Initial Response of 'Concord' and 'Sunbelt' Grapes to Pruning and Fruit Thinning

Justin Morris^{1,3}, Gary Main¹, Renee Threlfall¹, and Keith Striegler²

ADDITIONAL INDEX WORDS. mechanized, minimal, *Vitis labruscana*, lag phase, composition

SUMMARY. Balanced, dormant hand pruning was compared with minimal and machine box-cut pruning with no fruit thinning, thinning at 27 to 45 days postbloom, or thinning at veraison on *Vitis labruscana* grape cultivars, Concord and Sunbelt. Weekly berry weights measured during the growing season showed that minimally pruned 'Concord' and 'Sunbelt' generally had lower berry weights than hand-pruned vines. Lag phase occurred 50 ± 7 days postbloom in 'Concord' and 58 ± 7 days postbloom in 'Sunbelt'. The duration of harvest period was longer for 'Concord' than 'Sunbelt', and minimally pruned vines without thinning had the most delayed ripening regardless of cultivar or time of fruit thinning. The desired soluble solids of 17% for 'Concord' and 18% for 'Sunbelt' were achieved without differences in other fruit composition parameters on all treatments. Delaying harvest of minimally pruned vines without thinning by about 7 days was required to achieve the desired soluble solids. Pruning methods had more effect on yield components than time of thinning. At harvest, minimally pruned vines had lower cluster weights, berry weights, and yield per node compared with hand pruning in both cultivars and years. In terms of second year yield response, 'Sunbelt' was not as detrimentally impacted by machine and minimal pruning without thinning compared with 'Concord'. Preliminary results indicate that machine and minimal pruning with and without thinning are viable alternatives to hand pruning for 'Concord' and 'Sunbelt' grapes in irrigated vineyards with warm, long growing seasons.

Decreasing availability and increased cost of hand labor have increased grower interest in mechanized systems for vineyard operations. Because hand pruning is labor intensive, machine and minimal (unpruned vines with or without skirting) pruning have been incorporated into vineyards to reduce labor costs and the time spent pruning (Clingeleffer, 1988; Morris, 2005). About 60% to 70% of Australia's wine grapes receive some form of mechanical pruning (Clingeleffer, 1993; Clingeleffer and Possingham, 1987). Although machine and minimal pruning can be cost effective, the impact of these pruning systems on grape yield and fruit composition is a concern.

Machine-pruned 'Concord' (*Vitis labruscana*) vines sustained higher yields with similar grape quality compared with balanced-pruned vines (Keller et al., 2004). Although mechanical pruning can produce higher

yields initially compared with dormant hand pruning, less difference in the following years demonstrate the vines' ability to acclimate to pruning methods (Clingeleffer, 1993; Keller et al., 2004; Reynolds and Wardle, 1993; Sims et al., 1990; Zabadal et al., 2002). Zabadal et al. (2002) concluded that due to development of less fruitful nodes in 'Concord', an increase in number of nodes retained for machine-pruned vines was needed to maintain comparable yield to manual commercial pruning.

Minimal pruning applied over 17 seasons on *Vitis vinifera* vines showed

that vines have the capacity to maintain productivity and fruit composition (Clingeleffer, 1993). Minimal pruning of *V. vinifera* vines followed by skirting (cutting the lower section of the vine to aid vineyard operations) increased quality compared with severe machine pruning (Clingeleffer, 1988). Minimal pruning with and without skirting of 'Chancellor' grapevines resulted in higher yields than hand pruning, but with lower cluster weights, fewer berries per cluster, lower berry weight, and lower grape soluble solids (Reynolds and Wardle, 2001).

Successful implementation of minimal or machine pruning in vineyards often requires hand follow-up or fruit thinning to achieve desired fruit maturity and composition (Fendinger et al., 1996; Fisher et al., 1996a, 1996b; Morris, 2005; Petrie and Clingeleffer, 2006; Reynolds and Wardle, 2001; Smith et al., 1996). Hand pruning during dormancy can control crop level, but pruning is done before potential natural crop reduction (spring freezes, hail storms, and poor fruit set) occurs. In a "balanced cropping" method, a larger potential crop (more nodes) can be retained at dormant pruning as a buffer against natural crop reduction, and then shoot and fruit thinning is used for crop adjustment as required. Yield prediction is required to establish thinning parameters for balanced cropping (Fisher et al., 1996b; Petrie et al., 2003), but the method of yield prediction is dependent on the cultivar and trellis system (Lange, 2003).

Many yield prediction methods depend on maintaining long-term records for each vineyard site to establish accurate yield predictors. Cluster weights, cluster counts, and berry

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10	%	g·L ⁻¹	0.1
29,574	fl oz	μL	3.3814×10^{-5}
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
1.4882	lb/ft	kg·m ⁻¹	0.6720
28.3495	oz	g	0.0353
2.2417	ton/acre	t·ha ⁻¹	0.4461
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

¹Institute of Food Science and Engineering, University of Arkansas, 2650 North Young Avenue, Fayetteville, AR 72704

²Institute for Continental Climate Viticulture and Enology, University of Missouri, Columbia, MO 65211

³Corresponding author. E-mail: jumorris@uark.edu.

weights have been used to estimate yield. For yield prediction, Price (1988) discussed four factors that growers need to measure each year in a uniform vineyard: 1) number of bearing vines per block, 2) clusters per vine, 3) cluster weight at lag phase of berry growth, and 4) cluster weight at harvest. Crop prediction can also be accomplished using yield predictor data, including berry size at different growth stages (50% final berry weight, lag phase, and veraison) (Morris, 2005; Pool et al., 1996).

Machine pruning was most effective in nonirrigated 'Concord' grapes when node, shoot, or fruit adjustments followed pruning to prevent overcropping (Morris and Cawthon, 1980, 1981). Mechanical thinning reduced crop level to the target yield and improved fruit quality in *V. vinifera* vines (Lange, 2003; Petrie and Clingeleffer, 2006). Crop adjustments of machine-pruned 'Concord' vines resulted in lower yields with higher fruit soluble solids than machine pruning alone (Smith et al., 1996; Zabadal et al., 2002). In a 6-year study on irrigated double curtain-trained 'Concord', machine-pruned vines that were mechanically fruit thinned yielded 29% more fruit than balanced, hand-pruned vines at a similar fruit composition (J. Morris, unpublished data).

Timing of thinning operations can vary from bloom to veraison. Pool et al. (1993) recommended machine thinning of 'Concord' 20 to 30 d following bloom. Berry weight greater than 1 g was required for efficient machine thinning of 'Concord' (Pool et al., 1996). Dokoozlian and Hirschfeld (1995) recommended cluster thinning early to midseason in table grapes before berry softening to increase amount of usable fruit. The date of cluster thinning from prebloom to veraison did not have a major impact on final berry size, but thinning before berry softening improved cluster color.

The demand for juice and juice products has increased due to public knowledge of health benefits associated with grape product consumption (Morris and Striegler, 2005). Outside of California, the primary red juice grape is 'Concord', which is produced in Washington, Michigan, New York, Pennsylvania, and Ohio. As an alternative, 'Sunbelt' (*V. labruscana*) can be grown where 'Concord' grapes

display uneven fruit ripening associated with high temperatures (Moore et al., 1993; Morris et al., 2007; Striegler et al., 2002). Initial research indicated that 'Sunbelt' grown on a six-arm kniffen training system did not produce yields suitable for commercial production (Moore et al., 1993). However, when grown on a double curtain training system, 'Sunbelt' produced commercially acceptable yield and quality in California and Arkansas (Morris et al., 2007; Striegler et al., 2002).

The purpose of this study was to examine the influence of hand, machine, and minimal pruning with no fruit thinning, midseason fruit thinning, or veraison fruit thinning on berry growth, berry composition, and yield parameters of 'Concord' and 'Sunbelt'. This was the first study to monitor *V. labruscana* fruit development in a warm growing region and to examine the influence of pruning and fruit thinning applications, simultaneously, in 'Concord' and 'Sunbelt' grapes. The effects of mechanical pruning and fruit thinning on yield components and fruit composition have not been established for 'Sunbelt' grapes.

Materials and methods

EXPERIMENTAL DESIGN. Seven crop-adjustment treatments were evaluated on 'Concord' and 'Sunbelt' grapes. The treatments were: dormant hand pruning 50 + 10 with a maximum of 80 nodes (50 nodes retained for the first 1 lb of dormant pruning and 10 additional nodes retained for each additional 1 lb) on six-node spurs; minimal pruning with no fruit thinning; minimal pruning with fruit thinning at 27 to 45 d postbloom; minimal pruning with fruit thinning at veraison; machine pruning to 120 nodes with no thinning; machine pruning to 120 nodes with fruit thinning at veraison (berry softening). All vines in each treatment were skirted at veraison to 40 cm from the vineyard floor to allow vineyard operations. Treatments were applied to single vine plots in a complete randomized block design with four replications. The study was initiated in 2004 and continued through the 2005 harvest. Phenological data are listed in Table 1.

Table 1. Average phenological data and treatment application dates for 'Concord' and 'Sunbelt' grapes.

Cultivar	Budbreak date	Bloom date	Target yield (t·ha ⁻¹) ^z	Postbloom thinning date	Avg lag phase (d postbloom)	Veraison thinning	Harvest period ^y
Concord	27 Mar.	16 May	37.4	24 June (39 d postbloom)	49	22 July (67 d postbloom)	24 Aug.–20 Sept. (100–127 d postbloom)
		10 May	28.9	24 June (45 d postbloom)	60	22 July (73 d postbloom)	23 Aug.–8 Sept. (105–121 d postbloom)
Sunbelt	8 Apr.	18 May	29.3	14 June (27 d postbloom)	52	19 July (62 d postbloom)	2 Sept.–23 Sept. (107–128 d postbloom)
		16 May	22.8	14 June (29 d postbloom)	55	19 July (64 d postbloom)	8 Sept.–26 Sept. (115–133 d postbloom)

^zThe target yield for fruit thinning treatments was the projected yield of hand-pruned vines to 50 + 10 [50 nodes retained for the first 1 lb (0.45 kg) of dormant pruning and 10 additional nodes retained for each additional 1 lb] with a maximum of 80 nodes; 1 t·ha⁻¹ = 0.4461 ton/acre.

^yRange indicates first harvest of hand- and machine-pruned vines to last harvest of minimally pruned vines based on the soluble solids goal for 'Concord' and 'Sunbelt' at 17% and 18%, respectively.

STATISTICAL ANALYSIS. Data were analyzed using SAS (version 8.2; SAS Institute, Cary, NC) analysis of variance procedure. The significance of the separations of mean values was determined using Tukey's test for differences and least significance difference test at $P \leq 0.05$. Data were analyzed by year due to significant year by pruning treatment interactions. Pearson's correlation coefficients (r) between berry weight, berry volume displacement, and berry diameter were assessed.

VINEYARD. Two-year-old 'Concord' and 'Sunbelt' vines were planted in Spring 2000 at the University of Arkansas Agricultural Research and Extension Center vineyards, Fayetteville, AR (lat. 36°10'N, long. 94°17'W). Vines were trained to the Geneva double curtain (GDC) training system described by Shaulis et al. (1966). Vine row orientation was north-south. Vines had a single trunk and were trained to 6-ft-high bilateral cordons that alternated to the east or west cordon wire with 3 ft between wires to provide a horizontally divided double curtain. Vines were spaced 8 ft in row and 10 ft between rows. This created 16 ft of cordon for each vine. Vines were well established in their fifth leaf at the beginning of the experiment. The soil was a Captina silt loam (fine-silty, siliceous, active, mesic Typic Fragiuults) with a pH of 6.8. Vines were drip irrigated. The vineyard floor was sod with a 1-m vegetation-free zone under the vines maintained with pre- and postemergent herbicide.

FERTILIZATION APPLICATIONS. Fertilizers were applied as granular soluble material with localized placement under the drip emitters with one emitter on either side of the trunk. In 2004, two postbloom applications of 272 lb/acre of 13N-5.8P-10.8K were applied on 25 May and 8 June. Minimally pruned vines received an additional application of ammonium nitrate 34N-0P-0K equivalent to 54 lb/acre nitrogen on 24 June. Veraison petiole analysis in 2004 revealed similar nitrogen concentrations among treatments, but the phosphorous levels were lower in minimally pruned vines. In 2005, 200 lb/acre 13N-5.8P-10.8K were applied by broadcast 27 Apr., and three additional localized under-emitter applications of 144 lb/acre of 13N-5.8P-10.8K were made on 28 Apr., 15 May, and 22 June.

Fig. 1. Effect of pruning and fruit thinning on berry weight of 'Concord' grapes (2004 and 2005). MIN-NT = minimal pruning (unpruned) with no fruit thinning, MIN-PBT = minimal pruning with fruit thinning 27–39 d postbloom, MIN-VT = minimal pruning with fruit thinning at veraison, MACH-NT = machine (box cut) pruning with no fruit thinning, MACH-PBT = machine pruning with fruit thinning 27–39 d postbloom, MACH-VT = machine pruning with fruit thinning at veraison, HAND = hand pruning to 50 + 10 [50 nodes retained for the first 1 lb (0.45 kg) of dormant pruning and 10 additional nodes retained for each additional 1 lb] with a maximum of 80 nodes, LSD = least significant difference at $P \leq 0.05$ (1 g = 0.0353 oz).

Veraison petiole analysis in 2005 showed similar nitrogen, phosphorus, and potassium values among treatments (data not shown).

PRUNING APPLICATIONS. All vines were dormant hand pruned to about 80 nodes on five- to six-node spurs in the year before the study began. The hand-pruned vines were pruned to 50 + 10 (50 nodes retained for the first 1 lb of dormant pruning and 10 additional nodes retained for each additional 1 lb) with a maximum of 80 nodes on six-node spurs. Machine-pruning treatments were applied using a gas-powered hedge trimmer to make an offset box-cut with box horizontal $\times$ vertical dimensions of $\approx 20 \times 30$ cm for ‘Concord’ and 25×35 cm for ‘Sunbelt’. The box related to the cordon such that ≈ 10 cm was above the cordon and 5 cm was to the trunk-side middle. After machine pruning, nodes were counted and box dimensions were shortened by hand, if necessary, to obtain 120 nodes. Minimally pruned vines were left unpruned. Hand- and machine-pruned vines were shoot positioned downward following bloom and again 10 to 14 d later. Minimally pruned vines were not shoot positioned, but long 2-year-old wood was tucked into the upper two-thirds of the canopy when necessary to maintain a fruiting area at least 90 cm above the vineyard floor. In the first year of the study (2004), several minimally pruned ‘Concord’ vines had excessive (1200) nodes. Based on previous experience, it was evident that this high node number would not produce suitable fruit composition. Therefore, the maximum number of nodes allowed on ‘Concord’ was 850. The ‘Sunbelt’ minimally pruned vines had lower node numbers (500–700) and were not adjusted.

YIELD PREDICTION. To project yield and determine the amount of fruit to remove from individual vines, all of the fruit from two representative extra vines of hand-, machine-, and minimal-pruned vines were removed, and the number of clusters/vine, total weight of fruit/vine, and berry weights were determined. The target yield for thinning treatments was a yield equivalent to the projected yield of the hand-pruned vines (Table 1). Yield was extrapolated from fruit weight of each vine $\times$ number of vines/acre at 8×10 -ft vine spacing.

Fig. 2. Effect of pruning and fruit thinning on berry weight of ‘Sunbelt’ grapes (2004 and 2005). MIN-NT = minimal pruning (unpruned) with no fruit thinning, MIN-PBT = minimal pruning with fruit thinning 29–45 d postbloom, MIN-VT = minimal pruning with fruit thinning at veraison, MACH-NT = machine (box cut) pruning with no fruit thinning, MACH-PBT = machine pruning with fruit thinning 29–45 d postbloom, MACH-VT = machine pruning with fruit thinning at veraison, HAND = hand pruning to 50 + 10 [50 nodes retained for the first 1 lb (0.45 kg) of dormant pruning and 10 additional nodes retained for each additional 1 lb] with a maximum of 80 nodes, LSD = least significant difference at $P \leq 0.05$ (1 g = 0.0353 oz).

FRUIT THINNING. Fruit thinning treatments were applied by hand to machine- and minimal-pruned vines 27 to 45 d postbloom and at veraison (Table 1). Fruit was thinned by removing clusters randomly selected from each vine until a predetermined weight of fruit was removed from each vine. In the second year of the study, fruit thinning was done earlier (at 50% of final berry weight), which may be more appropriate for *V. labruscana* (Pool et al., 1996).

HARVEST PARAMETERS. Each vine was harvested at a soluble solids level of $\approx 17\%$ for 'Concord' and 18% for 'Sunbelt'. This is higher than the commercial 16% soluble solids target usually associated with *V. labruscana* grapes and was chosen to help differentiate the effect of the pruning and fruit thinning methods. Cluster weight and yield at harvest were determined by counting clusters while harvesting individual vines.

GRAPE SAMPLING AND PREPARATION. Berries were sampled weekly during the growing season to monitor pruning and fruit-thinning treatments. Twenty-five berries per cultivar, treatment, and replication were randomly collected from clusters within the vine each week during the growing season. The 25-berry sample was weighed, and the displacement of water of the 25-berry sample was measured volumetrically. The diameter of each berry was measured using an electronic digital caliper (VWR, West Chester, PA). When total soluble solids reached $\approx 10\%$, samples were further analyzed for pH, soluble solids, and titratable acidity. For these analyses, residual surface water on the 25-berry sample was removed with an absorbent towel, and the fruit was then homogenized (Osterizer model 848-31N; Jarden Corp., Rye, NY) for 5 s on the lowest speed. At harvest, a final 100-berry sample was taken from each treatment, placed in polyethylene bags, sealed, and frozen.

SAMPLE PREPARATION OF FROZEN BERRIES. Frozen grapes were held at $-29\text{ }^{\circ}\text{C}$ for 2 months. Final berry weights at harvest were determined by counting and weighing the frozen berries. The bags containing frozen grapes were held at room temperature ($25\text{ }^{\circ}\text{C}$) for 18 h before analysis. After thawing, each sample of grapes was

Table 2. Effect of pruning and fruit thinning on yield components of 'Concord' grapes (2004 and 2005).

Pruning ^z	Fruit thinning	Avg harvest (d postbloom)	Yield (kg/vine) ^y	Clusters (no./vine)	Cluster wt (g) ^x	Berry wt (g)	Yield (g/node) ^w	Clusters (no./node)
2004								
Hand	None	108	25.8	258 c ^v	99 a	3.08 a	331 a	3.30 a
Machine	None	115	29.8	331 c	91 a	2.89 a	249 a	2.76 ab
Machine	39 d postbloom	118	26.1	343 c	75 a	2.88 a	241 a	3.15 a
Machine	Veraison	110	27.4	324 c	84 a	2.94 a	228 a	2.70 ab
Minimal	None	124	37.7	1,106 a	35 b	2.44 b	57 b	1.69 bc
Minimal	39 d postbloom	108	26.5	724 b	43 b	2.40 b	38 b	1.06 c
Minimal	Veraison	121	27.8	920 ab	32 b	2.34 b	38 b	1.29 c
P value			NS	***	***	***	***	***
2005								
Hand	None	118	28.3	332	85 a	3.19 a	358 a	4.21 a
Machine	None	125	29.2	432	68 ab	3.08 ab	243 b	3.60 ab
Machine	27 d postbloom	118	21.9	342	65 ab	3.00 ab	183 b	2.85 bc
Machine	Veraison	118	24.7	335	80 a	3.18 a	206 b	2.79 bc
Minimal	None	118	21.0	500	43 b	2.90 b	73 c	1.73 cd
Minimal	27 d postbloom	118	21.6	589	37 b	2.66 b	53 c	1.44 d
Minimal	Veraison	114	20.1	521	39 b	2.90 b	66 c	1.71 cd
P value			NS	NS	***	*	***	***

^zHand = hand-pruned to 50 + 10 [50 nodes retained for the first 1 lb (0.45 kg) of dormant pruning and 10 additional nodes retained for each additional 1 lb] with a maximum of 80 nodes, machine = box cut, minimal = unpruned.

^y1 kg = 2.2046 lb.

^v1 g = 0.0353 oz.

^wVine yield (kilograms) per nodes retained $\times 1000$.

*Means within cultivar and column having the same or no letters are not significantly different by Tukey's test; NS, *, **, *** (not significant or significant at $P \leq 0.05$, 0.01, and 0.001).

removed from the bag and placed in a 1-L blender container. Grapes were homogenized and must was poured into a 250-mL beaker. Must treatments were placed in a hot water bath set at 80 °C. Samples were lightly stirred at 10-min intervals, and temperatures were monitored. When samples reached 71 °C (≈ 20 min), beakers were removed from the water bath. Samples were cooled to 40 °C and were then squeezed through cheesecloth until 150 mL of juice was collected. A pectolytic enzyme, Scottzyme Pec5L (Scott Laboratories, Petaluma, CA), was added at 100 μ L/150 mL to each sample. Samples were cooled to ambient temperature. A 45-mL aliquot of juice was centrifuged at 13,250 g_n for 15 min and was used for analysis.

FRUIT COMPOSITIONAL ANALYSES.

Grape juice pH was measured with a pH meter (model 250 pH; Beckman Coulter, Fullerton, CA) with a probe using a three-point calibration (1.68, 4.0, and 7.0). Titratable acidity (tartaric acid in grams per liter) was measured by placing 5 mL of juice into 125 mL of degassed, deionized water and titrating with 0.1 N sodium hydroxide to an endpoint of pH 8.2. Total soluble solids were measured using a refractometer (Bausch & Lomb Abbe Mark II; Scientific Instrument, Keene, NH). L-Tartaric acid, D-glucose, and D-fructose were measured by high-performance liquid chromatography using methods described by Walker et al. (2003).

Color and phenolics of juice were determined using a spectrophotometer (Unicam Helios Beta ultraviolet-VIS; Thermo Fisher Scientific, Waltham, MA). Absorbance was read at 520 nm to measure red-colored pigments in juice. Color density was defined as the intensity of color [yellow/brown (420 nm) + red (520 nm)]. Total red pigment color was measured using the procedure in Iland et al. (2004). In this procedure, juice samples were diluted with 1 M hydrochloric acid (HCl). Dilution factor varied with cultivar. The low pH of the HCl solution causes anthocyanins to be in the bright red-colored form (flavylium cation) and gives an estimation of total red pigments (anthocyanins and tannins) in juice. Absorbance (280 nm $\times$ dilution factor -4) of the sample diluted with HCl provides a measure of phenolic

Table 3. Effect of pruning and fruit thinning on yield components of 'Sunbelt' grapes (2004 and 2005).

Pruning ^z	Fruit thinning	Avg harvest (d postbloom)	Yield (kg/vine) ^y	Clusters (no./vine)	Cluster wt (g) ^x	Berry wt (g)	Yield (g/node) ^w	Clusters (no./node)
2004								
Hand	None	113	19.1 bc ^v	147 c	130 a	4.43 a	307 a	2.35 a
Machine	None	113	20.2 bc	187 c	111 a	4.27 a	174 b	1.61 abc
Machine	45 d postbloom	113	17.8 c	157 c	114 a	4.41 a	168 b	1.49 bc
Machine	Veraison	117	21.9 bc	175 c	125 a	4.27 a	209 b	1.69 ab
Minimal	None	117	32.6 a	562 a	59 b	3.60 b	61 c	1.04 bc
Minimal	45 d postbloom	117	24.9 abc	389 b	65 b	3.60 b	55 c	0.86 c
Minimal	Veraison	117	26.9 ab	433 b	63 b	3.47 b	53 c	0.85 c
P value			***	***	***	***	***	***
2005								
Hand	None	121	20.7 b	199 d	108 a	4.40 a	295 a	2.80 a
Machine	None	125	26.9 b	286 cd	94 ab	4.14 ab	226 ab	2.41 ab
Machine	29 d postbloom	119	20.4 b	225 d	93 ab	4.44 a	170 bc	1.88 bc
Machine	Veraison	121	22.1 b	258 d	87 ab	4.10 ab	188 bc	2.20 ab
Minimal	None	131	36.3 a	586 a	62 b	3.65 b	142 cd	2.26 ab
Minimal	29 d postbloom	119	23.4 b	378 bc	63 b	3.66 b	91 d	1.45 c
Minimal	Veraison	124	27.0 b	408 b	66 b	3.58 b	92 d	1.38 c
P value			***	***	*	*	***	***

^zHand = hand-pruned to 50 + 10 [50 nodes retained for the first 1 lb (0.45 kg) of dormant pruning and 10 additional nodes retained for each additional 1 lb] with a maximum of 80 nodes, machine = box cut, minimal = unpruned.
^y1 kg = 2.2046 lb.
^x1 g = 0.0353 oz.

^wVine yield (kilograms) per nodes retained $\times 1000$.

*Means within cultivar and column having the same or no letters are not significantly different by Tukey's test; ns, *, **, *** (not significant or significant at $P \leq 0.05$, 0.01, and 0.001).

material (Iland et al., 2004). Spectrophotometric measurements were standardized to a 1-cm cell.

VINE GROWTH PARAMETERS.

Dormant pruning weights were taken on hand- and machine-pruned vines for pruning weight in kilograms per vine and kilograms per meter of cordon. Nodes retained per vine, yield (grams) per node [Vine yield (kilograms) per nodes retained $\times$ 1000], and clusters per node retained (clusters per vine/node retained) were determined.

Results and discussion

Of the three methods evaluated for assessing berry growth (weight of 25 berries, displacement of water of 25 berries, and average diameter of 25 berries), the average berry weight provided the best and most consistent method. The correlation of measurements of each cultivar, regardless of treatment (average of 2004 and 2005), were calculated. In 'Concord', berry diameter correlated to berry volume displacement ($r = 0.951$) and berry weight ($r = 0.939$), and berry weight correlated highest with berry volume displacement ($r = 0.992$). In 'Sunbelt', berry diameter correlated to berry volume displacement ($r = 0.958$) and berry weight ($r = 0.949$), and berry weight correlated highest with berry volume displacement ($r = 0.996$). Standard deviation values were smallest in berry weight measurements.

Berry weights were measured weekly during the growing season to monitor berry growth including lag phase, the physiological stage where little change in grape berry weight occurs (Coombe and McCarthy, 2000) (Figs. 1 and 2). Lag phase can last days to weeks depending on cultivar, cultural treatment, and growing season. Lag phase occurred 50 ± 7 d postbloom in 'Concord' and 58 ± 7 d postbloom in 'Sunbelt'. In 'Concord' grown in New York, Nitsch et al. (1960) showed that lag phase occurred 50 to 60 d postbloom at 65% of final berry weight. In this experiment, lag phase occurred at 75% to 80% of final berry weight for hand-pruned 'Concord' and 68% to 78% for 'Sunbelt'. Minimally pruned vines appeared to have an extended period of slow growth compared with hand- or machine-pruned vines.

At the first sample times for both cultivars and years, there were no

differences in berry weights between treatments (Figs. 1 and 2). Minimally pruned 'Concord' (2004) and 'Sunbelt' (2004 and 2005) had lower berry weights than hand-pruned vines at early season thinning, veraison thinning, and before harvest. The average harvest period (time between first and last vines to reach desired soluble solids level) was generally longer for 'Concord' than 'Sunbelt' (Table 1). Pruning method had more of an impact on soluble solids development than time of thinning. Minimally pruned vines without thinning were usually the last treatment harvested (about 7 d after the other treatments) (Figs. 1 and 2). Zabadal et al. (2002) found that vines with heavy fruit loads may not ripen to commercially desired soluble solids in climates with short growing seasons. Desired fruit composition could be achieved under high fruit load conditions in Arkansas partially due to the foliated period after harvest each year. The growing season at the Arkansas Agriculture Research and Extension Center, Fayetteville, AR, has an average of 184 frost-free days with the

average last and first freeze on 15 Apr. and 17 Oct., respectively. 'Concord' harvest usually begins the last week of August and may last through mid-September, which allows a foliated period of at least 30 d postharvest.

Fruit-thinning adjustments were targeted to achieve the same yield in the fruit-thinned vines as in hand-pruned vines. Therefore, yield (kilograms per vine) was similar among treatments within cultivar even though clusters per vine, cluster weight (grams), final berry weight (grams), yield (grams) per node, and clusters per node retained may have differed (Tables 2 and 3). Minimal pruning 'Sunbelt' without fruit thinning increased yield/vine compared with hand pruning in both years. Minimal pruning 'Sunbelt' (2004 and 2005) and 'Concord' (2004) increased clusters/vine compared with hand pruning. In both cultivars (2004), machine pruning increased cluster weight, berry weight, and yield (grams) per node compared with minimal pruning. Minimal pruning treatments decreased cluster weight, berry weight, and yield (grams) per

Fig. 3. Difference (%) in yield components from nonthinned machine and minimally pruned vines compared with hand-pruned 'Concord' and 'Sunbelt' grapevines. Minimal = minimal pruning (unpruned) with no fruit thinning, Machine = machine (box cut) pruning with no fruit thinning and hand-pruned = hand-pruned to 50 + 10 [50 nodes retained for the first 1 lb (0.45 kg) of dormant pruning and 10 additional nodes retained for each additional 1 lb] with a maximum of 80 nodes (1 kg = 2.2046 lb, 1 g = 0.0353 oz).

node compared with hand pruning in both cultivars and years. Bud fruitfulness appeared to be slightly higher in 2005 than 2004 in both cultivars based on the clusters per node for nonthinned treatments. Minimal pruning nonthinned vines decreased clusters per node retained in 'Concord' (2004 and 2005) and in 'Sunbelt' (2004) compared with hand pruning. 'Concord', hand pruned to six-node spurs, had strong fruitful wood, whereas machine-pruned vines had short spurs that were less fruitful. Minimally pruned vines can have retained nodes from less fruitful buds due to shading and node origin.

The percentage difference between machine- and minimally pruned vines without thinning compared with hand-pruned vines was calculated for select yield components (Fig. 3). Minimal pruning without thinning 'Concord' (2004) and 'Sunbelt' (2004 and 2005) increased yield/vine by more than 45% compared with hand pruning. Decreased yield/vine of 'Concord' in 2005 compared with hand-pruned vines may be a response due to previous over cropping, climate effect, or the ability of the vine to acclimate crop load (Clingeffer, 1993; Reynolds and Wardle, 1993; Sims et al., 1990). Most cultivars have lower yields the year after conversion to minimal pruning. Because 'Sunbelt' had similar yields in both years on nonthinned minimally pruned vines, 'Sunbelt' may have a greater ability to self adjust to varying fruit load conditions than 'Concord'. In 2004 and 2005, machine and minimal pruning without thinning 'Concord' and 'Sunbelt' increased clusters/vine, decreased cluster weights, and decreased berry weights compared with hand pruning. Machine-pruned vines without thinning had 27% to 44% more clusters/vine than hand-pruned vines, and minimally pruned vines without thinning had 51% to 329% more clusters/vine than hand-pruned vines.

In both cultivars and years, the number of nodes retained on minimally pruned vines was higher than hand-pruned or machine-pruned vines (Table 4). In 'Concord', the number of nodes retained on minimally pruned vines was 815% higher than on hand-pruned vines in 2004, but only 322% in 2005. In 'Sunbelt',

Table 4. Effect of pruning and fruit thinning treatments on pruning weights and nodes retained in 'Concord' and 'Sunbelt' grapes.

Cultivar	Pruning ^z	Fruit thinning	2003			2004			2005		
			Pruning wt (kg/vine) ^y	Nodes retained (no.)	Pruning wt (kg/vine)	Nodes retained (no.)	Pruning wt (kg·m ⁻¹) ^x	Nodes retained (no.)	Pruning wt (kg/vine)	Nodes retained (no.)	Pruning wt (kg·m ⁻¹)
Concord	Hand	None	2.02 ^w	78 b	2.12	78 b	0.41	79 c	1.73 a	79 c	0.36 a
	Machine	None	1.51	120 b	1.47	120 b	0.31	120 c	0.74 b	120 c	0.15 b
	Machine	27–39 d postbloom	2.04	111 b	2.12	111 b	0.44	120 c	1.13 b	120 c	0.27 b
	Machine	Veraison	1.96	120 b	1.91	120 b	0.39	120 c	0.92 b	120 c	0.19 b
	Minimal	None	— ^v	665 a	—	665 a	—	282 b	—	282 b	—
	Minimal	27–39 d postbloom	—	740 a	—	740 a	—	416 a	—	416 a	—
	Minimal	Veraison	—	739 a	—	739 a	—	304 b	—	304 b	—
Sunbelt	P value			***	NS	***	NS	***	***	***	***
	Hand	None	1.07	63 b	1.04	63 b	0.21	71 b	1.29 a	71 b	0.27 a
	Machine	None	1.10	116 b	1.11	116 b	0.23	119 b	0.74 b	119 b	0.15 b
	Machine	29–45 d postbloom	0.89	108 b	0.80	108 b	0.17	120 b	0.66 b	120 b	0.14 b
	Machine	Veraison	1.01	106 b	1.07	106 b	0.22	118 b	0.58 b	118 b	0.12 b
	Minimal	None	—	555 a	—	555 a	—	263 a	—	263 a	—
	Minimal	29–45 d postbloom	—	479 a	—	479 a	—	263 a	—	263 a	—
	Minimal	Veraison	—	517 a	—	517 a	—	301 a	—	301 a	—
	P value			***	NS	***	NS	***	*	***	*

^zHand = hand-pruned to 50 + 10 [50 nodes retained for the first 1 lb (0.45 kg) of dormant pruning and 10 additional nodes retained for each additional 1 lb] with a maximum of 80 nodes, machine = box cut, minimal = unpruned.

^y1 kg = 2.2046 lb.

^xkg·m⁻¹ = 0.6720 lb/ft.

^wMeans within cultivar and column having the same or no letters are not significantly different by Tukey's test; NS, *, **, *** (not significant or significant at $P \leq 0.05$, 0.01, and 0.001).

^vData not obtained for minimal pruning treatments.

number of nodes retained on minimally pruned vines was 720% higher than on hand-pruned vines in 2004, but only 288% in 2005. The lower bud numbers in the second year reflect vine adaptation that occurs with minimal pruning. Neither fruit thinning nor time of thinning seemed to affect bud number in the following season in 'Sunbelt'. In 'Concord', there were more buds in 2005 when vines were fruit thinned at veraison.

Two-year ranges of pruning weights (kg/m of cordon) for hand-pruned 'Concord' and 'Sunbelt' were 0.36 to 0.41 kg·m⁻¹ and 0.21 to 0.27 kg·m⁻¹, respectively. Pruning weights for machine-pruned 'Concord' and 'Sunbelt' were 0.15 to 0.44 kg·m⁻¹ and 0.12 to 0.23 kg·m⁻¹, respectively. The average yield to pruning weight ratio for hand-pruned vines was 14 for 'Concord' and 17 for 'Sunbelt', with much higher values for machine-pruned vines. Shaulis et al. (1966) suggested that the ideal pruning weight was 0.3 to 0.45 kg·m⁻¹ for hand-pruned, GDC-trained 'Concord' in New York. Morris et al. (2007) reported 0.38 kg·m⁻¹ pruning weight on GDC-trained 'Sunbelt' on shorter 1.8 × 2.7 m row spacing with yield to pruning weight ratio of 12. GDC-trained 'Sunbelt' grown in the San Joaquin Valley of California with

2.1 × 3.6-m spacing had an average pruning weight of 0.26 kg·m⁻¹ with a yield to pruning weight ratio of 16 (Striegler et al., 2002). Morris et al. (2007) and Striegler et al. (2002) had 5 kg/vine less fruit yield than hand-pruned vines in this experiment.

Because 'Sunbelt' had acceptable crop loads, pruning weight may not be a good indicator of vine balance in long-growing seasons and high-yield conditions. Clingeffer and Krake (1992) indicated that 1-year-old wood was not a good measurement of a vine's capacity for production on minimal-pruning systems. This thought was extrapolated to machine-pruned 'Concord' vines with high bud numbers (Keller et al., 2004). Pruning weights for the hand-pruned 'Concord' vines were similar in 2003 and 2004 and then declined 14% in 2005. This is partially attributable to the fruit yield of hand-pruned vines that averaged 2.5 kg/vine higher in 2005 than 2004 due to high bud fruitfulness. The lower pruning weights may also be due to the warmer growing season in 2005 with 39 d over 90 °F compared with 5 d in 2004 (weather reporting station was Arkansas Agricultural Experiment Station 32444, Fayetteville, AR). High temperatures negatively affect 'Concord' growth

(Striegler et al., 2002). Although bud fruitfulness was physiologically established the previous season, the warmer temperature had a visible effect on 'Concord' vines, causing yellowing and scorching of leaves and delayed the time from veraison to harvest by about 2 weeks compared with 2004. The diminished vine health probably reduced late season vegetative growth in 2005 and thereby reduced pruning weights compared with 2004. The extended period from veraison to harvest was also present in 'Sunbelt', but without the yellowing of leaves.

Regardless of pruning or fruit-thinning treatment, the desired soluble solids were achieved for 'Concord' (17%) and 'Sunbelt' (18%) (Tables 5 and 6). Minimally pruned vines were usually the last treatment harvested, regardless of cultivar (Figs. 1 and 2). Smith et al. (1996) found that thinning minimally pruned 'Concord' vines reduced yield (from 37 to 22 t·ha⁻¹) and increased soluble solids (from 14.8% to 17.0%) compared with nonthinned vines when harvested on the same date. Bates (2008) indicated a crop reduction of 4.5 to 6.5 t·ha⁻¹ in 'Concord' was necessary to increase juice soluble solids by 1% in New York. The 'Concord' grape juice industry usually uses

Table 5. Effect of pruning and fruit thinning on the development of 'Concord' grapes frozen for analysis (2004 and 2005).

Pruning ^a	Fruit thinning	Soluble solids (%)	pH	Titrateable acidity (g·L ⁻¹) ^b	Color density (AU) ^c	Red color (AU)	Total red pigments (AU)	Total phenolics (AU)
2004								
Hand	None	18.3 ^w	3.62	7.55	16.9	11.0	32.2	58.5
Machine	None	18.8	3.60	7.33	14.2	9.02	28.5	54.5
Machine	39 d postbloom	18.7	3.67	7.29	16.0	10.2	32.8	59.7
Machine	Veraison	18.8	3.57	7.49	14.8	9.58	28.7	53.5
Minimal	None	18.7	3.53	7.00	11.3	7.06	22.3	50.8
Minimal	39 d postbloom	18.3	3.60	6.94	12.1	7.54	24.5	49.2
Minimal	Veraison	18.4	3.61	6.89	12.9	7.98	24.5	51.6
P value		NS	NS	NS	NS	NS	NS	NS
2005								
Hand	None	17.7 ^c	3.64	6.44	7.19	3.81	14.9	40.1
Machine	None	17.6	3.59	6.79	7.39	3.95	14.9	40.5
Machine	27 d postbloom	17.7	3.72	6.57	8.54	4.59	18.5	45.1
Machine	Veraison	18.1	3.60	6.68	8.39	4.70	17.3	43.7
Minimal	None	18.3	3.61	6.56	8.70	4.94	17.9	43.6
Minimal	27 d postbloom	18.3	3.73	6.32	6.76	3.40	14.5	39.8
Minimal	Veraison	18.3	3.68	6.24	8.15	4.52	18.1	42.9
P value		NS	NS	NS	NS	NS	NS	NS

^aHand = hand-pruned to 50 + 10 [50 nodes retained for the first 1 lb (0.45 kg) of dormant pruning and 10 additional nodes retained for each additional 1 lb] with a maximum of 80 nodes, machine = box cut, minimal = unpruned.

^bExpressed as tartaric acid; 1 g·L⁻¹ = 0.1%.

^cAbsorbance units.

^wMeans within cultivar and column having the same or no letters are not significantly different by Tukey's test (NS = not significant at $P \leq 0.05$).

Table 6. Effect of pruning and fruit thinning on the development of 'Sunbelt' grapes frozen for analysis (2004 and 2005).

Pruning ^z	Fruit thinning	Soluble solids (%)	pH	Titrateable acidity (g·L ⁻¹) ^y	Color density (AU) ^x	Red color (AU)	Total red pigments (AU)	Total phenolics (AU)
2004								
Hand	None	19.1 ^w	3.42	8.94	20.3	14.6	58.7	64.6
Machine	None	18.7	3.43	8.96	21.8	15.7	61.3	67.0
Machine	45 d postbloom	19.1	3.42	8.94	23.6	17.2	65.2	69.9
Machine	Veraison	19.2	3.44	8.58	22.4	16.2	63.6	68.6
Minimal	None	18.5	3.42	8.25	22.8	16.6	65.4	75.2
Minimal	45 d postbloom	18.9	3.44	8.25	25.3	18.2	65.0	72.1
Minimal	Veraison	18.9	3.43	8.65	26.1	18.8	69.8	77.6
P value		NS	NS	NS	NS	NS	NS	NS
2005								
Hand	None	18.2	3.45	7.45	15.4	11.0	57.3	63.0
Machine	None	18.0	3.45	7.39	16.0	11.4	56.5	63.6
Machine	29 d postbloom	18.9	3.46	7.69	17.7	12.7	60.6	66.7
Machine	Veraison	18.1	3.44	7.64	16.7	11.9	56.0	62.8
Minimal	None	17.8	3.44	7.40	15.9	11.5	54.9	64.8
Minimal	29 d postbloom	18.9	3.45	7.24	19.9	14.5	63.5	67.5
Minimal	Veraison	19.0	3.47	7.22	20.1	14.6	66.6	70.5
P value		NS	NS	NS	NS	NS	NS	NS

^zHand = hand-pruned to 50 + 10 [50 nodes retained for the first 1 lb (0.45 kg) of dormant pruning and 10 additional nodes retained for each additional 1 lb] with a maximum of 80 nodes, machine = box cut, minimal = unpruned.

^yExpressed as tartaric acid; 1 g·L⁻¹ = 0.1%.

^xAbsorbance units.

^wMeans within cultivar and column having the same or no letters are not significantly different by Tukey's test (NS = not significant at $P \leq 0.05$).

15% soluble solids as the lower level of acceptable quality and pays a premium for each percentage increase in soluble solids up to 18% (Morris and Striegler, 2005).

Juice composition was measured in juice processed from grapes at harvest (Tables 5 and 6). There were no differences between total soluble solids, glucose, fructose, pH, titrateable acidity, tartaric acid, color density, red color, total red pigments, and total phenolics of juice of grapes at harvest. In 'Concord', the average glucose and fructose levels of grapes for both years were 68 and 77 g·L⁻¹, respectively. In 'Sunbelt', the average glucose and fructose levels of grapes for both years were 75 and 79 g·L⁻¹, respectively. In 'Concord' and 'Sunbelt', the average tartaric acid levels of the grapes for both years were 8.6 and 10.4 g·L⁻¹, respectively. Previous studies (Morris and Cawthon, 1980, 1981) have shown differences in fruit composition due to canopy management treatments, but treatments were harvested on the same calendar date as opposed to the same soluble solids level.

Conclusions

During the first year of the experiment, yield performance of cultivars was similar with respect to their response to pruning and thinning treatments. In the second year of the

experiment, minimally pruned 'Concord' vines had reduced yields, regardless of fruit thinning treatment. 'Sunbelt' treatments had similar yields in both years. The pruning method had more of an impact on yield components than thinning. The harvest period was generally longer for 'Concord' than for 'Sunbelt', with minimally pruned vines without thinning having the most delayed ripening. Desired soluble solids were achieved under long-season growing conditions in both cultivars with all pruning and fruit-thinning methods. Although other long-term viticulture factors need evaluation, machine and minimal pruning are promising alternatives to hand pruning for 'Concord' and 'Sunbelt' in areas with a long-growing season.

Literature cited

- Bates, T.R. 2008. Pruning level affects growth and yield of New York Concord on two training systems. *Amer. J. Enol. Viticult.* 59:276–286.
- Clingeleffer, P.R. 1988. Minimal pruning of cordon trained vines, p. 112–120. *Proc. Second Intl. Seminar on Mechanical Pruning of Vineyards*. Villanova di Motta di Livenza, Treviso, Italy.
- Clingeleffer, P.R. 1993. Vine response to modified pruning practices, p. 20–30. In: R. Pool (ed.). *Proc. Second N.J. Shaulis*
- Grape Symp., New York State Agr. Expt. Sta., Fredonia, NY.
- Clingeleffer, P.R. and J.V. Possingham. 1987. The role of minimal pruning of cordon-trained vines (MPCT) in canopy management and its adoption in Australian viticulture. *Austral. Grapegrower Winemaker*. 280:7–11.
- Clingeleffer, P.R. and L.R. Krake. 1992. Responses of Cabernet franc grapevines to minimal pruning and virus infection. *Amer. J. Enol. Viticult.* 43:31–37.
- Coombe, B.G. and M.G. McCarthy. 2000. Dynamics of grape berry growth and physiology of ripening. *Aust. J. Grape Wine Res.* 6:131–135.
- Dokoozlian, N.K. and D.J. Hirschfeld. 1995. The influence of cluster thinning at various stages of fruit development on Flame Seedless table grapes. *Amer. J. Enol. Viticult.* 46:429–436.
- Fendinger, A.G., R.M. Pool, R.M. Dunst, and R. Smith. 1996. Effect of mechanical thinning minimally pruned 'Concord' grapevines on fruit composition, p. 13–17. In: T. Henick-Kling, T.E. Wolf, E.M. Harkness (eds.). *Proc. Fourth Intl. Symp. Cool Climate Viticult.* Enol 1620 July 1996, Rochester, NY. Communication Services, New York State Agr. Expt. Sta., Geneva, NY.
- Fisher, K.H., B. Piott, and J. Barkovic. 1996a. Adaptability of labrusca and French hybrid grape varieties to mechanical pruning and mechanical thinning, p.

- 33–39. In: T. Henick-Kling, T.E. Wolf, E.M. Harkness (eds.). Proc. Fourth Intl. Symp. Cool Climate Viticult. Enol., 16–20 July 1996, Rochester, NY. Communication Services, New York State Agr. Expt. Sta., Geneva, NY.
- Fisher, K.H., B. Piott, and T. Tancock. 1996b. Estimating Concord crops for machine thinning accuracy, p. 28–32. In: T. Henick-Kling, T.E. Wolf, E.M. Harkness (eds.). Proc. Fourth Intl. Symp. Cool Climate Viticult. Enol., 16–20 July 1996, Rochester, NY. Communication Services, New York State Agr. Expt. Sta., Geneva, NY.
- Iland, P., N. Bruer, G. Edwards, S. Weeks, and E. Wilkes. 2004. Chemical analysis of grapes and wine: Techniques and concepts. Patrick Iland Wine Promotions, Campbelltown, South Australia.
- Keller, M., L.J. Mills, R.L. Wample, and S.E. Spayd. 2004. Crop load management in Concord grapes using different pruning techniques. Amer. J. Enol. Viticult. 55:35–50.
- Lange, C. 2003. Bunch thinning shows colour benefits. Austral. Viticult. 7:60–63.
- Moore, J.N., J.R. Morris, and J.R. Clark. 1993. ‘Sunbelt’: A new juice grape for the south-central United States. HortScience 28:859–860.
- Morris, J. 2005. Successful total vineyard mechanization. Vineyard Winery Mgt. 31(1):84–90.
- Morris, J.R. and D.L. Cawthon. 1980. Mechanical trimming and node adjustment of cordon-trained ‘Concord’ grapevines. J. Amer. Soc. Hort. Sci. 105:310–313.
- Morris, J.R. and D.L. Cawthon. 1981. Yield and quality response of Concord grapes (*Vitis labrusca* L.) to mechanized vine pruning. Amer. J. Enol. Viticult. 32:280–282.
- Morris, J.R. and R.K. Striegler. 2005. Grape juice: Factors that influence quality, processing technology, and economics, p. 585–616. In: D.M. Barrett, L. Somogyi, H. Ramaswamy (eds.). Processing fruits: Science and technology. 2nd ed. CRC Press, Boca Raton, FL.
- Morris, J.R., G.L. Main, and R.K. Striegler. 2007. Rootstock and training system affect ‘Sunbelt’ grape productivity and fruit composition. J. Amer. Pomol. Soc. 61(2):71–77.
- Nitsch, J.P., C. Pratt, C. Nitsch, and N.J. Shaulis. 1960. Natural growth substances in Concord and Concord seedless grapes in relation to berry development. Amer. J. Bot. 47:566–576.
- Petrie, P.R. and P.R. Clingeleffer. 2006. Crop thinning (hand versus mechanical), grape maturity and anthocyanin concentration: Outcomes from irrigated Cabernet Sauvignon (*Vitis vinifera* L.) in a warm climate. Aust. J. Grape Wine Res. 12:21–29.
- Petrie, P.R., P.R. Clingeleffer, and M.P. Krstic. 2003. Mechanical thinning to stabilise yield and improve grape maturity and colour. Aust. N. Z. Grapegrower Winemaker 473a:118–120.
- Pool, R.M., R. Dunst, and A. Fendinger. 1996. Regulating crop and quality of machine or minimally pruned Concord grapevines, p. 51–56. Proc. First Vincent E. Petrucci Viticulture Symp. Fresno, CA.
- Pool, R.M., R.E. Dunst, D.C. Crowe, H. Hubbard, G.E. Howard, and G. DeGoler. 1993. Predicting and controlling crop on machine or minimal pruned grapevines, p. 31–45. In: R. Pool (ed.). Proc. Second N.J. Shaulis Grape Symp., New York State Agr. Expt. Sta., Fredonia, NY.
- Price, S. 1988. Predicting yield in Oregon vineyards. Practical Winery Vineyard May/June:42–43.
- Reynolds, A.G. and D.A. Wardle. 1993. Yield component path analysis of Okanagan Riesling vines conventionally pruned or subjected to simulated mechanical pruning. Amer. J. Enol. Viticult. 44:173–179.
- Reynolds, A.G. and D.A. Wardle. 2001. Evaluation of minimal pruning upon vine performance and berry composition of Chancellor. Amer. J. Enol. Viticult. 52:45–48.
- Shaulis, N., E.S. Shepardson, and T.D. Jordan. 1966. The Geneva double curtain for Concord grapes. Vine training and trellis construction. New York State Agr. Expt. Sta., Geneva, NY. Bul. 811.
- Sims, C.A., R.P. Johnson, and R.P. Bates. 1990. Effects of mechanical pruning on the yield and quality of muscadine grapes. Amer. J. Enol. Viticult. 44:173–179.
- Smith, R.L., R.M. Pool, A.D. Fendinger, J. Barnard, and T.E. Acree. 1996. Effects of crop load on the flavor character of Concord grape juice determined by descriptive sensory analysis, p. 24–27. In: T. Henick-Kling, T.E. Wolf, E.M. Harkness (eds.). Proc. Fourth Intl. Symp. Cool Climate Viticult. Enol., 16–20 July 1996, Rochester, NY. Communication Services, New York State Agr. Expt. Sta., Geneva, NY.
- Striegler, R.K., J.R. Morris, R.T. Threlfall, G.L. Main, C.B. Lake, and S.G. Graves. 2002. Effect of minimal input production systems on yield and juice quality of ‘Sunbelt’ grapes grown in the San Joaquin Valley of California. HortScience 37:867–870.
- Walker, T., J. Morris, R. Threlfall, and G. Main. 2003. Analysis of wine components in Cynthiana and Syrah wines. J. Agr. Food Chem. 51:1543–1547.
- Zabadal, T.J., G.R. Vanece, T.W. Dittmer, and R.L. Ledebuhr. 2002. Evaluation of strategies for pruning and crop control of Concord grapevines in southwest Michigan. Amer. J. Enol. Viticult. 53:204–209.