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Mechanical Cane Pruning and Crop Adjustment Decreases Labor Costs and Maintains Fruit Quality in New York 'Concord' Grape Production

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SUMMARY. Four pruning techniques were evaluated from 1999 to 2003 in a commercial 'Concord' (*Vitis labruscana*) vineyard in Westfield, NY. Manual pruning, mechanical pruning with manual pruning follow-up, mechanical pruning with fruit thinning, and minimal pruning with fruit thinning averaged a 2.4-fold difference in retained nodes per vine. Treatments with crop adjustment required fruit thinning in 3 of 5 years to maintain an acceptable crop size. Manually pruned vines, mechanically pruned vines with manual follow-up pruning, and mechanically pruned vines with crop adjustment had similar yields, juice soluble solids, lignified periderm, juice color, juice titratable acidity, and juice pH in 4 of 5 years. Minimally pruned vines tended to have slightly higher yield and lower juice soluble solids, color, and titratable acidity in 3 of 5 years. Pruning system cost estimates indicated a 56% and 80% cost reduction per acre when comparing manual pruning with mechanical pruning plus manual follow-up or mechanical pruning plus mechanical fruit thinning, respectively. These results support two commercially acceptable and sustainable pruning management options for New York 'Concord' grape production.

Average production costs for commercial 'Concord' vineyards is \$1500/acre (Shaffer

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and White, 2006) and the break-even payment for a western New York 'Concord' vineyard yielding 6.0 tons/acre is \$250/ton. From 1996

to 2007, the cash market price for commercially acceptable 'Concord' grape fruit averaged \$236/ton, with 6 years above and 6 years below the break-even price. Although 'Concord' grape juice attributes such as flavor, color, titratable acidity, and pH affect the final processed juice quality, processors purchase 'Concord' grapes primarily on yield, with a minimum juice soluble solids concentration requirement and secondarily on juice soluble solids with a graduated payment increase with increasing concentration. 'Concord' grape crop adjustment research in western New York suggests a 4.5 to 6.5 t·ha⁻¹ reduction in crop yield is needed to increase harvest juice soluble solids by 1% (Bates, 2008). Currently, the sliding payment increase for juice soluble solids does not match this yield-juice soluble solids relationship; therefore, the highest producer return is at maximum yield with minimum acceptable juice soluble solids. With little control over the cash market pricing, 'Concord' grape producers strive to increase profitability by increasing yield at acceptable juice soluble solids, decreasing production costs, or both. The challenge in achieving this goal lies in developing lower-cost mechanical techniques within the framework of sound viticulture concepts such as optimum vine size, canopy density, and leaf area to crop weight ratios (Howell, 2001).

INCREASING YIELD AT ACCEPTABLE JUICE SOLUBLE SOLIDS. Adjusting retained nodes per vine through pruning to influence vine vegetative and reproductive growth has been a long-studied management practice. In the western New York cool climate, conservative balanced pruning formulas, such as retaining 20 nodes/lb with a maximum of 60 retained nodes per

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
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	micron	µm	1
28.3495	oz	g	0.0353
0.001	ppm	g·L ⁻¹	1000
0.9072	ton(s)	t	1.1023
2.2417	ton/acre	t·ha ⁻¹	0.4461
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

vine on standard vine spacing (9 ft between rows $\times$ 8 ft between vines), give adequate exposed leaf area-to-fruit ratio to fully mature the crop in any season (Kimbal and Shaulis, 1958). However, the conservative crop load also limits the maximum potential crop that can be matured in warmer and longer-than-average growing seasons (Cawthon and Morris, 1977; Clore and Brummund, 1961; Morris et al., 1984). On the other end of the pruning spectrum, minimal pruning retains the maximum number of nodes per vine with high crop levels and dense canopy structures that delay juice soluble solids accumulation (Fendinger et al., 1996; Lakso et al., 1996; Morris and Cawthon, 1981). In cool climates and poor growing seasons, commercial minimal pruning can lead to unacceptable juice soluble solids by the end of commercial harvest (Bates, 2008; Zabadal et al., 2002). A recent New York 'Concord' grape pruning study compared a range of retained nodes (56–383 nodes/vine) on crop size and juice soluble solids accumulation rates to a harvest parameter of 16% juice soluble solids (Bates, 2008). Doubling retained nodes from 65 to 130 nodes/vine increased yield by 4 kg/vine with a harvest delay of only 1 week (2-d delay for each additional kilogram per vine yield increase) and no loss in vine size. Therefore, a commercial compromise exists in the New York 'Concord' grape industry to increase yield with an acceptable delay in harvest date. The potential for increased yields by increasing retained nodes within acceptable commercial parameters has also been illustrated in eastern Washington (Keller et al., 2004). There is a risk for overcropping with high retained nodes per vine if the buds have above-average fruitfulness (clusters/node) or high fruit set (berries/cluster), leading to low juice soluble solids accumulation rates. However, mid-season crop estimation and fruit thinning about 1 month after bloom to improve juice quality has been studied as a viable commercial option in 'Concord' vineyards (Bates, 2006; Pool et al., 1993).

DECREASING PRODUCTION COSTS. After the adoption of mechanical harvesting in 'Concord' vineyards in the early 1970s, labor for dormant vine pruning became the largest

production cost (Morris, 2007). Mechanical pruning or prepruning 'Concord' grapevine research began in the mid-1970s with the intention of lowering production costs and maintaining appropriate node quantity and quality (Cawthon and Morris, 1977; Pollack et al., 1977). Original techniques were conservative with respect to retained node number and employed downward mechanical shoot positioning 15 to 20 d after bloom, mechanical pruning to leave only fruiting canes below the high wire cordon, manual cane thinning, and mechanical scrubbing of green shoots originating above the cordon. Mechanical minimal pruning minimizes pruning cost, but can have unacceptable reductions in juice quality and, in extreme cases, induction of alternate bearing (Goffinet, 2000). The Morris-Oldridge System, a vineyard mechanization system developed in Arkansas for 12 trellis configurations, addressed the issue of balanced cropping and economic viability (Morris, 2007). For high-wire cordon trained and cane pruned grape varieties, such as Concord, a pruning machine was developed to retain more nodes than needed, which could be followed by mechanical shoot thinning or mechanical fruit thinning or both if necessary (Morris and Oldridge, 2002; Oldridge, 1996).

The objective of this study was to compare the viticulture and economic characteristics of commercial manual pruning, mechanical pruning plus manual pruning follow-up, mechanical pruning with fruit thinning, and minimal pruning with fruit thinning.

Materials and methods

VINEYARD. The experiment was conducted from 1999 to 2003 in a commercial 'Concord' vineyard in Westfield, NY, owned by Robert and Dawn Betts (lat. 42°20'27", long. 79°34'18", elevation 204 m). The vineyard soil was a mix of somewhat poorly drained Canandaigua silt-loam and Minoa sandy-loam with 3.5% to 4.5% organic matter and 5.5 soil pH. The own rooted 'Concord' grapevines had moderate vine size (0.47 and 0.54 kg dormant cane pruning weight per meter of row and the beginning and end of the experiment, respectively) and were planted 9 ft between rows and 7 ft between vines with rows in a north-south direction. Vines were cordon trained to a trellis wire at 6.0 ft and, before the experiment, all vines were mechanically pruned for 3 years with a Morris-Oldridge pruning unit (Oldridge, 1996). Floor, nutrient, pest, and disease management were done according to commercial standards for western New York 'Concord' vineyards (Jordan et al., 1980). Fungicide

Fig. 1. Modified Morris-Oldridge mechanical pruning unit used for dormant cane pruning of 'Concord' grapevines in western New York (left, front view; right, rear view). For the mechanical + manual pruning treatment, rotation of the oval rotary cane positioners in the rear of the unit were in an upward direction to position canes into the upper cutter bars. For the mechanical only pruning treatment, rotation of the oval rotary cane positioners were in a downward direction to position canes into the lower cutter bars.

and insecticide materials and application rates were done according to the New York and Pennsylvania Pest Management Guidelines for Grapes (Weigle, 2006) and varied annually depending on seasonal weather conditions.

TREATMENTS. Four management techniques with different levels of mechanical intervention were compared with the objective of achieving similar and commercially acceptable crop yields. “Manual only” pruning to a constant 100 nodes/vine. “Mechanical + manual” consisted of mechanical pruning with the Morris-Oldridge pruning head with manual follow-up pruning to retain 110 to 120 nodes/vine. For mechanical pruning, the rotation of the pruning unit’s rear oval rotary cane positioners (Fig. 1) were in the upward direction with the objective of lifting canes developed from sun exposed shoots and pruning them to retain five to seven nodes/cane with the upper cutter bars while reducing or eliminating shaded canes with the lower cutter bars. For manual follow-up pruning, two to four large pruning cuts/vine were made to further reduce node number and remove weak or dead perennial tissue. Small pruning cuts to adjust cane length or retained nodes per vine were avoided. “Mechanical only” was mechanical pruning with the Morris-Oldridge pruning head with the oval rotary cane positioners moving in a downward direction to position and retain nodes below the cordon with no manual follow-up pruning. Thirty days after bloom, crop size was machine-estimated on separate vines within the same vineyard block and with the same pruning management, and mechanical fruit thinning was done if necessary with a mechanical grape harvester (Chisholm Ryder, Niagara Falls, NY) (Bates, 2003). “Minimal” pruning consisted of a single horizontal mechanical pruning pass 36 inches from the ground with a reciprocating sickle bar and no manual follow-up pruning. Mechanical crop estimation and adjustment was done similar to the mechanical only treatment.

The experimental design was a randomized complete block with four blocks. Treatments were imposed on 50-vine rows, and five random count vines/row were tagged for data

Table 1. Average and yearly phenological data for ‘Concord’ grapevines at the Cornell Vineyard Laboratory in Fredonia, NY, and ‘Concord’ harvest date for the pruning study in Westfield, NY.

	30-year-mean	1999	2000	2001	2002	2003
Bud break (date)	5 May	4 May	4 May	1 May	19 Apr.	5 May
Bloom (date)	15 June	9 June	13 June	13 June	20 June	25 June
Veraison (date)	23 Aug.	14 Aug.	22 Aug.	19 Aug.	25 Aug.	2 Sept.
Experiment harvest (date)		5 Oct.	17 Oct.	5 Oct.	13 Oct.	23 Oct.
Growing degree day accumulation 1 Apr.–31 Oct. (base 10 °C) ^z	1,373	1,664	1,462	1,625	1,686	1,435
Precipitation 1 Apr.–31 Oct. (cm) ^y	67.1	56.9	69.2	52.1	69.4	59.4

^z(1.8 × °C) + 32 = °F.

^y1 cm = 0.3937 inch.

Table 2. Effect of pruning method and season on retained nodes, yield, juice soluble solids, and lignified periderm of ‘Concord’ grapevines in Westfield, NY.

Treatment ^z	Retained nodes (no./vine)					P ^v
	1999	2000	2001	2002	2003	
Manual only	100 d ^x	100 b	100 c	100 c	100 c	NS
Mechanical + manual	122 c	113 b	105 c	126 c	117 c	NS
Mechanical only	166 b	143 a	138 b	196 b	160 b	**
Minimal	267 a	157 a	234 a	296 a	262 a	***
P ^w	***	***	***	***	***	*** ^{††}
Treatment	Yield (t·ha ⁻¹) ^y					P
	1999	2000	2001	2002	2003	
Manual only	31.0 ab	20.9	16.6 b	18.4	19.1 a	***
Mechanical + manual	26.2 b	20.2	16.0 b	20.1	16.0 b	*
Mechanical only	25.8^t b	20.6	17.2 b	19.4	11.8 c	***
Minimal	32.6 a	18.4	24.3 a	22.9	13.3 bc	***
P	*	NS	**	NS	**	***
Treatment	Juice soluble solids (%)					P
	1999	2000	2001	2002	2003	
Manual only	16.1 ab	16.6	16.4 a	16.5	14.2 b	***
Mechanical + manual	16.9 a	16.1	16.5 a	16.3	14.9 a	***
Mechanical only	15.9 b	16.0	16.2 ab	16.2	15.2 a	*
Minimal	14.3 c	16.4	15.6 b	15.7	14.5 ab	***
P	***	NS	*	NS	*	***
Treatment	Lignified periderm (nodes/vine)					P
	1999	2000	2001	2002	2003	
Manual only	364 a	494	455	358 ab	254	***
Mechanical + manual	339 a	492	436	378 a	284	**
Mechanical only	246 b	439	408	282 b	278	***
Minimal	238 b	445	413	293 b	276	***
P	***	NS	NS	*	NS	NS

^zManual only = hand pruning to a constant 100 nodes/vine; Mechanical + manual = mechanical pruning with manual follow-up pruning to retain 110 to 120 nodes/vine; Mechanical only = mechanical pruning only with fruit thinning; Minimal pruning = a single horizontal mechanical pruning pass 36 inches (91.4 cm) from the ground with fruit thinning.

^y1 t·ha⁻¹ = 0.4461 ton/acre.

^zMeans within columns followed by the same letter do not differ significantly at P = 0.05 by Duncan’s new multiple range test.

^wEffect of pruning (within seasons); NS, *, **, *** = not significant or significant at P < 0.05, 0.01, or 0.001, respectively.

^vEffect of season (within pruning treatments).

^wPruning × season interaction.

^tBold numbers on yield indicates mechanical crop adjustment 30 d after bloom.

collection; therefore, each treatment-block combination had a single experimental unit of five vines.

VINE MEASUREMENTS. Before dormant cane pruning each year, lignified nodes per count vine were measured. For the manual-only pruning treatment, dormant cane prunings were weighed after the vines were pruned to 100 nodes. Juice soluble solids were monitored weekly after veraison and when the juice soluble solids of the manual only treatment approached 16% or, in the case of 2003, when the end of commercial harvest was reached, an 80 to 100 berry sample was randomly collected from vertical planes transecting the east and west side of each count vine and measured for berry weight and juice soluble solids. Juice soluble solids were measured with a hand-held refractometer (model 10423; Leica, Buffalo, NY) and the remaining fruit was frozen at -5°C for further juice analysis. Cluster number and yield from count vines were measured by manually harvesting the remaining fruit (Table 1).

JUICE ANALYSIS. Harvest berry samples were further analyzed for juice pH, titratable acidity, and color. Juice pH was determined on 150 mL after thawing and homogenizing the samples (model 340 pH meter; Corning, Corning, NY). For color and titratable acidity, each 150-mL homogenized grape sample was brought to 60°C in a water bath, treated with a 1-mL solution of 1% pectinase (9032-75-1; Sigma-Aldrich, St. Louis) for 25 min, and filtered by gravity (12–25 μm particle retention; Whatman, Florham Park, NJ). For color, 5 mL of the gravity-filtered juice sample was diluted with 95 mL of McIlvaine's buffer (LC16300-4, pH 3.2; LabChem, Pittsburgh, PA) and was suction filtered (glass fiber filter type A/E, 1.0 μm particle retention; Pall Corp., East Hills, NY). Absorbance at 520 and 430 nm was measured with a spectrophotometer (20 Genesys; Spectronic Instruments, Rochester, NY) on the double-filtered juice samples against a 100% McIlvaine buffer standard at 22°C . Titratable acidity was determined by diluting 10 mL of the gravity-filtered juice sample with 40 mL of distilled water and titrating with 0.1 N sodium hydroxide solution (Zoecklein et al., 1999).

DATA ANALYSIS. Statistical analyses were carried out using SAS (version 8.02; SAS Institute, Cary, NC). Data were tested for homogeneity of variance using Levene's test and were subjected to two-way (pruning system $\times$ season) analysis of variance (ANOVA), using the general linear model and F test. Pruning systems were also analyzed as one-way ANOVA for each season, and post hoc mean comparisons were done using Duncan's new multiple range test. Seasons were also analyzed as one-way ANOVA for each pruning treatment.

Results and discussion

The four pruning systems had an effect on pruning severity with a 1.6- to 3.0-fold difference in retained nodes per vine (Table 2). Manual-only pruning and machine + manual pruning targeted and retained ≈ 100 to 120 nodes/vine and this did not differ between seasons. Mechanical-

only and minimal pruning averaged 160 and 243 nodes/vine, respectively. Retained nodes on the two less severe pruning systems were affected by growing season, with 1999, 2002, and 2003 having the highest node numbers. Mechanical crop adjustment was used on the mechanical-only and minimal-pruned vines in the same 3 years to reduce yields and make them similar to the more severe pruning treatments. Given this objective, mechanical thinning was successful in 1999 and 2002. In 2003, mechanical thinning was too aggressive, partially in the authors' response to a cool spring and late bloom, and produced lower yields than the two lower node number and unthinned treatments.

Manual-only, mechanical + manual, and mechanical-only treatments had similar yield, juice soluble solids, lignified periderm, juice color, juice titratable acidity, and juice pH in 4 of 5 years (Tables 2 and 3). In 2003,

Table 3. Effect of pruning method and season on 'Concord' grape juice color, titratable acidity, and pH in Westfield, NY.

Treatment ^z	Juice color (A_{520}) ^y					P^u
	1999	2000	2001	2002	2003	
Manual only	8.9 a ^w	13.0	12.9	11.7 a	8.8 b	*
Mechanical + manual	11.0 a	11.2	12.7	11.2 ab	12.4 a	NS
Mechanical only	8.7 a	10.5	11.5	10.2 ab	12.0 a	NS
Minimal	4.7 b	12.6	9.9	8.3 b	11.0 a	***
P^v	***	NS	NS	*	**	*** ^t
Treatment	Juice titratable acidity ($\text{g}\cdot\text{L}^{-1}$) ^x					P
	1999	2000	2001	2002	2003	
Manual only	11.2 a	13.7	13.7	12.3 ab	16.2	***
Mechanical + manual	11.3 a	13.9	13.7	12.4 a	16.6	***
Mechanical only	11.0 ab	13.5	13.4	12.0 b	16.8	***
Minimal	10.8 b	13.7	13.0	11.6 c	16.6	***
P	*	NS	NS	**	NS	*
Treatment	Juice pH					P
	1999	2000	2001	2002	2003	
Manual only	3.18	3.11	3.16	3.28	3.06	**
Mechanical + manual	3.21	3.07	3.18	3.30	3.03	***
Mechanical only	3.19	3.06	3.18	3.30	3.04	***
Minimal	3.14	3.07	3.16	3.24	3.04	**
P	NS	NS	NS	NS	NS	NS

^zManual only = hand pruning to a constant 100 nodes/vine; Mechanical + manual = mechanical pruning with manual follow-up pruning to retain 110 to 120 nodes/vine; Mechanical only = mechanical pruning only with fruit thinning; Minimal pruning = a single horizontal mechanical pruning pass 36 inches (91.4 cm) from the ground with fruit thinning.

^y A_{520} = Spectrophotometer absorption at 520 nm.

^xTitratable acidity as tartaric acid, $1\text{ g}\cdot\text{L}^{-1} = 1000\text{ ppm}$.

^wMeans within columns followed by the same letter do not differ significantly at $P = 0.05$ by Duncan's new multiple range test.

^vEffect of pruning (within seasons); NS, *, **, *** = not significant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

^uEffect of season (within pruning treatments).

^tPruning $\times$ season interaction.

Table 4. Effect of pruning method and season on yield components of ‘Concord’ grapevines in Westfield, NY.

Treatment ^z	Clusters (no./vine)					P ^v
	1999	2000	2001	2002	2003	
Manual only	206 c ^x	153 b	154 b	190 c	142 b	***
Mechanical + manual	192 c	162 b	156 b	207 c	149 b	NS
Mechanical only	256 b	197 a	192 b	269 b	148 b	***
Minimal	372 a	202 a	316 a	338 a	199 a	***
P ^w	***	**	***	***	***	*** ^u

Treatment	Cluster wt (g) ^y					P
	1999	2000	2001	2002	2003	
Manual only	88.4 a	80.3 a	63.5 a	56.3 a	78.6 a	***
Mechanical + manual	79.9 b	73.5 a	60.3 a	55.9 a	62.5 b	***
Mechanical only	59.2 c	61.5 b	52.6 b	42.2 b	46.5 c	***
Minimal	51.3 d	53.6 c	45.0 c	39.8 b	39.5 c	***
P	***	***	***	***	***	***

Treatment	Berries (no./cluster)					P
	1999	2000	2001	2002	2003	
Manual only	34 a	22 a	18 a	17 ab	29 a	***
Mechanical + manual	31 b	20 b	17 a	18 a	22 b	***
Mechanical only	24 c	18 c	15 b	14 b	17 c	***
Minimal	23 c	16 c	14 b	14 b	16 c	***
P	***	***	**	*	***	***

Treatment	Berry wt (g) ^y					P
	1999	2000	2001	2002	2003	
Manual only	2.62 a	3.70 a	3.57 a	3.32 a	2.69	***
Mechanical + manual	2.58 ab	3.75 a	3.54 a	3.16 b	2.81	***
Mechanical only	2.50 b	3.49 b	3.42 a	2.95 c	2.67	***
Minimal	2.25 c	3.35 b	3.16 b	2.75 d	2.54	***
P	***	***	***	***	NS	*

^zManual only = hand pruning to a constant 100 nodes/vine; Mechanical + manual = mechanical pruning with manual follow-up pruning to retain 110 to 120 nodes/vine; Mechanical only = mechanical pruning only with fruit thinning; Minimal pruning = a single horizontal mechanical pruning pass 36 inches (91.4 cm) from the ground with fruit thinning.

^y1 g = 0.0353 oz.

^xMeans within columns followed by the same letter do not differ significantly at $P = 0.05$ by Duncan's new multiple range test.

^wEffect of pruning (within seasons); NS, *, **, *** = not significant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

^vEffect of season (within pruning treatments).

^uPruning $\times$ season interaction.

treatments with higher yield had lower juice soluble solids, but none of the fruit matured to 16% juice soluble solids because of the poor ripening season. Minimal pruned vines tended to have slightly higher yield and lower juice soluble solids, color, and titratable acidity in 1999, 2001, and 2002, but were similar to the other treatment vines in 2000. Because juice soluble solids has an important economic role in the ‘Concord’ grape juice industry, it is important to note that minimally pruned vines only reached the 16% juice soluble solids standard in 1 of the 5 years of the experiment. Increasing retained nodes per vine increased clusters per vine but decreased cluster weight through fewer berries per

cluster and lower berry weight, leading to variable degrees of yield compensation (Table 4); however, yield compensation in this experiment had little economic importance when final yield and juice soluble solids were all similar.

Pruning and crop adjustment costs were analyzed for the systems studied (Table 5). As expected, manual-only pruning had the highest cost per acre because of labor and benefit costs. Mechanical + manual reduced costs per acre by 56% compared with manual-only pruning. Mechanical-only pruning with mechanical fruit thinning reduced costs per acre by 80% compared with manual-only pruning. The Morris-Oldridge mechanical pruning head currently retails

for \$28,000 in New York [Rammelt and Son's (Westfield, NY); unpublished data]. The additional equipment used to modify the pruning head in the mechanical pruning + manual follow-up treatment cost an additional \$3,000. Comparing the cost savings when converting from manual pruning to either of the two mechanized systems, the time required to recover the principle cost of the mechanical pruning unit varied with vineyard size (Fig. 2). A minimum vineyard size of 40 acres, with a principle equipment payback of 4 years, is arguably acceptable for conversion to mechanical pruning. About 35% of grape farms representing 80% of the grape acres in western New York are 40 acres or larger in size.

Each pruning system evaluated in this trial is currently used in commercial ‘Concord’ grape production in western New York because each system has particular benefits illustrated in this study. Manual pruning had the highest production cost, but allowed for individual vine crop management with a high degree of control over the quantity and quality of retained nodes. Minimal pruning had low pruning costs and responded positively to mechanical crop adjustment, but also represented a viticulture risk of low juice soluble solids in the cool climate of western New York. Mechanical + manual reduced pruning costs by 56% compared with manual pruning and maintained the canopy structure of manual-only pruned vines by retaining light exposed canes, removing dead perennial tissue from the canopy, and retaining 100 to 120 nodes/vine. Manual follow-up, although it added to production costs over full mechanization, maintained an open canopy structure and allowed for individual vine management and observation. Mechanical-only pruning with mechanical crop adjustment reduced costs by 80% from manual-only pruning and was successful in controlling yield and fruit quality. Waiting until after the spring frost threat and fruit set to adjust final crop size with mechanical fruit thinning can be advantageous in matching maximum crop size with growing season characteristics. The downward cane positioning during mechanical pruning without manual pruning follow-up caused accumulation of dead perennial

Table 5. Cost comparison for manual only, mechanical + manual, and mechanical-only pruning^z treatments of Concord grapevines in Westfield, NY.

	Cost calculation ^y	Cost (\$/acre) ^x
Manual only		
Manual pruning labor	$\$0.30/\text{vine} \times 691 \text{ vines}/\text{acre}$	207.30
Manual follow-up labor (tying and suckering)	$2.3 \text{ h}/\text{acre} \times \$8.00/\text{h}$	18.40
Benefit rate	43%	97.05
Total		322.75
Mechanical + manual		
Mechanical pruning labor	$1 \text{ h}/\text{acre} \times \$12.00/\text{h}$	12.00
Manual follow-up labor (large pruning cuts, tying, and suckering)	$6.91 \text{ h}/\text{acre} \times \$12.00/\text{h}$	82.92
Equipment maintenance labor	$0.125 \text{ h}/\text{acre} \times \$12.00/\text{h}$	1.50
Benefit rate	43%	41.46
Pruning fuel	$\text{h}/\text{acre} \times 1 \text{ gal}/\text{h} \times \$4.00/\text{gal}$	4.00
Total		141.88
Mechanical Only		
Mechanical pruning labor	$1 \text{ h}/\text{acre} \times \$12.00/\text{h}$	12.00
Manual follow-up labor (tying and suckering)	$2.3 \text{ h}/\text{acre} \times \$8.00/\text{h}$	18.40
Equipment maintenance labor	$0.125 \text{ h}/\text{acre} \times \$12.00/\text{h}$	1.50
Mechanical crop estimation labor	$0.17 \text{ h}/\text{acre} \times \$12.00/\text{h} \times 2 \text{ workers}$	4.08
Mechanical crop thinning labor	$0.33 \text{ h}/\text{acre} \times \$12.00/\text{h} \times 1 \text{ worker}$	3.96
Benefit rate	43%	17.17
Pruning fuel	$1 \text{ h}/\text{acre} \times 1 \text{ gal}/\text{h} \times \$4.00/\text{gal}$	4.00
Thinning fuel	$0.33 \text{ h}/\text{acre} \times 1 \text{ gal}/\text{h} \times \$4.00/\text{gal}$	1.32
Total		62.43

^zManual only = hand pruning to a constant 100 nodes/vine; Mechanical + manual = mechanical pruning with manual follow-up pruning to retain 110 to 120 nodes/vine; Mechanical only = mechanical pruning only with fruit thinning when needed.

^y1 vine/acre = 2.4711 vines/ha, 1 h/acre = 2.4711 h·ha⁻¹, 1 gal = 3.7854 L, \$1.00/gal = \$0.2642/L.

^x\$1.00/acre = \$2.4711/ha.

tissue in the canopy often associated with hedge pruning. This structure can increase disease incidence, decrease pesticide spray penetration,

and add debris to harvest bins during mechanical harvesting (Becker and Pearson, 1993; Landers and Farooq, 2004).

Fig. 2. Relationship between vineyard operation size and the time it would take to recover the principle equipment investment when converting from manual only pruning to mechanical pruning with manual follow-up or mechanical pruning with mechanical fruit thinning. The Morris-Oldridge mechanical pruning head cost \$28,000 and the additional equipment used to modify the pruning head in the mechanical pruning + manual follow-up treatment cost an additional \$3,000. The calculation is based only on the pruning cost per acre of the three pruning systems, irrespective of other variables such as yield per acre or price per ton; 1 acre = 0.4047 ha.

When considering the overall picture of production costs and viticulture benefit, the two mechanical pruning systems with manual pruning follow-up or fruit thinning to maintain vine balance in this study offer viable options that satisfy current 'Concord' grape industry objectives to increase yield at acceptable juice soluble solids and to lower production cost. The average yield for commercial 'Concord' grapevine production in the Lake Erie region is 6 tons/acre. The mechanical + manual treatment in this study averaged 8.8 tons/acre with acceptable juice quality. In a manual-pruned 'Concord' vineyard, the average production cost is \$1500/acre, with $\approx 27\%$ of that cost in pruning labor (\$405/acre). By converting to machine pruning with manual follow-up, the pruning labor is reduced 56% to \$178/acre and lowers the overall production cost from \$1500/acre to \$1273/acre. At 8.8 tons/acre and \$1273/acre, the break-even price is \$145/ton. Therefore, with an average price for 'Concord' grapes of \$236/ton (12-year average), New York 'Concord' grape producers could gain

\$91/ton profit by converting from manual pruning to machine pruning with manual follow-up. With the machine-only pruning and fruit thinning treatment in this study, the profit gain would increase to \$102/ton.

Conclusion

All of the pruning methods used in this study are being commercially implemented in New York vineyards with some success. There are cost savings associated with mechanical pruning that can increase grower profitability. Mechanization reduced the cost associated with pruning by 56% to 80%, depending on the degree of mechanization. Minimal pruning reduced the cost the most, but minimum soluble solids were not achieved in most years. Therefore, minimal pruning cannot be recommended for New York vineyards without further research on crop thinning. The use of mechanical pruning with dormant season bud adjustment or midseason crop adjustment when necessary provides an attractive cost-saving alternative to conventional manual pruning of 'Concord' grapes.

Literature cited

- Bates, T.R. 2003. Concord crop adjustment: Theory, research, and practice. *Lake Erie Vineyard Notes* 6:1-11.
- Bates, T.R. 2006. Crop load management in western New York. *Wine East* 34:10-19.
- Bates, T.R. 2008. Pruning level affects growth and yield of New York Concord on two training systems. *Amer. J. Enol. Viticult.* 59(3):276-286.
- Becker, C.M. and R.C. Pearson. 1993. Disease and insect management considerations for machine pruned vineyards. *Proc. N.J. Shaulis Grape Symp.: Pruning mechanization and crop control*. Fredonia, NY, 13-14 July 1993. p. 46-50.
- Cawthon, D.L. and J.R. Morris. 1977. Yield and quality of 'Concord' grapes as affected by pruning severity, nodes per bearing unit, training system, shoot positioning, and sample date in Arkansas. *J. Amer. Soc. Hort. Sci.* 102:760-767.
- Clore, W.J. and V.P. Brummund. 1961. The effect of vine size on the production of Concord grapes balanced pruned. *Proc. Amer. Soc. Hort. Sci.* 78:239-244.
- Fendinger, A.G., R.M. Pool, R. Dunst, and R. Smith. 1996. Effect of mechanical thinning minimally-pruned 'Concord' grapevines on fruit composition. *Proc. 4th Intl. Symp. Cool Climate Viticult.* 4:13-17.
- Goffinet, M.C. 2000. Flower "malady" and poor fruit set of grapevines with respect to training system, crop load, shoot growth, and cane carbohydrate reserves. 1999 *Viticult. Consortium East Res. Rpts.*, Cornell Univ., New York State Agr. Expt. Sta. p. 62-67.
- Howell, G.S. 2001. Sustainable grape productivity and the growth-yield relationship: A review. *Amer. J. Enol. Viticult.* 52:165-174.
- Jordan, T.D., R.M. Pool, T.J. Zabadal, and J.P. Tomkins. 1980. Cultural practices for commercial vineyards. *New York State Agr. Expt. Sta. Misc. Bul.* 111.
- 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.
- Kimbal, K. and N. Shaulis. 1958. Pruning effects on the growth, yield, and maturity of Concord grapes. *Proc. Amer. Soc. Hort. Sci.* 71:167-176.
- Lakso, A.N., S.S. Denning, R. Dunst, A. Fendinger, and R.M. Pool. 1996. Comparisons of growth and gas exchange of conventionally- and minimally-pruned 'Concord' grapevines. *Proc. 4th Intl. Symp. Cool Climate Viticult.* 4:11-12.
- Landers, A.J. and M. Farooq. 2004. Factors influencing air and pesticide penetration into grapevine canopies. *Asp. Appl. Biol.* 71:343-348.
- Morris, J.R. 2007. Development and commercialization of a complete vineyard mechanization system. *HortTechnology* 17:411-420.
- 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 T.L. Oldridge. 2002. United States Patent 6,374,538 B1. Vineyard apparatus, system, and method for vineyard mechanization, U.S. Patent and Trademark Office, Washington, DC.
- Morris, J.R., D.L. Cawthon, and C.A. Sims. 1984. Long-term effects of pruning severity, nodes per bearing unit, training system, and shoot positioning on yield and quality of 'Concord' grapes. *J. Amer. Soc. Hort. Sci.* 109:676-683.
- Oldridge, T.L. 1996. United States Patent 5,544,444. Single curtain wine and juice grape vine pruner, U.S. Patent and Trademark Office, Washington, DC.
- Pollack, J.G., E.S. Shepardson, N.J. Shaulis, and D.E. Crowe. 1977. Mechanical pruning of American hybrid grapevines. *Trans. Amer. Soc. Agr. Eng.* 20:817-821.
- Pool, R.M., R. Dunst, D.C. Crowe, H. Hubbard, G.E. Howard, and G. DeGoller. 1993. Predicting and controlling crop on machine or minimal pruned grapevines. *Proc. N.J. Shaulis Grape Symp.: Pruning mechanization and crop control*. Fredonia, NY, 13-14 July 1993. p. 31-45.
- Shaffer, B.E. and G.B. White. 2006. Lake Erie grape farm cost survey 2001-2005. *Cornell Univ. Ext. Bul.* 2006-19.
- Weigle, T.H. 2006. 2006 New York and Pennsylvania pest management guidelines for grapes. *Cornell Univ., Ithaca, NY.*
- 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.
- Zoecklein, B.W., K.C. Fugelsang, B.H. Gump, and F.S. Nury. 1999. *Wine analysis and production*. Kluwer Academic/Plenum Publishers, New York.