor cost for the grower. Moreover, UK canopies, arising from the head, also tend to be more crowded with basal nodes confined to a smaller area than HRU, which is able to spread growth out horizontally with the use of a cordon.

Contrarily, node levels above 80 fixed nodes resulted in a decrease in yield components but did not significantly affect overall yield (Fig. 2). Reduction in yield and sugar components above 80 nodes per vine (≈ +8%) can be attributed to a decrease in cluster and berry weight as well as a decrease in bud fruitfulness. Decreased fruitfulness was most likely a result of crowding and shading in the canopy (Smart and Robinson, 1991) and the shaded inner-canopy leaves produce few carbohydrates with a detrimental effect on fruit and shoot maturation (Sabbatini et al., 2012). The Ravaz Index (RI) in our study was above the optimum range of 5–10 (at 30–50) in the 80 and 120 nodes retained treatments and in the range of 6–12 for 20 and 40 nodes retained treatments, respectively (Table 3). The RI in the 80 and 120 nodes per vine may have been close to the upper limit

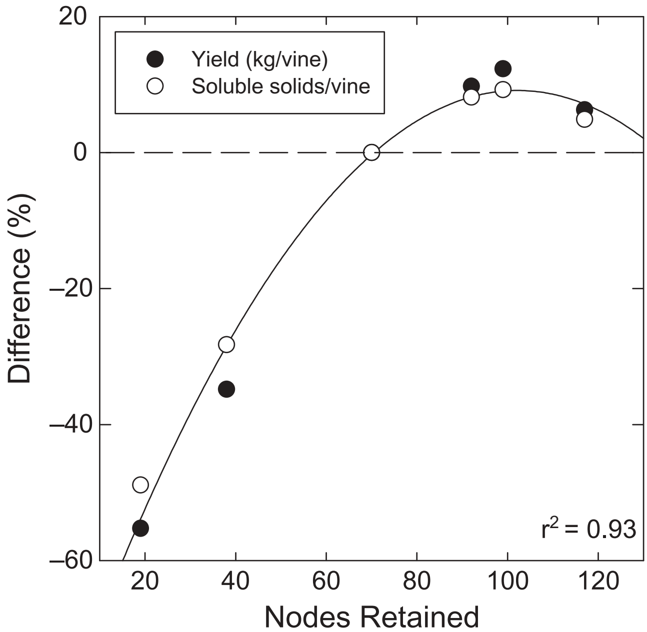

FIGURE 2 Variation (%) from 80-node treatment (equal zero) of yield (kg/vine) and soluble solids (°Brix) per vine of Niagara grown in Scottdale (southwest Michigan) from 1999 to 2003. The correlation indicates a plateau effect at just over 80 nodes retained with the winter pruning.

of the vine's capacity to fully ripen fruit and replenish storage reserves to maintain vine size, but leaf area per gram of fruit was in the optimum range of ~11–14 cm^2/g in all of the treatments (Miller et al., 1993).

Between 12–14 °Brix, 'Niagara' juice has balanced sugar and acid (Howell et al., 1982) yielding better juice qualities. This level was reached in all of the treatments applied in this 5-year study. Large vines could sustain considerably higher yields of quality fruit than could be achieved by classical balanced pruning and the effect of fertilization and summer canopy management to maximize fruit quality of high yielding Niagara vines may merit specific study.

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