Justin R. Morris Vineyard Mechanization Symposium

~ Proceedings ~

February 2-3, 2008
Midwest Grape and Wine Conference
Osage Beach, Missouri

Sponsors
Institute for Continental Climate Viticulture and Enology
College of Agriculture, Food and Natural Resources, University of Missouri-Columbia

The Justin R. Morris Vineyard Mechanization Symposium

Honoring Dr. Justin R. Morris

Dr. Morris is currently Distinguished Professor and Director of the Institute of Food Science and Engineering at the University of Arkansas. He has directed his research toward developing processing, handling, harvest and production systems for numerous fruit crops, but is best known and held in high regard for his work on grapes and wine. Throughout his academic endeavors, he has consistently maintained focus upon the importance of final product quality.

Earning his doctorate from Rutgers University in 1964, Dr. Morris has now provided research, teaching, leadership and service to the grape and wine industries for over 40 years. The culmination of his research was the development of the Morris-Oldridge Vineyard Mechanization System, which was patented by the University of Arkansas in 2002 and acquired for commercial production by the Oxbo International Corporation shortly thereafter. He continues to publish research results from experiments with this system, and other industry-oriented publications as well.

Dr. Morris is well recognized as a leader in the U.S. grape and wine industries. His efforts will continue to benefit untold numbers of persons in these industries for decades to come.

Proceedings of the

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Editors:

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Cover photo: Pruning machine operating on high-trained vines in central Missouri.

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Commercialization of the Morris-Oldridge Vineyard Mechanization System

Justin R. Morris

Distinguished Professor
Institute of Food Science and Engineering
University of Arkansas

Acknowledgements

This research was a cooperative effort with French Camp Vineyards (Santa Margarita, Calif.) and OXBO International Corp. (Clear Lake, Wis.). The author acknowledges the scholarship and dedication of over 30 graduate students during the past 38 years and current post doctoral associates, Drs. Gary Main and Renee Threlfall, who have worked on the myriad aspects of vineyard mechanization. Thanks are also given to Drs. Pamela Brady and Janice Blevins for their assistance in preparing this manuscript, and to Greg Berg, OXBO viticulturalist, and Hank Ashby (French Camp Vineyard Manager) for their invaluable assistance during this research.

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Abstract

Researchers in the University of Arkansas Viticulture and Enology Program have been working on the development of a total vineyard mechanization system for over 37 years. This system allows maintenance or enhancement of fruit quality while mechanizing almost all vineyard operations, including dormant and summer pruning, leaf removal, shoot and fruit thinning, and harvesting. Research efforts were aimed at mechanizing these tasks on the 12 major trellising systems used throughout the industry. Plans for the sequencing and timing of operations on each of these trellis systems were also developed. In 2002 the University of Arkansas patented the Morris-Oldridge Vineyard Mechanization System (M-O System). This patent was sold to OXBO International Corp., which is marketing system components under the name Korvan™ Vineyard System. Beginning in 2002, studies were initiated at French Camp Vineyards, Santa Margarita, Calif., a commercial Vitis vinifera vineyard in the central coast region, to compare the effectiveness of machine-farming (mechanization) using the M-O System with traditional methods of canopy management using hand labor (hand-farmed). The study was conducted with the cultivars ‘Chardonnay’, ‘Sauvignon blanc’, and ‘Syrah’ trellised on a lyre system and ‘Merlot’, ‘Zinfandel’, and ‘Sangiovese’ trellised on a vertical shoot-positioned (VSP) system. Yield, fruit growth, fruit composition, wine quality, wine sensory attributes and economics of mechanization were evaluated on machine- and hand-farmed grapes. Mechanization at French Camp Vineyards used a balanced cropping concept which incorporated three operations: 1) machine dormant pruning; 2) machine shoot thinning; and 3) machine fruit thinning. Results of research from 2002-05 showed that yield and quality characteristics of machine-farmed grapes were not statistically different from those of hand-farmed grapes for the cultivars in this study. Wines from each cultivar and farming treatment were produced at a commercial winery and, after appropriate aging, sensory characteristics were evaluated by a professional wine analysis service. The only sensory difference found between wines from the two farming systems was with sweetness of the Sangiovese wine. Further objective analyses of the wine components showed no commercially practical differences. In 2006, cost estimates were derived for the three vineyard activities necessary to achieve balanced cropping. Use of machine farming for the three operations resulted in savings over hand farming of 45 percent on the lyre trellis, 49 percent on the VSP system and 62 percent on the quadrilateral (quad) trellis. Studies of mechanization of vineyard activities using the M-O System to achieve balanced cropping have shown grapes and their wines were equivalent to those obtained using hand labor for these operations with the added benefit of cost savings for the operations evaluated.

Introduction

Growers of premium wine grape cultivars traditionally have used hand labor in vineyards. However, scarcity of laborers, the expense of hand labor and increased competition from global markets with inexpensive labor have caused commercial growers to seek methods of mechanizing vineyard operations. Since 1966, the Viticulture and Enology Program at the University of Arkansas, Fayetteville has conducted research on postharvest handling, adapting harvesters to different trellises, and adapting, developing, and evaluating machines that mechanize canopy management practices such as dormant and summer pruning, leaf removal, shoot positioning and shoot and fruit thinning. The goal of this work was to develop systems that would allow complete mechanization of mature commercial vineyards without loss in fruit quality (Morris, 1979, 1985, 1986; Morris and Cawthon, 1979, 1980a, 1980b, 1980c, 1981a, 1981b; Morris et al., 1984a, 1984b).

Vineyard mechanization research began in the early 1950s at the University of California (UC), Davis with work involving harvesting (Winkler et al., 1957). Trellises were developed that positioned the grapes to hang under the wire. The grapes were harvested by severing the clusters from the vine with a cutter-bar machine that was mounted on a tractor. Severed clusters dropped onto a conveyor belt. This approach was never commercialized since the cutter bar frequently cut through the clusters.

In 1957, a team of scientists at Cornell University's Experiment Station, Geneva, N.Y., took a different approach. A specialized double curtain trellis, which became known as the

Geneva double curtain (GDC), was developed for growing ‘Concord’ grapes (Shaulis et al., 1960). Grapes were harvested using a mechanical harvester that literally shook the grapes off the vines one half row (one of the two curtains) at a time. This harvester was produced commercially by the Chisholm Ryder Co. (Niagara Falls, N.Y.).

In the early 1960s, two ‘Concord’ grape growers, R. Orton and M. Orton from Ripley, N.Y., adapted a cane fruit harvester designed by B. Weygandt to harvest grapes. Large plywood panels were mounted on the harvester so that they struck each side of a cordon row. This machine was the prototype of the O-W harvester (Chisholm Ryder Co.) (Shepardson et al., 1969) which became the model for all other shaker action machines (May, 1995; Morris, 2006).

As mechanical harvesters gained widespread use in commercial vineyards for both juice and wine grapes, there was a need to investigate the postharvest quality of mechanically harvested grapes. Researchers at the University of Arkansas (Morris et al., 1979) measured alcohol and soluble solids from grapes in harvest bins at six hour intervals. They found that mechanically-harvested ‘Concord’ grapes had a rapid increase in fermentation rates with time, demonstrating that the time between mechanical harvesting and processing of grapes could significantly affect product quality. Industry used this information to establish a maximum six hour interval between mechanical harvesting and processing. The researchers also found that fruit temperature in bulk pallets did not change significantly with holding time, but higher fruit temperatures increased the rate of grape deterioration. As a result, the processing industry in warm regions began to require growers to harvest at night, when fruit temperatures were cooler, to retain or improve the commercial quality of machine-harvested grapes.

Mechanical harvesters underwent continuous developments. Beater rods were improved and eventually evolved into bow rods on a majority of the harvesters. After mechanization of the harvesting operation, pruning and tying operations were the most time-consuming hand-labor operations in the vineyard. By 1971, preliminary research at the University of Arkansas indicated that grape vines could be mechanically pruned and that this could reduce pruning labor significantly (Morris et al., 1975).

The development and adoption of trellises that could be totally mechanized became of paramount importance. Trellises were needed that would allow maximum accessibility of the fruit to the harvester’s shaking mechanism and effective mechanical pruning for each vine growth habit. Properly trained vines had to accommodate efficient machine operations without excessive damage to the vines or reductions in fruit yield and/or quality (Morris, 2000; Morris and Cawthon, 1979). Training systems meeting these requirements included the single wire cordon and the Geneva Double Curtain (Shaulis et al., 1960). Research in Arkansas (Morris and Cawthon, 1980c) comparing the Umbrella Kniffin, bilateral single cordon (BC), and Geneva Double Curtain (GDC) trellis systems showed that the BC system was as productive as the Umbrella Kniffin and fruit produced on the two systems were comparable in quality. However, the GDC system was more productive than the other two systems with no reduction in fruit quality. Because both the BC and the GDC systems were effective for mechanized harvesting and pruning, these systems were recommended for vineyards.

Mark Greenspan (2007) reported on a survey conducted by Wine Business Monthly to determine the level of adoption of mechanization by growers and wineries. It was no surprise to find that mechanization practices were more common for larger operations, defined as having more than 500 acres, than for smaller ones (see Figure 1). Greenspan attributed this trend to the facts that larger operations often produce fruit for lower price point wines and so must reduce costs as much as possible, hand labor is too time consuming for larger operations, and larger operations can make more extensive use of equipment so can more easily justify the capital investments. In an effort to make mechanization more attractive to medium- and small-size operations, equipment manufacturers offer vineyard mechanization equipment that is tractor mounted. This approach may increase adoption of mechanization in small- and medium-size vineyards, particularly in the eastern and northwestern U.S.

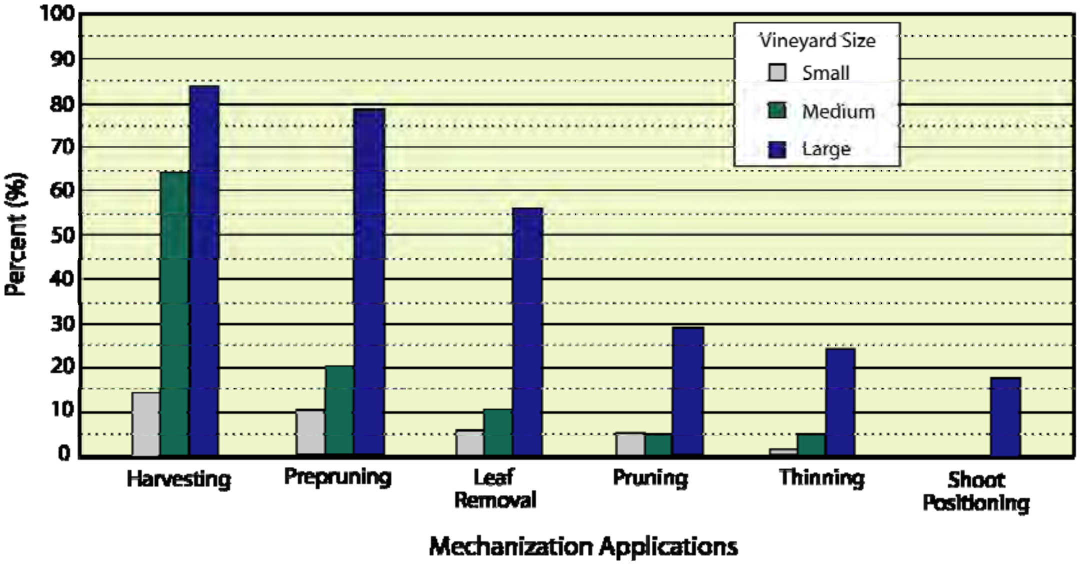


Figure 1. Mechanization of vineyard operations has been more aggressive in larger wine grape vineyards than in medium and smaller operations. (Greenspan, 2007. Chart used with permission of Wine Business Monthly).

California has been a leader in vineyard mechanization with harvesting being the operation most extensively mechanized (see Figure 2). Greenspan speculated that this may be, in part, due to the prevalence of larger vineyards in California. Within California, vineyards in certain areas are more mechanized than those in other parts of the state. For example, a representative from the Central California Winegrowers Association, which represents a region accounting for approximately half of the state's wine grape crush, indicated that, in the area they represent, 85 percent to 90 percent of the wine grapes are mechanically harvested. Mechanical harvesting has been almost totally implemented for juice grapes in the U.S. Wine grape growers have been slower to adopt mechanical harvesting primarily due to the reluctance of some wineries and winemakers, particularly in some regions of California, to accept mechanically-harvested fruit. This reluctance is being overcome as experience is showing that, with proper mechanical harvesting conditions and appropriate post-harvest handling, wines from mechanically harvested grapes can be as good or better than wines from grapes that were hand-harvested. With labor and immigration issues becoming the major concern, other U.S. grape growing regions may soon reach levels of mechanization adoption comparable to California.

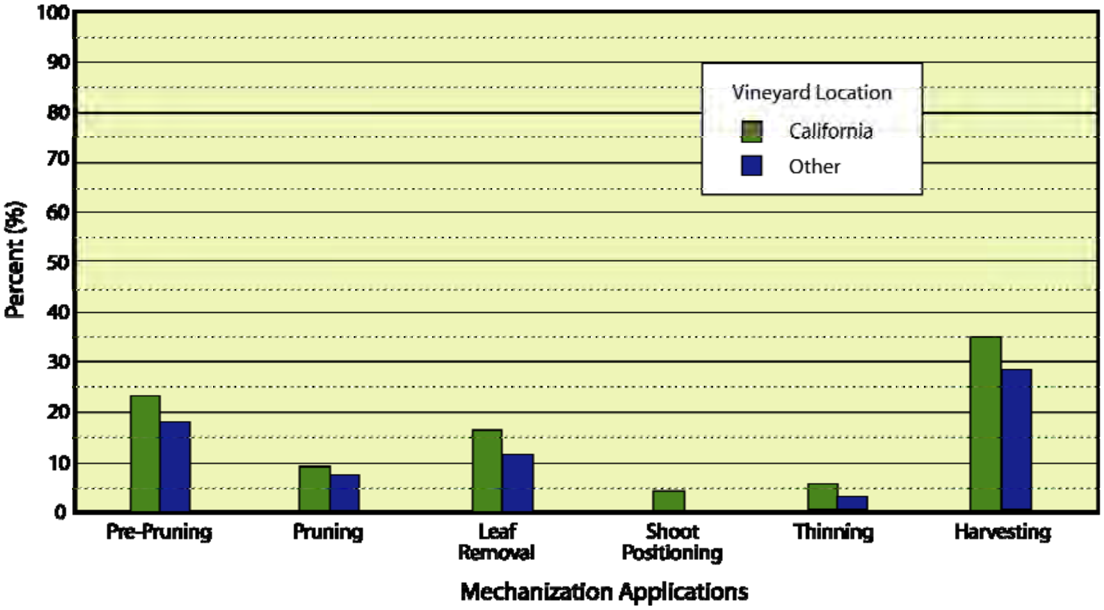


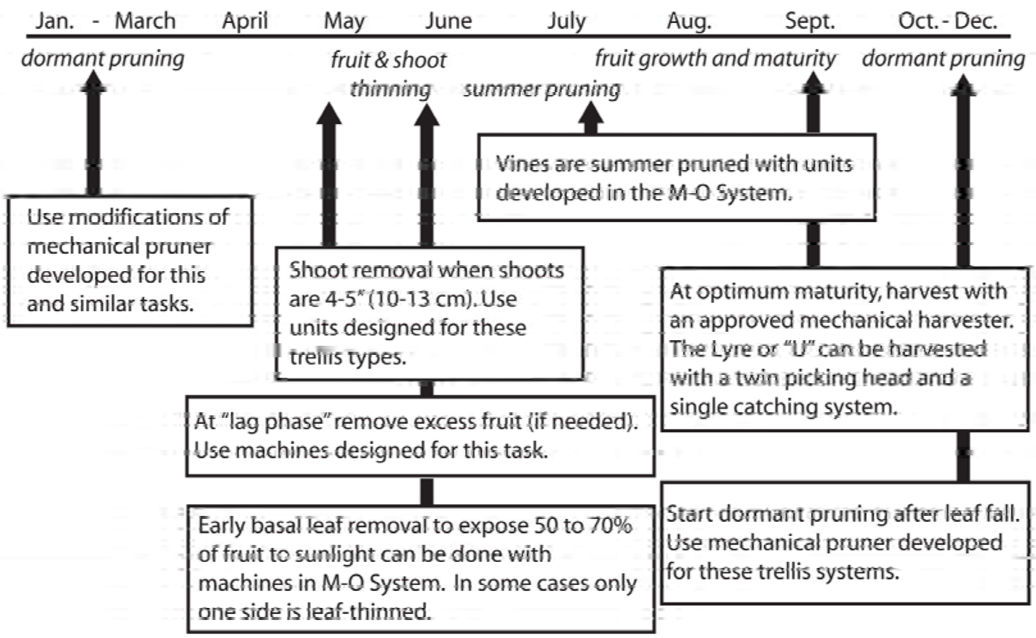
Figure 2. Although California has been a leader in adoption of vineyard mechanization, applications are becoming more common in other U.S. wine grape-growing regions. (Greenspan, 2007. Chart used with permission of Wine Business Monthly).

Work is currently underway at the University of Arkansas to develop a bibliography of vineyard mechanization literature from around the world. This project is providing confirmation that development of vineyard mechanization has not been sole domain of researchers in the United States. To date, over 1,500 articles from more than 30 countries have been identified. The worldwide interest in vineyard mechanization was emphasized in a symposium entitled "Development and Incorporation of Mechanization into Intensely Managed Grape Vineyards" at the 6th International Cool Climate Symposium for Viticulture and Enology held in New Zealand in 2006. During this symposium, Cesare Intrieri (2006) provided participants with insight into advancements in training systems and harvesters in Italy. He described work that has been done to improve and refine harvesters and to develop training systems favorable for use in a mechanized vineyard. Australia's Peter Hayes (2006) highlighted pressures on wine grape production which have necessitated a shift to more mechanization as well as mechanization trends in Australia. Hayes went on to predict that other new technologies, such as GIS, precision viticulture and nanotechnologies will soon be melded with traditional ideas of vineyard mechanization to allow even broader approaches to vineyard management. Richard Smart (2006) took a look into his crystal ball to describe the vineyard of 2056. He predicted that climatic changes would result in the development of new grape growing regions and shifts away from some areas long associated with grape production. At the same time, vineyard operations will have become extensively mechanized with many of the "new" technologies discussed by Peter Hayes being commonplace in the vineyard of the future.

The M-O System

The author and Tom Oldridge, a northwest Arkansas grape grower and inventor, developed the M-O System, which includes over 40 different machines and attachments (20 of the machines or attachments used in the M-O System already existed in industry) for the mechanization of the 12 major trellis configurations used throughout the world. During years of research and development, the M-O System was foremost monitored for its ability to efficiently mechanize vineyard activities while maintaining fruit quality. In April 2002, the U.S. patent "Vineyard apparatus, system, and method for vineyard mechanization" (Morris and Oldridge, 2002) was issued to the University of Arkansas. The OXBO International Corp. (Clear Lake, Wis.) acquired the license to the M-O System and began manufacturing and marketing the system as the Korvan™ Vineyard System.

The M-O System includes comprehensive plans for the appropriate machine to use at the proper time for each operation on the major trellis configurations. Details and timetables for the mechanization of both upright and drooping growth habit grape cultivars are included in the system designs. Until the development of the M-O System, there had been no commercial system developed that provided this information. An example of the sequence of steps and timing of operations for the lyre or “U” trellis is shown in Figure 3.



Use modifications of mechanical pruner developed for this and similar tasks.

Shoot removal when shoots are 4-5" (10-13 cm). Use units designed for these trellis types.

At “lag phase” remove excess fruit (if needed). Use machines designed for this task.

Early basal leaf removal to expose 50 to 70% of fruit to sunlight can be done with machines in M-O System. In some cases only one side is leaf-thinned.

Vines are summer pruned with units developed in the M-O System.

At optimum maturity, harvest with an approved mechanical harvester. The Lyre or “U” can be harvested with a twin picking head and a single catching system.

Start dormant pruning after leaf fall. Use mechanical pruner developed for these trellis systems.

[a]Designed for viticultural areas in the United States. Appropriate timing would be modified for the southern hemisphere and other viticultural regions.

Figure 3. Steps and timing of operations in the Morris-Oldridge Vineyard Mechanization System (M-O System) for *Vitis vinifera* on lyre or “U” trellises.[a]

A key component to the efficient use of the M-O System is the concept of “balanced cropping.” Balanced dormant hand pruning based on records of past yields and vine vigor had been used to control crop level prior to the introduction of mechanization systems. But this hand pruning was done before hard spring freezes, hail storms, poor fruit set and other acts of natural crop reduction, and therefore could result in low yields. Because mechanized thinning can be performed rapidly, a larger potential crop (more nodes) can be left after pruning as a buffer against nature’s own crop reduction activities. Then, after the risk of most natural disasters has passed, shoot thinning and, if needed later, fruit thinning, can be used to fine-tune the crop load.

Although balanced cropping can be accomplished by hand, use of mechanized systems to adjust fruit load is more cost and time effective.

A study was established to evaluate the effectiveness of mechanization using the M-O System for pruning, shoot thinning, and fruit thinning in a commercial V. vinifera vineyard in the central coast region of California. The study was also designed to compare mechanized methods of canopy management with traditional methods using hand labor. Yield, fruit growth, fruit composition, wine composition, wine sensory analysis, and economics of mechanization using the M-O System were compared for hand- and machine-farmed grapes.

Materials and Methods

The commercial vineyard site used in this study was French Camp Vineyards (Santa Margarita, Calif.). The vineyard owners (Miller Family) and the vineyard manager (Hank Ashby) had followed the development of the M-O System and were committed to evaluating the system on high quality grapes. The vineyard site (Region III) has a soil type of Arbuckle sandy loam with a sprinkler system for overhead frost protection and a drip irrigation system. Machine-farming was used on 474 acres in 2003, 899 acres in 2004, and 1,021 acres in 2005. Cultivars evaluated included ‘Chardonnay,’ ‘Sauvignon blanc’ and ‘Syrah’ trellised on a 2-ft lyre, and ‘Merlot,’ ‘Sangiovese’ and ‘Zinfandel’ trellised on a vertical shoot-positioned (VSP) system. A 3-ft quad trellis also was used for the economic evaluation study.

Standard procedures for canopy management at French Camp Vineyards used hand labor (hand-farmed) to carry out all canopy management and fruit thinning operations. Mechanization studies were designed to evaluate the three operations necessary to implement a balanced cropping concept. Operations studied included:

1. **Machine dormant pruning.** Precision dormant pruning was carried out to retain the number of nodes necessary to achieve an estimated 200 percent of the final desired yield level. This left a cushion for unforeseen natural conditions without reducing the crop load below the intended target. Pruning weights were recorded. This operation uses the M-O System chassis with pruning attachments shown in Figure 4.

Figure 4. Shear pruning attachments on Korvan™ Vineyard System chassis shown working in *Vitis vinifera* vineyard at French Camp Vineyards, Santa Margarita, Calif. This configuration allows the tractor-pulled unit to prune facing sides of adjacent rows. (Photo courtesy of OXBO International Corp., Clear Lake, Wis.)

Figure 5. Korvan™ Vineyard System chassis equipped for shoot thinning. The speed of the tractor pulling the chassis and the speed of the thinner paddles can be adjusted so that the thinner leaves the desired number of shoots per meter of cordon, depending on cultivar and vigor. (Photo courtesy of OXBO International Corp., Clear Lake, Wis.)

2. **Machine shoot thinning.** To achieve an estimated 130 percent to 140 percent of the desired final yield level, the shoot thinner shown in Figure 5 was used with no hand follow-up when the new shoots were 10 cm to 20 cm. The tractor and paddle speed were adjusted so that the shoot thinner left 10 shoots/m to 30 shoots/m of cordon, depending on cultivar, vine vigor and the target yield requested by the commercial winery purchasing the grapes. Following shoot thinning, shoots/m of cordon were counted to determine accuracy of the mechanized operation.

3. **Machine fruit thinning.** If the vines still exceeded the target yield after dormant pruning and shoot thinning, then the fruit thinner attachment shown in Figure 6 was used to reach the desired crop levels. This operation was performed during or after the berry growth lag phase (a period of one to two weeks when there is a pause in fruit growth).

In order to achieve optimum rate of operation for the equipment used for each of these operations, it was necessary to adjust operating parameters such as tractor speed, striking force, etc., to account for climatic conditions, cultivar, amount of crop to be removed and other variables (Morris, 2004).

With both hand and machine farming, estimating crop yield is an essential aspect of balanced cropping. This estimate forms the basis for determining how much fruit, if any, to remove. In addition, winery buyers often set a target yield that they feel will produce fruit with the quality characteristics needed for their wines. Crop yield estimation is critical for adjusting crop levels to achieve these target yields.

In the past, for hand farming, cluster weights were used in combination with cluster counts to estimate final crop load. However, this method does not work well on machine-

Figure 6. Korvan™ Vineyard System chassis equipped with grape thinning attachments for bottom thumper fruit thinning on 2-ft lyre and quadrilateral-trained vines. Shown working in *Vitis vinifera* at French Camp Vineyards, Santa Margarita, Calif. (Photo courtesy of OXBO International Corp., Clear Lake, Wis.)

pruned vines (Pool et al., 1996). A more effective estimation method uses viticultural records of average berry weights at harvest in combination with average lag phase berry weights. Lag phase crop level was determined by removing all the fruit from a given length of cordon (to include at least four vines). The fruit removed was weighed and the average weight of crop per meter of cordon determined. This value was multiplied by the number of meters of cordon/ha in the plot to provide an estimate of the lag phase crop load.

Average lag phase berry weight was calculated from 200-berry samples. Since lag phase berry weight has been shown to correlate with final berry weight (Fisher et al., 1997), dividing the historical average harvest berry weight by the lag phase berry weight gave a multiplication factor which, when applied to the value obtained for lag phase crop load, provided an estimate of final crop load.

A comparison of the estimated final crop load to the target yield set by the winery buyer provided guidance in determining the amount of fruit to remove to achieve the target yield. A fruit thinner was then used to adjust the crop load to desired levels. When determining the amount of fruit to be thinned, it was also necessary to include a correction factor to account for berries and clusters damaged during thinning but left on the vine.

While mechanically fruit thinning, it was necessary to adjust the thinner to achieve the desired level of fruit removal. To adjust the thinner, fruit was removed from a given length of cordon after the fruit thinner was used. The fruit was weighed and the resulting crop load calculated. If the desired crop load was not achieved, the operating speed of the fruit thinner was adjusted and the procedure repeated until the desired amount of fruit was removed.

At harvest, 30 clusters from each cultivar and farming method were randomly selected for analysis. Clusters were weighed and the berries on each cluster counted to determine average berry weight. For juice analysis, clusters were put through a hand-operated crusher with the rollers adjusted so that stems and rachises were not crushed. Standard juice analyses were conducted as described by Morris (2007).

After the 2004 harvest, equal lots (4,000 lbs) of grapes from each cultivar and farming method were processed into wine at Paso Robles Wine Services Winery (Paso Robles, Calif.). The wines were produced using the winery's commercial method with all cultivars and farming methods receiving comparable treatment.

Sensory evaluation was performed on the wine from the 2004 vintage by Vinquiry Analytical Services (Windsor, Calif.) in 2005. Wines from each cultivar and farming method were evaluated using the UC, Davis 20-point system (Amerine and Singleton, 1977).

In June 2006, Mike Thomsen, University of Arkansas, Department of Agricultural Economics, and the current author worked with the French Camp vineyard manager to gather data and develop budgets to estimate the economic impact of mechanizing balanced cropping operations for wine grapes grown on three types of trellises: VSP, 2-ft lyre, and 3-ft quad. Data for these estimates were obtained from records maintained by the vineyard manager as well as from actual operating costs during the study years. Production operations that were not mechanized were assumed to be the same for both farming systems and were not included in the cost estimates.

All data were subjected to analysis of variance with the Statistical Analysis System (SAS Institute, Cary, N.C.). Mean separations were accomplished using Tukey's multiple comparison test at $P<0.05$ (SAS, 2000)

Results and Discussion

Pruning weights were similar between hand and machine farming (see Table 1). In a high percentage of the cultivars, shoots/m of cordon on machine-farmed plots were approximately double the number of shoots on the hand-pruned plots.

The results of the 2003-05 seasons’ yields are shown in Table 2. These data show that actual yields were close to target yields required by the purchasing winery, but the accuracy of achieving the target yields was somewhat variable between cultivars and years. The vineyard manager suggested that the data may not be a true reflection of the accuracy of hand labor since, for this research study, workers were monitored vigilantly resulting in more precise yields than are generally seen with hand farming. He predicted that in actual large-scale production, the machine-farmed vines may more closely reach target production levels than the hand-farmed vines since mechanized farming is more precise and consistent than hand farming.

Average berry sizes from the two farming treatments are shown in Table 3. For all cultivars except 'Chardonnay,' the berries were slightly smaller with machine farming than with hand farming. However, the differences were not significant in this study. A similar pattern was seen by Petrie et al. (2003) when comparing hand and machine thinning. Wample et al. (1996) reported a slight reduction in berry size with mechanized farming of 'Concord' grapes during a 10-year study conducted in Washington State. They hypothesized this could be a positive outcome since smaller grapes have a higher skin-to-berry volume ratio that can result in improved color of juice and wine products.

Farming method did not result in any significant differences in fruit composition for any of the cultivars (see Table 3). Sensory evaluation found no differences between wines from hand- and machine-farmed grapes, in nine of the 10 attributes evaluated or in the total sensory score (see Table 4). The one exception was that wine made from the machine-farmed 'Sangiovese' grapes was identified as more sweet than wine from the hand-farmed fruit (data not shown). However the residual glucose + fructose levels of the machine-farmed and hand-farmed 'Sangiovese' wine were 0.43 percent and 0.12 percent, respectively, which are below the 2 percent limit for a table wine (see Table 4).

Though statistical differences were found between wines from the two farming methods, there were no commercially practical differences (see Table 4). The pH (3.35-3.77) and titratable acidity (6.44 g/L to 7.31 g/L) levels of the wines were in acceptable ranges. The red grape cultivars produced wine with total red pigment values ranging from 4.52 absorbance units (a.u.) for Zinfandel to 9.32 a.u. for Syrah. Total phenolics of the red wines were 34 a.u. to 43 a.u. The residual glucose + fructose levels of the wines were <0.5 percent. Ethanol levels of the wines were 12.6 percent to 15.3 percent.

In 2006 a study was initiated to compare the costs of activities necessary to achieve balanced cropping under hand- and machine-executed regimes. Results revealed that hand farming costs were mainly associated with maintaining a large enough labor pool to assure all operations were performed in a timely fashion. For machine farming, costs included purchasing or leasing equipment, equipment maintenance and repair, labor to operate and maintain the equipment, and fuel and lubrication costs. Also included in cost calculations was the fact that machine farming increased trellis maintenance requirements by one percent for lyre and VSP systems.

The costs of mechanically pruning, shoot thinning and fruit thinning reflected the costs of owning and operating the Korvan™ equipment associated with the M-O System. In the region being studied, shoot thinning was necessary in most years while fruit thinning was necessary in about one of two years. For this reason, the budgets reflected the full costs of a shoot thinning operation and one-half of the costs of a fruit thinning operation. It was found that while the mechanized operations greatly reduced the need for hand labor it did not entirely eliminate hand operations. Small ground crews were needed to follow-up, measure, and provide information to machine operators. Hand farming costs used in the calculations reflected typical practices in the region. Hand pruning was charged as a piece rate and followed a pre-pruning operation. Hand labor for shoot and fruit thinning were charged hourly. While not directly evident from the data presented, hand labor costs under mechanized farming were only 8 percent to 15 percent of those under traditional methods.

The economic analysis of balanced cropping operations showed that costs saved through mechanization were economically significant (see Table 5). For the operations studied, machine farming resulted in a 45 percent savings over hand farming for grapes produced on the lyre trellis, 49 percent savings on the VSP system, and 62 percent savings on the quad trellis. The largest cost savings were realized from the shoot-thinning and fruit-thinning operations. Differences in cost savings for these operations among the trellising systems largely reflected differences in vine spacing that impacted field speeds. Piece rates for pruning operations varied by trellising system.

The vineyard manager noted that mechanization provides other benefits in addition to the economic advantages shown here. First, mechanization helps stabilize grape yield through the concept of balanced cropping. Because the grower was able to make the final adjustment on crop size late in the growing season, growers were afforded an opportunity to compensate for crop losses due to frost injury, poor growing conditions or poor fruit set. Second, by eliminating reliance on hand labor, the vineyard manager was able to retain fewer but better trained workers. Over time, this promises to reduce overhead for human resources-related expenses and to lower costs associated with managing liability.

Conclusions

Results of research for the 2003-05 seasons at the French Camp Vineyards, Calif., have shown that yield and quality characteristics of machine-farmed grapes were not different from those of hand-farmed grapes for the cultivars in this study (‘Chardonnay,’ ‘Sauvignon blanc,’ ‘Merlot,’ ‘Syrah,’ ‘Zinfandel’ and ‘Sangiovese’). Almost no sensory differences between wines from the two farming systems were identified for the cultivars studied.

In 2006, cost estimates were derived for each of the vineyard activities necessary to achieve balanced cropping. Machine farming of the three operations resulted in a 45 percent savings over hand farming for grapes produced on the lyre trellis, 49 percent savings on the VSP trellis, and 62 percent savings on the quad trellis.

Commercial verification studies of mechanization of vineyard activities to achieve balanced cropping have shown that grapes and wine were equivalent to those obtained using hand labor for these operations. With the added benefit of cost savings, it can be concluded that implementation of mechanization systems such as the M-O System will assist growers in remaining competitive in world markets.

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Table 1. Comparison of shoot density after pruning and pruning weight for *Vitis vinifera* grapes that were either machine- or hand-farmed at French Camp Vineyards, Santa Margarita, Calif. (2003-05).

Cultivar	Farming method	Pruning weight (kg/m) [1]		Shoots density (shoots/m)		
		2003	2004	2003	2004	2005
‘Chardonnay’[2]	Hand	0.52	0.33	10	13	16
	Machine	0.45	0.33	18	32	25
‘Sauvignon blanc’[2]	Hand	0.79	0.30	13	13	13
	Machine	0.79	0.37	24	30	32
‘Merlot’[3]	Hand	0.45	0.52	13	13	13
	Machine	0.36	0.49	17	30	28
‘Sangiovese’[3]	Hand	0.57	0.58	13	13	11
	Machine	0.39	0.39	18	24	26
‘Syrah’[2]	Hand	0.67	0.48	13	13	13
	Machine	0.64	0.45	27	25	28
‘Zinfandel’[2]	Hand	0.61	0.82	10	13	13
	Machine	0.43	0.74	20	31	23

[1] Pruning weights were taken only during the first two years of this study.

[2] 2-ft lyre trellis

[3] Vertical shoot-positioned trellis

Table 2. Comparison of target yields requested by winery with actual yields for *Vitis vinifera* grapes hand or machine farmed at French Camp Vineyards, Santa Margarita, Calif. (2003-05).

Cultivar	Farming method	2003 Target yield (t/ha)	2003 Actual yield (t/ha)	2004 Target yield (t/ha)	2004 Actual yield (t/ha)	2005 Target yield (t/ha)	2005 Actual yield (t/ha)
‘Chardonnay’[1]	Hand	17.9	14.1	18	18.8	22.4	28.8
	Machine	17.9	15.7	18	15.7	22.4	24.4
‘Sauvignon blanc’[1]	Hand	17.9	18.2	20	20.8	22.4	20.9
	Machine	17.9	15.7	20	24.2	22.4	20
‘Merlot’[2]	Hand	13.5	13.2	15.7	20.2	15.7	19.8
	Machine	13.5	14.6	15.7	17.5	15.7	13.8
‘Sangiovese’[2]	Hand	6.7	6.7	9	15.7	11.2	10.8
	Machine	6.7	7.4	9	10	11.2	16.5
‘Syrah’[1]	Hand	15.7	14.3	17	12.8	18	20.9
	Machine	15.7	14.6	17	22	18	15.6
‘Zinfandel’[2]	Hand	15.7	16.1	13.5	8.7	13.5	17
	Machine	15.7	16.8	13.5	11.4	13.5	10.7

[1] 2-ft lyre trellis

[2] Vertical shoot-positioned trellis

Table 3. Berry weight and composition for grapes hand- or machine-farmed at French Camp Vineyards, Santa Margarita, Calif. (2003-05).

Cultivar	Farming method	Berry wt. (g)	pH	Soluble solids (%)	Titratable acidity (g/L)
‘Chardonnay’[1]	Hand	1.02	3.65	23.0	8.6
	Machine	1.03	3.56	23.1	8.4
‘Sauvignon blanc’[1]	Hand	1.09	3.71	22.7	6.0
	Machine	1.04	3.64	22.8	5.9
‘Merlot’ [2]	Hand	0.92	3.53	24.3	7.8
	Machine	0.91	3.53	24.7	8.2
‘Sangiovese’[2]	Hand	1.22	3.68	25.1	6.8
	Machine	1.14	3.56	26.7	6.7
‘Syrah’[1]	Hand	0.93	3.68	25.4	8.0
	Machine	0.83	3.64	24.5	7.8
‘Zinfandel’[2]	Hand	1.27	3.49	24.6	8.4
	Machine	1.18	3.50	24.3	8.0
P value		ns	ns	ns	ns

[1] 2-ft lyre trellis

[2] Vertical shoot-positioned trellis

ns = Means (average of three years) within a column and cultivar are not significantly different by Tukey test ($P \leq 0.05$)

Table 4. Evaluation of wine made from grapes hand or machine farmed at French Camp Vineyards, Santa Margarita, Calif. (2004 vintage).

Cultivar	Farming method	Total sensory score[1]	pH	Titratable acidity (g/L)	Total red pigments	Total phenolics (a.u.)	Residual glucose + fructose (%)
'Sauvignon blanc'[2]	Hand	15.0 a	3.39 a[4]	6.56 a	-[5]	-	0.11a
	Machine	15.4 a	3.35 b	6.53 a	-	-	0.09 b
'Chardonnay'[2]	Hand	15.2 a	3.43 a	6.57 b	-	-	0.23 a
	Machine	14.2 a	3.43 a	7.08 a	-	-	0.18 b
'Sangiovese'[3]	Hand	14.8 a	3.60 b	6.87 b	5.81 b	36.8 b	0.12 b
	Machine	14.0 a	3.77 a	7.17 a	7.14 a	42.6 a	0.43 a
'Syrah'[2]	Hand	13.0 a	3.67 a	6.73 a	9.32 a	36.3 a	0.10 a
	Machine	13.0 a	3.66 a	7.31 a	9.32 a	35.8 a	0.08 b
'Merlot'[3]	Hand	13.4 a	3.62 a	6.44 a	8.13 a	34.3 a	0.06 a
	Machine	14.0 a	3.53 b	6.77 a	7.53 b	33.8 a	0.06 a
'Zinfandel'[3]	Hand	12.2 a	3.60 a	6.85 a	4.62 a	36.4 a	0.11 a
	Machine	11.2 a	3.54 b	6.89 a	4.52 b	36.5 a	0.10 a

[1] Sensory score based on total scores for evaluation of sensory criteria. Total ratings classified as superior (17-20), standard (13-16), below standard (9-12), and unacceptable or spoiled (1-8)

[2] Lyre trellis

[3] Vertical shoot positioned trellis

[4] Means within cultivar and component having the same letters are not significantly different using Tukey test at $P \leq 0.05$

[5] Data not obtained

Table 5. Comparison of total costs (dollars/acre) for pruning, shoot thinning and fruit thinning by hand or machine farming of *Vitis vinifera* grapes grown on three trellis systems at French Camp Vineyards, Santa Margarita, Calif. (2005 season).

	Total cost ($/acre)		
Farming Method	VSP[1]	Lyre[2]	Quad[3]
Machine Farmed			
Prune	119.84	239.67	157.87
Follow-up	67.35	72.08	47.36
Shoot thin	78.03	156.07	117.05
Fruit thin	78.46	78.46	58.84
Total	343.68	546.28	380.53
Hand Farmed			
Pre-prune	26.93	53.86	37.87
Prune	251.04	386.92	317.76
Shoot thin	232.00	463.99	463.99
Fruit thin	109.16	175.87	175.87
Total	619.13	1080.64	995.49
Difference (Hand – Machine)	275.45	534.36	614.96

[1] Vertical shoot-positioned (VSP) trellis

[2] 2-ft lyre trellis

[3] 3-ft quadrilateral trellis

Status and Future of Vineyard Mechanisation in Australia and New Zealand

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Abstract

The Australian viticultural landscape is comprised of a nominal 150,000 ha, of which 90,000 ha are "warm region" (Inland Irrigated) and 60,000 ha are "cool region" vineyard (i.e., so-called Non-Irrigated region). This latter region produces an average 6 t/ha to 8 t/ha, compared with a "warm region" average of 15 t/ha to 18t/ha both from generally wider row spacings (2.5m to 3.3m), and with respectively annual production costs ranging from around A$6,000/ha to A$18,000/ha.

Labour costs are significant and comprise between 50 percent and 75 percent of total production costs and consequently mechanisation has been a serious focus in a large proportion of Australian vineyards. This most notably arises in the Inland Irrigated areas and the larger-scale, cooler vineyards with accommodating topography.

This applies particularly to the operations of mechanical harvesting (applied to possibly 90 percent to 95 percent of the national crop), mechanical pre-pruning of cordon trained/spur-pruned vines, and in very high yield years, mechanical thinning of crops.

Given the fundamental issues of 1) pressure on productivity and financial returns (the "cost-price squeeze"), 2) uncertain availability, irregular adequacy of skills and the relative expense of labour, and 3) the heightened demands for critical timeliness of viticultural interventions, it appears increasingly inevitable that further mechanisation must occur, especially in the relatively high cost/low productivity regions. In accepting this premise, the likely influence of climate change on vineyard site, vine performance and operational imperatives should equally be considered.

Thus it is likely that we will see the interfacing of "conventional mechanisation" with other new technologies including GIS, precision viticulture techniques (near and remote sensing and control), field sensor and communication networks, scenario modeling (site, season, yield-quality targeting, etc.) and nanotechnologies. The resolution focus will range from a broad or narrow-scale zonal management outcome to individualised vine treatments such as selective harvest or thinning on a vine-by vine basis.

These innovations will see a need for development of the following:

- Effective R&D linkages between viticultural sciences, engineering and the related geographic, oenological and sensory sciences
- Specific skills in the consultancy/service sector

- New management approaches and operational capacity within vineyards
- An even more close relationship and understanding between viticulturist/grower, the oenologist/winemaker and their market

The presentation to be delivered at this meeting will address a number of these issues and will illustrate progress towards optimising vineyard performance. Examples will demonstrate a particular approach that we term “zonal viticulture,” and which involves a range of remote sensing, precision techniques, people and devices to identify and manage individual vineyards in a zoned manner.

N.B. This paper is based closely on a paper presented at the 6th International Cool Climate Viticulture and Oenology Symposium, Christchurch, New Zealand, 2006.

Research and Innovations for Vineyard Mechanization in Italy

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Abstract

Some of the more notable innovations introduced into the landscape of Italy's viticulture over the past three decades have been the short-cane, spur-pruned training systems developed at the University of Bologna and designed to replace such traditional long-cane systems as Guyot, Sylvoz, arch, and the like that are still used in many of the country's districts today. These new models embody features aimed at upgrading crop quality, lowering overhead outlays, reducing environmental impact and raising yield potential. The conceptual framework needed to achieve these four goals was constructed on core principles enabling an "organic approach" to vineyard architecture design that essentially led to seven model training systems: an upgraded variation of the textbook Spur-pruned Cordon, Double Curtain, Free Cordon, Moveable Free Cordon, Moveable Spur-pruned Cordon, COMBI and, most recently, the Semi-minimal-pruned Hedge. Their subsequent testing and fine-tuning elicited their baseline physiological responses, laid down proper field-management criteria and led to the design of specific mechanical harvesting and pruning units. The new training systems proved well-matched to a broad range of the environmental conditions found in the districts of central and northern Italy and, especially, to the key factors that deliver crop quality and yield in vineyards designed for machine integration.

Introduction

Italy's winegrape acreage has registered a gradual decline from a peak of more than 1.1 million hectares (ha) in 1970 to the estimated 0.7 million ha or so today, with a possible further slight drop being projected over the next few years (see Table 1). Yet this retrenchment, which is the result of a cap on new plantations under European Union legislation that has led to the uprooting and demise-by-neglect of the oldest vineyards, also has an upside in that many small holdings with vines diseased, unproductive or obsolescent in terms of crop quality and management practices have disappeared and in part been replaced by new ones incorporating innovations long advocated by researchers (Baldini and Intrieri, 1978; Baldini and Intrieri, 1982; Intrieri and Silvestroni, 1983; Volpelli and Poni, 1988; Poni and Tabanelli, 1994; Intrieri et al., 1994).

Despite this ongoing and irreversible retrenchment, Italy's viticulture holdings are still notably fragmented, including those strewn along steep hillsides, and marked by too many, and too old, training systems maintained by small growers very much attached to traditional ways and means (see Table 2). The upshot of this situation is the survival of bush-like and low hedgerow systems of Goblet origin in the less fertile areas of both north and south, but especially in upland districts, and pergola- and Sylvoz-based models like tendone, pergola-hedge, pergolette, free-cane Casarsa and Raggi in the more fertile central and northern zones. In other words, most of the traditional systems in the former are medium-density hedgerows at 3,000 vines/ha to 3,500 vines/ha with long-pruned, often arched Capovolto-like canes, and in the latter expansive canopies with roughly 2,000 vines/ha but still pruned long with downward growing canes.

The striking fact about all these systems is that the short spur-pruning that came with the original Goblet and its initial offshoots came to be replaced by long pruning. While this switch may be due to the relative ease of the latter method, it certainly failed to take account of the functional imbalances and subsequent adverse effects thereby produced. Put another way, long pruning and arched canes give rise to several 'blind buds' near the middle of the cane and non-uniform shoot growth resulting in staggered bunch ripening, especially pronounced in seasons of adverse weather (Baldini et al., 1974; Intrieri and Poni, 1997). Another drawback to these traditional systems is a tall, complicated trellis that is ill-suited to mechanization. Even where these vines are hedgerow and can thus be cut back somewhat and lowered, their long canes permit only mechanical harvesting and summer, but not winter, pruning. Not to mention the fact that manual harvesting and pruning of these traditional systems almost always take more than 400 man-hours/ha/year to 500 man-hours/ha/year, meaning a net loss on the balance sheet.

If Italy's viticulture industry is to remain competitive, it must thus accelerate the pace both of converting existing plantations to more efficient procedures and, above all, of new plantations that embody advanced criteria to ensure high performance in terms of crop physiology and management. This means, in effect, the new training models must be perfectly matched to the mechanical units designed for pruning and harvesting operations.

New Vineyard Planning

The core building block for vineyards of advanced design and better balanced cropping is the spur-pruned permanent cordon. With all things being equal, all the training systems employing it produce less crop per meter of row than traditional models but grapes are almost always of better quality. The main advantage of these models is their distribution of bud load on a limited number of spurs with one to three nodes. It has been widely demonstrated that the cropping shoots on these spurs develop uniformly because the effects of acrotony and competition are reduced as the shoots in early development have a better chance of drawing directly on the nutrients stored in the old wood. Leaf area too is thus more evenly distributed and berry ripening more uniform because the clusters have enough assimilates in their shoot leaves.

While these elements are key to enabling mechanical picking and pruning, new plantations should also incorporate a set of features that are tightly integrated with one another and are solidly backed by the findings of research over the last two decades. In other words, the entire package should lead to a vineyard embodying (i) improved crop quality, (ii) improved productivity, (iii) low environmental impact and (iv) lower overhead outlays. These targets are perfectly compatible and equally important. Indeed, it is self-evident that crop quality would make no sense if yields were too low and overhead too high such that the whole enterprise is economically unfeasible. It would be just as unacceptable if new plantations had too costly an impact on their environments and the growers who work in them.

Innovative Machine-integrated Training Systems Developed in Italy

While there are many possible variations on the basic spur-pruned cordon model, all must be capable of integrating trellis systems and machinery, and adapting plant response to cultivar traits and the given environmental conditions. This short-list of specifications essentially points to little more than a handful of training systems in Italy: “Spur-pruned Cordon,” “Double Curtain,” “Free Cordon,” “Moveable Free Cordon,” “Moveable Spur-pruned Cordon,” “COMBI” and the recent “Semi-minimal-pruned Hedge,” which is still being tested.

Depending on the system, the harvesters employed are either a “horizontal” or a “vertical” head**.** On the other hand, pruning does not depend on the training system, as all of them can accommodate different type of units, including the low-cost three-bar cutter called the TRIMMER (see Figure 1) that can be mounted on any mid-sized tractor. Designed and developed by the University of Bologna’s Chair of Viticulture in 1975 and now embodying later upgrades (Intrieri et al., 1995), the TRIMMER can readily handle all summer and winter pruning operations quickly and efficiently.

Spur-pruned Cordon (SPC). The textbook SPC (also called Vertical Shoot Positioned) is best suited in its structurally upgraded and physiologically balanced version to less fertile, hillside areas because it is concordant with vine vigor and better exploits natural energy sources. Its main structural changes include a trellis height reaching 1.2 m to 1.3 m above the cordon to make more room for the hedgewall and moveable foliar wires for vertical positioning of cropping shoots from the onset of growth so as to limit summer operations to cuts above and on the side of the wall and to heading of shoots jutting from the top pair of wires or out into the interrow alley (see Figure 2).

Figure 1. The TRIMMER machine. Incorporating all the upgrades since the original 1975 model, the unit has three adjustable cutters for winter-summer pruning of most systems, especially Spur-pruned Cordon, Double Curtain and Free Cordon. The current TRIMMER was designed by the University of Bologna's Chair of Viticulture in 1995 and built by the Faenza-based Tanesini company.

Generally speaking, the revamped SPC yields a quality crop and offers a good level of mechanization, but in most cases it permits only mechanical pre-pruning and not a full regime. Conventional over-row horizontal shakers can be used for harvesting, units that today are so efficient they appear to have reached their operational ceiling, as established by slappers, for both must loss (10 percent to 15 percent) and vine damage.

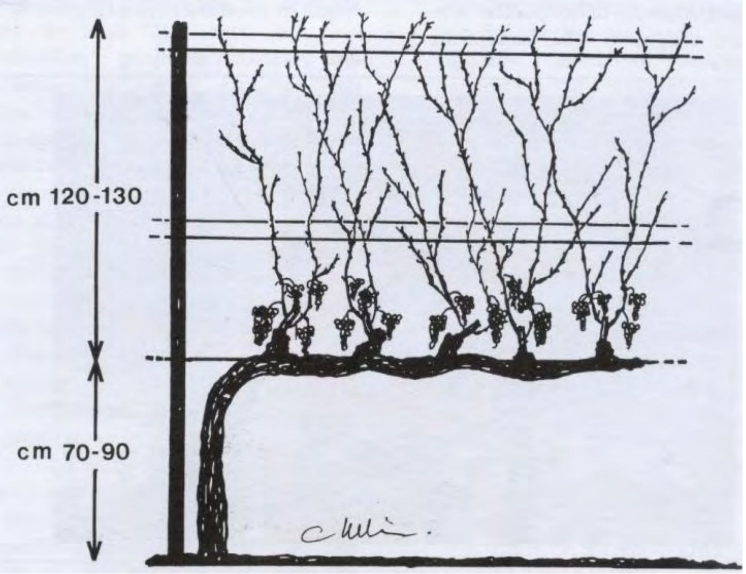

Figure 2. Schematic rendering of the upgraded SPC. Trellis height at least 1.2 m to 1.3 m above the cordon and pairs of moveable foliar wires are the main variations.

Double Curtain (DC). The DC, a derivative of the GDC, was introduced in Italy in 1970. The DC is without foliar wires and features two parallel permanent cordons spaced 1.4 m apart along the horizontal plane whose canes grow freely downward. The DC's greater inter-cordon spacing, moveable horizontal arms, and so on, are the elements of fine-tuning that have made possible full mechanization of harvesting and summer-winter pruning (see Figure 3).The DC can be harvested with commercial inter-row, half-row units first developed as a prototype by the University of Bologna Chairs of Viticulture in 1972 (Baldini et al., 1973). Harvesting is done by vertical head on the main cordon wire, not as in the traditional direct horizontal slapping of the SPC vegetative wall, and as such yields the best results in terms of crop quality and must loss reduction compared to the SPC (see Table 3).

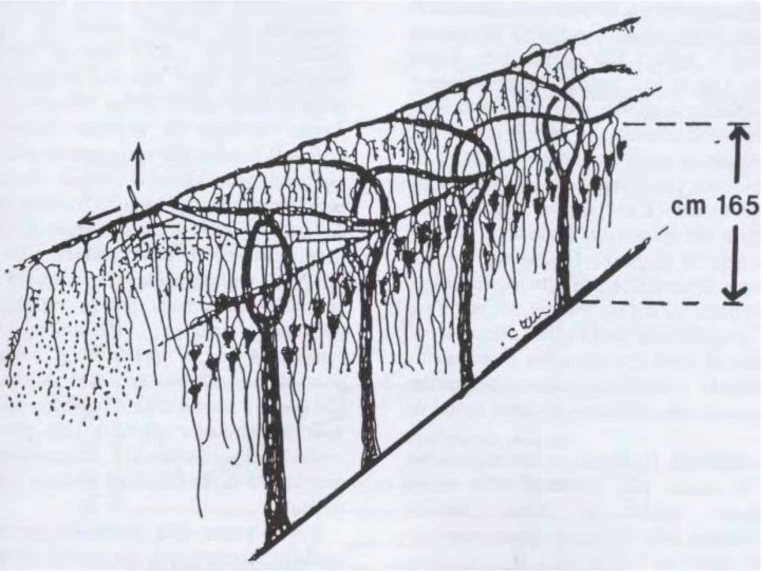

Figure 3. Schematic rendering of the upgraded Double Curtain (DC), derived form the American GDC. The DC is well-suited to vertical-head harvesting and mechanical summer-winter pruning. The main DC changes include horizontally positioned moveable arms to facilitate pruning and enhanced inter-cordon spacing to harvest one curtain at a time with a simple inter-row half-row unit.

A look at a few items from trial data sets stretching back many years, but still valid, underscore the effectiveness of the DC (Intrieri et al., 1988**).** Data shows that its performance under full mechanization is perfectly analogous to its performance under all-manual management in terms of cropping capacity and crop quality (see Table 4). Unsurprisingly, substantial differences emerge in the time and man-hours needed for these operations under the two regimes. Even if we foreshorten our perspective to harvesting and summer-winter pruning, including manual combing for both regimes, we find that over 320 hours/ha/year were needed on average over 7 years for hand management against just over 33 hours/ha/year for mechanical, a time savings of nearly 90 percent (see Table 4). When canes were later combed in a semi-mechanized approach using metal spacers with end-wires on trellising to push the growing shoots to the outside of the DC's curtains, further savings were achieved (Intrieri et al., 1994, l.c.).

The DC is also capable of notable shoot vigour control because of the downward-growing shoots and, hence, is well matched to fertile soils, where it even enables planting densities up to 4,000 vines/ha to 4,500 vines/ha, or 5 km of cropping cordons/ha. All in all, the DC represents a mainstay of advanced viticulture, and its all-around integration with mechanical units, including sprayers, corresponds in every way to the four targets today's systems must deliver.

Free Cordon (FC) and Moveable Free Cordon (MFC). The FC is made by a single horizontal cordon, but without foliage wires, and can be mechanically harvested using the over-row horizontal shaker machines and pruned with cutter units like the TRIMMER (see Figure 4).

Since its introduction over 20 years ago, the FC has undergone significant changes (Intrieri and Silvestroni, 1983, l.c.; Intrieri, 1988; Intrieri and Filippetti, 2000). It currently features tautly coiled support wire to keep the permanent cordon straight; a permanent cordon of two entwined canes in order to increase bud number, offset any broken shoots and prevent the cordon rolling over under bunch weight; and spurs positioned vertically from year one of cordon formation to ensure an "open" canopy of upward-growing shoots (see Figure 5).

Figure 4. The Free Cordon (FC) during winter pruning with the TRIMMER unit.

The most notable modifications to change from FC to MFC are the bowed trunk and moveable main wire, features that do not limit the harvest by traditional horizontal shaking units but make possible the use of the vertical-shaker harvesters which proved to reduce must losses and improve vintage quality (see Figure 5). A special unit called the TRINOVA Harvester was developed for the MFC (Intrieri, 1988, l.c.) and is widely used today in large vineyard operations (see Figure 6). An overhead TRINOVA Pruner was also developed (Intrieri, 1988, l.c.) to provide full mechanization or allows, as an alternative, rapid manual retouching since it has two rear platforms equipped with power shears (see Figure 7).

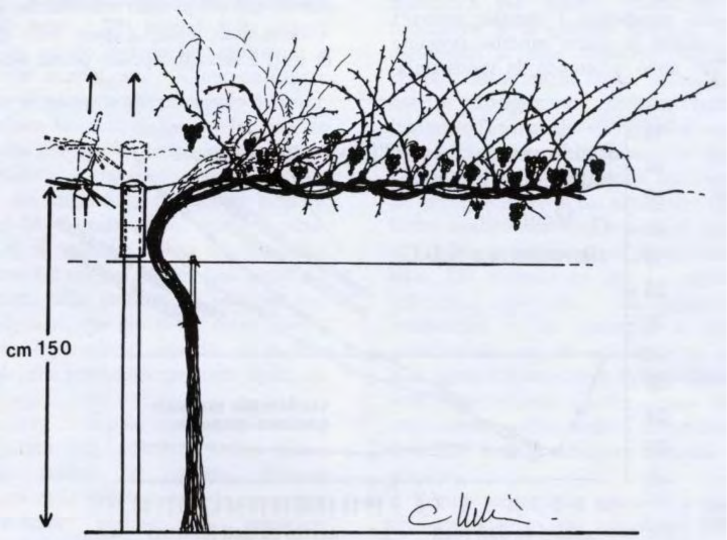

Figure 5. Schematic rendering of the Moveable Free Cordon (MFC). The cordon-support wire runs through plastic caps atop the trellis posts and arched vine trunks enable the cordon wire to move during vertical-head harvesting. The MFC lends itself to vertical and horizontal head harvesting as well as summer-winter pruning units.

Figure 6. The overhead TRINOVA vertical head unit, specifically designed for the MFC.

Figure 7. The TRINOVA during winter pruning of the MFC. It features two rear platforms equipped with power shears for rapid hand retouching.

Independent from the type of harvesting, the big advantages of the FC and MFC in their current forms are that they require no combing and provide a natural balance of light and shade around clusters. While FC and MFC are not suggested for cultivars with downward growing habit, they are best utilized for cultivars of upright or semi-upright habit like Cabernet Sauvignon, Cabernet Franc, Sauvignon Blanc, Chardonnay and Sangiovese, to which the free cordon is particularly suited. The cropping shoots of such cultivars give rise to a well-defined, high fruiting zone extending unbroken along the row in an open canopy well-exposed to sunlight. On the MFC, trials using the TRINOVA on various cultivars show that all the advantages of indirect vertical shaking can even be more pronounced than usual (see Table 5). Since both the FC and MFC have no obstacles like trellises or wires above the permanent cordons, they permit the use of different units (including the TRIMMER), whose cutters can be adjusted to both summer and winter pruning regimes.

Moveable Spur-pruned Cordon (MSPC). Given the vertical shaker's proven success in reducing losses and notably improving crop quality, we decided to apply this harvesting head to other systems either by adapting it to traditional ones or developing novel models for it.

The most interesting variation on a traditional model was the reshaping of the SPC to the MSPC. Here the permanent cordon's wire is strung through a "button-hole" bracket on the side of the posts and, as in the MFC, the trunks are bowed so as to enable cordon, wire and vine to move upward as the vertical head harvests without damaging the trunks (see Figure 8). Of course, the MSPC may also be harvested with the traditional horizontal slapping machines.

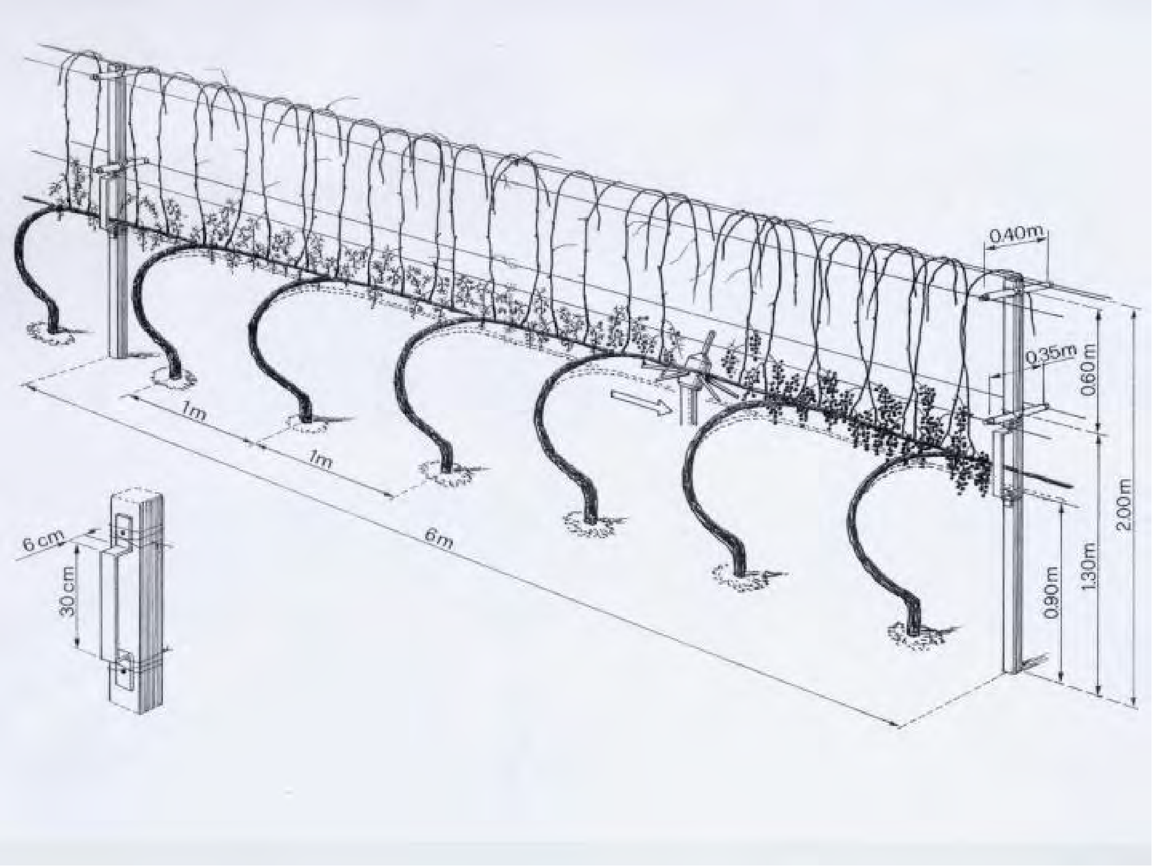

Figure 8. Schematic rendering of the Moveable Spur-pruned Cordon (MSPC). Vine trunks are bowed and the cordon wire is strung through "button holes," enabling upward movement during harvest by the vertical-head TRINOVA. The MSPC can also be harvested by conventional over-row, horizontal-head units.

The response from the initial trials run in 2002 on several cultivars using a TRINOVA vertical-shaking unit adapted for cordons set 70 cm to 80 cm from the ground was very good (see Table 6). Another trial comparing vertical and horizontal heads (TRINOVA against traditional slapper unit) with MSPC also showed that the former improved the harvested crop, delivering more intact clusters and a very low count of both free must and debris (see Table 7).

COMBI. This is a recently developed system (Intrieri and Filippetti, 2000 l.c.) designed to incorporate the advantages inherent in the DC and California U-trellis. The vines are spaced 50 cm to 70 cm along the row and every other cordon is deployed on the outside wires about 110 cm to 120 cm from the ground so as to create dual parallel walls vertical shoot positioned by paired foliar wires, with the U-trellis every three to four posts and moveable arms as in the DC on the intermediate posts. The main support wires are strung through “button-holes” on trellis U arms, as in the MSPC, to enable vertical shaking of each wall’s cordons and canes by a “pivoting-star” head (see Figure 9). The harvest trials were run with a single-row unit like that used for the DC and the results were very good (see Table 8). The COMBI can be mechanically pruned in summer and winter with a multiple-bar unit like the TRIMMER used with the DC (see Figure 10).

Figure 9. A COMBI vineyard. The system features a double horizontal wall, alternating U-shaped trellising with moveable arms like those in the DC. The cordons are secured to main wires running through “button holes” on the U frame to enable movement during vertical-head harvesting. COMBI is compatible with the same single-row vertical shaking units used for the DC.

Since the COMBI's paired moveable foliar wires position the shoots upward and, hence, they do not jut out towards the alley, inter-row spacing can be narrowed to 3.2 m to 3.5 m, compared to the 4 m of the DC. This makes it possible to reach more than 6 km of cropping cordons per hectare, against the DC's 5 km of cropping cordons per hectare. The COMBI thus lets you improve crop quality by reducing yield per linear meter while raising overall yield per hectare.

Figure 10. The COMBI can be pruned with the same multiple-blade TRIMMER unit used for DC.

Semi-minimal-pruned Hedge (SMPH). Though still undergoing fine-tuning trials, the SMPH is essentially a variant on the minimum pruning (MP) model developed and tested over the last twenty years in Australia (Clingeleffer 1983; Clingeleffer and Possingham, 1987; Pool et al., 1993). While the MP proved successful in Australia's hot-dry districts and with irrigated vines of such premium cultivars as Riesling, Chardonnay, Shiraz and Cabernet Sauvignon, trials in cooler areas of Australia and in the northern United States, as well as in France, Spain and Germany (Carbonneau, 1991; Ollat et al., 1993; Martinez de Toda and Sancha, 1998; Schultz et al., 1999) have often yielded contradictory results. It appears that MP is sensitive to original environmental and management conditions and, hence, is best suited to warm climates and early- to mid-season cultivars. In effect, this was corroborated in MP trials run in Italy on the early Chardonnay (Iacono et al., 1998; Poni et al, 2000) which responded well, but MP proved unsatisfactory on the mid- to late-Sangiovese in a northern temperate area, where the MP vines showed alternate cropping and more than double the crop of control on the average. Additionally, despite an earlier formation of active leaf area, Sangiovese berries showed a marked delay in sugar storage and incomplete ripening, effects even more pronounced under high crop load with final sugar content being reduced (Intrieri et al., 2001).

In the latter, however, a three-year comparative trial run (1996 to 1998) on MP vines with nearly 650 buds/m of row against 18 buds/m of cordon on control SPC vines demonstrated the more numerous MP clusters were, unusually so for Sangiovese's notably compact ones, much smaller and their berries less compact so that they were far less susceptible to botrytis infection, also unusual for Sangiovese. This suggested that by decreasing the bud load on the MP this system may maintain vine performance and berry quality in Sangiovese without losing the capability to produce less compact clusters that are less susceptible to bunch rot. New tests to fine-tune the training system thus began in 1997 and have since led to SMPH, a model suited to the more severe mechanical pruning needed to cut bud load and balance cropping while retaining pruning efficiency and resistance to botrytis.

Year 1- Winter hand pruning. Some of the previous year canes were maintained and tied to the foliage wires

End of year 1- First semi-minimal mechanical pruning

End of year 2- Second semi-minimal mechanical pruning

End of year 3- Third semi-minimal mechanical pruning. The "hedge" was shaped
Year 4- Beginning of data collection

Figure 11. Upper left: initial development stage of the Semi-minimal-pruned Hedge (SMPH), starting from a traditional Spur-pruned Cordon (SPC). In the subsequent years (upper right and bottom pictures) the use of the multiple-blade TRIMMER makes it easy to prune shorter or longer on both sides of the SMPH to balance the bud load.

Figure 12. Two Sangiovese clusters: one (left) taken from an SMPH vine and the other (right) from an SPC vine. SMPH bunches are smaller and looser than those of the SPC, and are virtually immune to botrytis attack.

The SMPH is derived from a spur-pruned cordon that retains several year-old canes secured to horizontal foliage wires of the trellis to form a hedge (see Figure 11). A multi-blade unit with an upside-down, U-shaped cutting profile is used in subsequent years to prune the hedge’s top and sides short in winter to eliminate some of the buds (see Figure 11). Trials comparing SMPH and SPC as control (Intrieri and Filippetti, 2007) showed that the SMPH reduced the bud load by about 50 percent when compared to our original MP trials and led to a slightly higher cropping than, and similar berry ripening pattern to SPC (see Table 9 and Table 10). Alternate cropping was also notably reduced as compared to that observed in our original MP trials (Intrieri et al. 2001, l.c.), but clusters still were more numerous, smaller, less compact and notably resistant to rot (see Figure 12). The fact that the clusters were distributed broadly along the hedgewall made them readily harvestable by conventional horizontal heads (see Figure 13). The SMPH thus combines ease of mechanical pruning; early leaf-area formation with marked photosynthetic capacity and dry matter storage; and a crop of high yield and quality with smaller, less compact clusters, proper ripening, protection against botrytis attack and ease of mechanical harvesting. Our ongoing trials should determine if these advantages hold in the long term.

Figure 13. The SMPH can readily be harvested by conventional horizontal slapper-head units.

Conclusions

All the training models reviewed perform to a broad range of adaptability and cropping, are well-suited in almost all cases to full mechanization and well exploit Italy's differing environmental conditions. These advantages should promote their use on a much larger, more generalized scale as these systems lay the necessary groundwork for upgrading crop quality and appreciably boosting per-unit yields under more efficient management at lower overhead outlays, factors crucial to the present and future of the country's viticulture industry.

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Table 1. Italy's winegrape acreage trends.

Year	Hectares
1970	1,109,000
1982	1,063,000
1990	865,000
1997	788,000
2000	675,000
2002	700,000
2003	680,000
2005	700,000
2007	???

Table 2. Breakdown (by percent) of Italy’s winegrape holdings by acreage class

1980		2000	
Hectares	(%)	Hectares	(%)
Less than 1	81.5	Less than 5	85
1 to 2	10.5	5 to 50	10
2 to 5	5.4	More than 50	5
5 to 10	2.1		
More than 10	0.5		

Table 3. Horizontal and vertical harvesting heads compared on Spur-pruned Cordon and Double Curtain (1978). Gross average of several trials on several *V. vinifera* cvrs.[1]

Grape and must loss and free must in harvested crop	Horizontal head (SPC)	Vertical head (DC)
Loss	(%)	(%)
- grape on vine	1.8 a	1.2 a
- grape on ground	2.4 a	1.7 a
- must	12.2 a	6.5 b
Total loss (grape + must)	16.4 a	9.4 b
Free must in harvested crop	18.1 a	5.9 b

[1] Statistical differences within rows are marked by different letters.

SPC = Spur-pruned Cordon

DC = Double Curtain

Table 4. Long-term comparison (1981-1988) of hand management and full mechanization of *V. vinifera* cv. Montuni, Double Curtain trained.

Yield & grape quality (average 1981-1988)			Labour				
			Man-hours per ha per year (average 1981-1988)				
	Yield	°Brix	Pruning and shoot positioning		Harvesting		
Treatment	(t/ha)	(%)	Manual	Mechanical	Manual	Mechanical	Total
Hand harvest & pruning	17.0 t/ha	19.7	79 hrs 52 min	0 hrs 55 m	239 hrs 38 m	NA	320 hrs 25 m
Mechanical harvest & pruning (2 to 4 node spurs)	18.7 t/ha	19.6	17 hrs 36 m	4 hrs 29m	NA	11 hrs 57 m	33 hrs 25 m

Table 5. Moveable Free Cordon. Vertical shaker trials (1996) with TRINOVA Harvester on several *V. vinifera* cvrs.

	Harvest quality (gross average of cvrs.)			
Crop	Berry (%)	Bunch or part of (%)	Free must[1] (%)	Debris (leaves, etc.)
White cvrs.				
(Chardonnay, I.M. 6.0.13, Riesling r.)	71.8	24.9	3.3	Trace
Black cvrs.				
(Carménère, Cabernet f., Carbernet S.)	91.4	4.6	4.0	Trace

[1] Free must collected 30 minutes after harvest.

Table 6. Moveable Spur-pruned Cordon. Vertical shaker trials (2001) with TRINOVA Harvester on several *V. vinifera* cvrs.

	Harvest quality (gross average of cvrs.)			
Crop	Berry (%)	Bunch or part of (%)	Free must[1](%)	Debris (leaves, etc.) (%)
White cvrs.				
(Ansonica, Bombino, Chardonnay, Garganega, Pignoletto, Pinot gris, Verdicchio, Vermentino)	79.5	14.2	4.0	2.3
Black cvrs.				
(Aglianico, Carbernet s., Carménère, Montepulciano, Negro amaro, Nero d'Avola, Primitivo, Raboso Piave)	77.3	17.0	2.3	3.5

[1] Free must collected 30 minutes after harvest

Table 7. 2003. Comparison of horizontal and vertical shaker heads on several *V. vinifera* cvrs. trained to Moveable Spur-pruned Cordon (MSPC).

Crop and harvesting head		Harvest product (gross average of cvrs.) Berries (%)	Bunch or part of (%)	Free must[1] (%)	Debris (leaves, etc.) (%)
White cvrs.					
(Tocai friulano, Chardonnay, Pinot bianco, Verduzzo friulano, Verduzzo trevigiano)	Horizontal	86.1	3.5	9.3	1.1
	Vertical	80.5	15.7	3.6	0.2
Black cvrs.					
(Pinot grigio, Pinot nero, Merlot, Carbernet S., Cabernet F., Carmémère, Raboso Piave, Raboso veronese)	Horizontal	81.8	9.9	6.8	1.5
	Vertical	73.0	23.7	2.9	0.4

[1] Free must collected 30 minutes after harvest

Table 8. Preliminary harvest trials with traditional half-row vertical head on several *V. vinifera* cvrs. trained to COMBI system (2002)

	Harvest product			
V. vinifera cvrs.	Berry (%)	Bunch or part of (%)	Free must[1] (%)	Debris (leaves, etc.)
Barbera	86.2	7.3	6.5	Trace
Bonarda	77.8	20.1	2.1	Trace
Sangiovese	94.0	5.5	0.5	Trace
Shiraz	79.1	20.6	0.3	Trace
Average	84.3	13.4	2.3	-

[1] Free must collected 30 minutes after harvest

Table 9. Comparison of Semi-minimal-pruned Hedge (SMPH) and Spur-pruned Cordon (SPC) on Sangiovese grapevine (*V. vinifera*). Yield, must biochemical profile and balance index. Average 2000-2002.[1]

Treatment	Yield/m of row (kg)	Soluble solids (° Brix)	pH	Titratable acidity (g/L)	Leaf area/yield ratio (m^2/kg)
SMPH	9.1 a	20.6 a	3.35 a	8.18 a	4.0 a
SPC	6.4 b	20.8 a	3.34 a	8.75 a	1.2 b

[1] Statistical differences within columns are marked by different letters.

Table 10. Comparison of Semi-minimal-pruned Hedge (SMPH) and Spur-pruned Cordon (SPC) on Sangiovese grapevine (*V. vinifera*). Shoot fertility, cluster number and their characteristics. Average 2000-2002.[1]

Treatments	Cluster/shoot (n°)	Cluster/m of row (n°)	Cluster weight (g)	Cluster compactness (O.I.V. classes from 1 to 9)	Botrytis infection (% of cluster surface)
SMPH	0.4 b	63 a	137 b	4.2 b	0.07 b
SPC	1.4 a	23 b	275 a	7.5 a	8.75 a

[1] Statistical differences within columns are marked by different letters.

O.I.V. = Organisation Internationale de la Vigne et du Vin, Paris, France

Vineyard Mechanization and Site Specific Viticulture Practices in New York

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Introduction

The evolution of mechanization in agriculture has often come about because of the difficulty in finding sufficient labor to do many of the tasks required on a farm, as well as the increasing costs of that labor. The development of the mechanical grape harvester is an example of this evolution, transforming a job that required many people to complete by hand to one that requires just a few people. Despite the large capital outlay required to purchase the equipment, mechanical grape harvesting has become the norm for juice and bulk wine growers, as well as for a growing number of premium winegrape growers because of the labor savings.

In recent years, the mechanization focus has been on another major cost for grape growers – pruning. Winter pruning costs for bulk juice grape growers in the Lake Erie region can exceed $250 per acre. Previous efforts in mechanical pruning usually focused on the use of sickle bars to ‘skirt’ or ‘hedge’ grapevines in one or two passes, with no further follow-up. While a few growers still utilize this practice on a portion of their vineyards, it has not been widely adopted in the Lake Erie region.

Mechanical Cropload Management

For the past several years, Dr. Terry Bates and the Lake Erie Regional Grape Program (LERGP) have been involved in the evaluation of some newer systems that more closely replicate hand pruning, but still achieve the cost-savings available by mechanizing the operation. We have found that it is possible for growers to achieve both of these goals, but in order to do so over the long-term, growers must be willing to incorporate additional practices to make this new ‘cropload management system’ work. The three parts of this system are:

1. Mechanical pruning
2. Follow-up pruning done by hand
3. Mechanical crop estimation and thinning

Because pruning performed by a machine followed by rapid hand follow-up is less selective for the best fruiting canes on a vine, growers are encouraged to leave 10 percent 20 percent more nodes than they would when pruning by hand in order to compensate for the retention of potentially less-fruitful buds. In some years, however, this higher node number can result in a higher crop load than is appropriate for the vineyard and for the conditions of the particular growing season. It is necessary, therefore, for growers to be willing to mechanically estimate their crop every year and to thin it when conditions appear to require it.

Analyses of viticultural and financial data indicate that this system has the potential for significant financial savings for growers while facilitating sustainable crop production over the long term.

Comparison of Mechanized Pruning Systems (Betts' Vineyard)

An experiment was initiated in 1999 to compare mechanical production systems on single-wire high cordon vines.

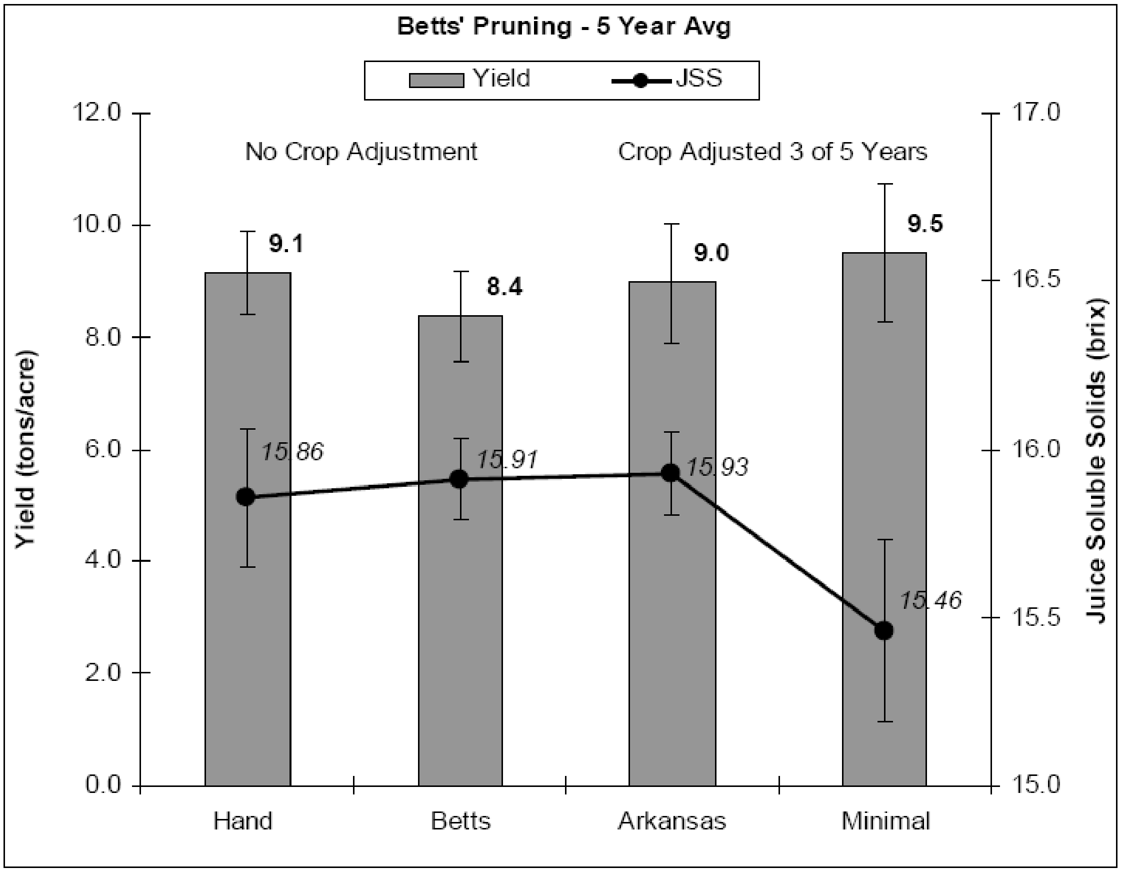
Treatments:

1. Hand prune to the best 100 nodes
2. Betts' system (Morris-Oldridge machine pruning with hand pruning follow-up)
3. Arkansas system (Morris-Oldridge system for pruning, shoot positioning and thinning)
4. Minimal prune (undercut only)

Results:

Figure 1 shows the five-year yield and juice soluble solids averages from the mechanical pruning trial at the Betts' vineyard.

Figure 1.



Although there were year-to-year differences between the pruning treatments (see Table 1), there were no statistical yield differences between any of the pruning treatments over the five year period. However, one of the goals of the experiment was to maintain similar yields between the treatments. The Hand and Betts' treatments controlled crop through pruning alone, while the Arkansas and Minimal treatments required mechanical thinning at 30 days after bloom, three out of five years, to control crop. Juice soluble solids were similar for the Hand, Betts', and Arkansas treatments, while minimal pruning gave significantly lower juice soluble solids on average.

General Conclusions:

1. Bud selection with a machine was inferior to hand pruning, which led to less fruitful buds (clusters/node). Therefore, 10 percent to 20 percent more nodes per vine were needed in the Betts' treatment to achieve the same yield as the Hand treatment.

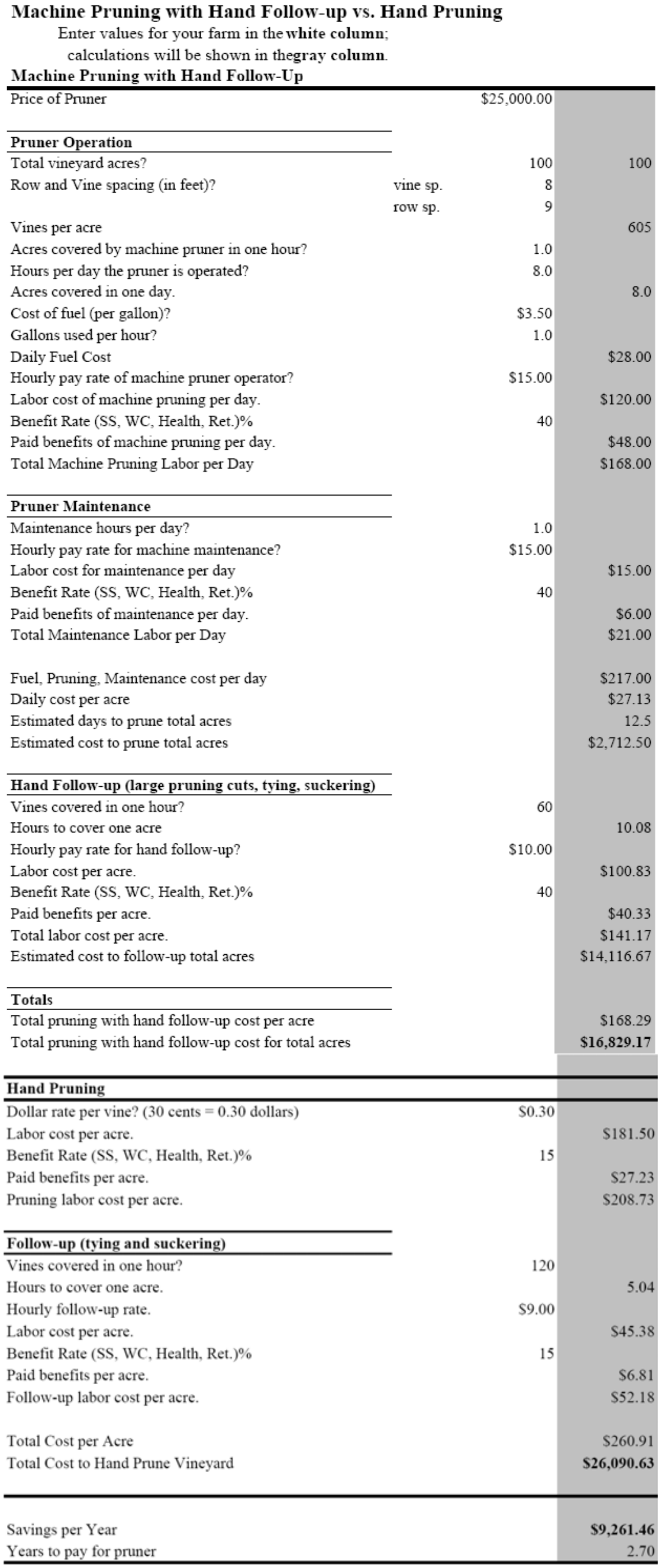
2. Betts' pruning (machine pruning with hand follow-up) was nearly identical to hand pruning in canopy structure, yield and Brix. On average, the Betts' treatment retained 112 nodes per vine and the target should probably be closer to 120 to 130 nodes per vine to compensate for lower fruitfulness.
3. Machine pruning alone (Arkansas, without hand follow-up) retained more buds than Hand or Betts', which led to a higher crop that needed to be adjusted by crop thinning 30 days after bloom. The Arkansas treatment was thinned three of the five years of the experiment.
4. Minimal pruning retained even more buds than the other treatments, which led to high yield, low Brix, low periderm and low fruitfulness. It is important to note that Minimal pruned vines did not make minimum Brix in 1999, even with thinning.

Economics of Hand Pruning vs. Modified Machine Pruning

Since the Betts' and Hand treatments are identical in yield and juice quality, an Excel™ based 'pruning calculator' (see Figure 2) was created to compare the costs of the two pruning systems. The calculator includes mechanical pruner operation and maintenance as well as hand follow-up costs. The Betts' system is compared to hand pruning at 30 cents per vine with additional costs for tying and suckering.

The pruning calculator in this example compares the cost of hand pruning with mechanical pruning and hand follow-up of 100 acres of Concord grapes. This example assumes the mechanical pruner costs $25,000, the pruner operator is paid $15/hour with a 40 percent benefit rate and hand follow-up is done at $10/hour plus benefits. For hand pruning, the piece rate is $0.30/vine with the same 40 percent benefit rate. In this comparison, mechanical pruning with hand follow up saves $9,261.46/year. This savings would pay for the pruning machine within three years.

Figure 2.



Machine Pruning with Hand Follow-up vs. Hand Pruning

Enter values for your farm in the **white column**;
calculations will be shown in the **gray column**.

Machine Pruning with Hand Follow-Up			
Price of Pruner		$25,000.00	
Pruner Operation			
Total vineyard acres?		100	100
Row and Vine spacing (in feet)?	vine sp.	8	
	row sp.	9	
Vines per acre			605
Acres covered by machine pruner in one hour?		1.0	
Hours per day the pruner is operated?		8.0	
Acres covered in one day.			8.0
Cost of fuel (per gallon)?		$3.50	
Gallons used per hour?		1.0	
Daily Fuel Cost			$28.00
Hourly pay rate of machine pruner operator?		$15.00	
Labor cost of machine pruning per day.			$120.00
Benefit Rate (SS, WC, Health, Ret.)%		40	
Paid benefits of machine pruning per day.			$48.00
Total Machine Pruning Labor per Day			$168.00
Pruner Maintenance			
Maintenance hours per day?		1.0	
Hourly pay rate for machine maintenance?		$15.00	
Labor cost for maintenance per day			$15.00
Benefit Rate (SS, WC, Health, Ret.)%		40	
Paid benefits of maintenance per day.			$6.00
Total Maintenance Labor per Day			$21.00
Fuel, Pruning, Maintenance cost per day			$217.00
Daily cost per acre			$27.13
Estimated days to prune total acres			12.5
Estimated cost to prune total acres			$2,712.50
Hand Follow-up (large pruning cuts, tying, suckering)			
Vines covered in one hour?		60	
Hours to cover one acre			10.08
Hourly pay rate for hand follow-up?		$10.00	
Labor cost per acre.			$100.83
Benefit Rate (SS, WC, Health, Ret.)%		40	
Paid benefits per acre.			$40.33
Total labor cost per acre.			$141.17
Estimated cost to follow-up total acres			$14,116.67
Totals			
Total pruning with hand follow-up cost per acre			$168.29
Total pruning with hand follow-up cost for total acres			**$16,829.17**
Hand Pruning			
Dollar rate per vine? (30 cents = 0.30 dollars)		$0.30	
Labor cost per acre.			$181.50
Benefit Rate (SS, WC, Health, Ret.)%		15	
Paid benefits per acre.			$27.23
Pruning labor cost per acre.			$208.73
Follow-up (tying and suckering)			
Vines covered in one hour?		120	
Hours to cover one acre.			5.04
Hourly follow-up rate.		$9.00	
Labor cost per acre.			$45.38
Benefit Rate (SS, WC, Health, Ret.)%		15	
Paid benefits per acre.			$6.81
Follow-up labor cost per acre.			$52.18
Total Cost per Acre			$260.91
Total Cost to Hand Prune Vineyard			**$26,090.63**
Savings per Year			**$9,261.46**
Years to pay for pruner			2.70

Machine Pruning and Shoot Positioning of Geneva Double Curtain Vines (Vercant Vineyard)

An experiment was initiated in a commercial GDC vineyard in 1998 which compared two mechanized systems with hand pruning. Data collection was similar to the trial conducted at the Betts vineyard.

Treatments:

1. Hand pruned to 100 nodes with manual curtain separation
2. Arkansas system (Mechanical pruning, curtain separation and shoot positioning)
3. Vercant system (Mechanical pruning and curtain separation - no shoot positioning)

Results from this experiment can be found in Table 2.

Overall Conclusions:

1. Machine pruning, either Arkansas or Vercant, retained 100 percent more nodes and gave 100 percent more clusters/vine but yielded only 25 percent more crop than Hand pruned vines.
2. Yield compensation in mechanical treatments resulted in 6 percent to 9 percent lower berry weight, 18 percent to 23 percent fewer berries per cluster, and 25 percent to 27 percent lower cluster weight than in Hand pruned vines.
3. In large crop years (1999, 2000), the higher yield in the machine pruned treatments was accompanied by a significant decrease in juice soluble solids. In moderate crop years (2001, 2002), machine pruned vines still yielded significantly more crop but achieved the same concentration of juice soluble solids. In heavy years, the mechanically pruned vines are on the shoulder or downward slope of the crop load–Brix relationship. In light years, all treatments are on the plateau of the curve.
4. At harvest, the mechanical grape harvester missed between 0.5 and 1.0 tons/acre of fruit in the machine pruned treatments.
5. On average, machine pruning ripened 20 percent to 25 percent fewer nodes than hand pruning and this effect was more apparent on dry years (1999, 2002).

6. There was no effect of shoot positioning between the two machine pruned treatments except that shoot positioning further decreased the amount of ripe periderm (probably by depressing shoot growth). However, shoot positioning did not lead to higher bud fruitfulness *or* higher Brix at a given yield.

Mechanical Crop Estimation and Thinning

As mentioned earlier, because a machine is less selective for the more fruitful “sun wood” than a person is, more buds should be left in order to maintain equivalent yields. Based on the research at the Betts vineyard, we recommend that growers leave 10 percent to 20 percent more buds than they would when hand pruning their vines. If leaving these extra buds results in a heavier crop than can be ripened in a given year, some of that crop must be removed for the crop to achieve the minimum quality (i.e. Brix) standards of the processors. Work done by Bob Pool, Justin Morris, Terry Bates and others has shown that it is possible to use mechanical means to effectively *and predictably* estimate and reduce crop on Concord vines when the grower believes that the crop is too high for the given growing season.

In 2003, many vineyards in the Lake Erie region were significantly overcropped due primarily to unusually high bud fruitfulness and berry set. In addition, the growing season was cool and wet, which further threatened the ability of the crop to achieve minimal acceptable quality. This provided an excellent opportunity both to further study this technique under “real world” conditions in multiple vineyards, and to introduce the technique to growers.

The Technique. To successfully crop adjust, a grower needs to know what the balanced cropping potential is for a particular vineyard block in an average growing season. For example, a grower knows that Block A is in a poor spot and can only handle 5 tons/acre and that Block B is in a good spot and can run 8 tons/acre in an average growing season without loosing significant pruning weight. Next, all the grower needs to do is measure what crop is hanging in the vineyard and adjust the harvester to take off the excess crop to reach the target crop level.

The first step of the process is to clean pick one percent of an acre at 30 days after bloom with the harvester, when the berries are 50 percent of their final weight. At 9-foot row and 8-foot vine spacing, there are 605 vines in one acre. A row of 605 vines at 8-foot spacing would be 4,840 feet long. 1/100th or one percent of that row would be 48.4 feet.

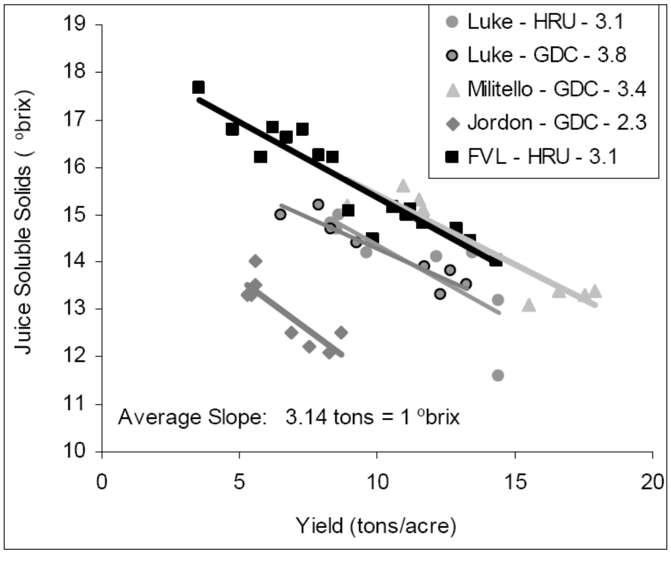
The picked green berries are then sent across the harvester belt to a barrel on a scale (many growers use a milk scale on a trailer). The weight of the berries is read, and the approximate yield is determined using the crop estimation table developed by Terry Bates (see Table 3). Based on this result, the grower sets up the harvester to remove the desired amount of crop. The exact parameters for doing this (speed, beater RPMs, number of rods used, etc.) are determined by trial and error by the grower. This process should be done in different parts of a vineyard if the grower knows that there are typical yield differences among and within blocks.

Research. Four off-station mechanical thinning plots were established in 2003 and compared to manual thinning at the Fredonia Vineyard Lab. The plots were as follows:

Grower	Location	Training	Machine
Vineyard Lab	Fredonia, N.Y.	HRU	Manual
Militello	Forestville, N.Y.	GDC	Korvan
Luke	North East, Pa.	HRU	Chisholm-Ryder
Luke	North East, Pa.	GDC	Pic-Ryte
Jordon	Portland, N.Y.	GDC	Gregoire

All of the off-station plots were machine-thinned by the grower cooperators using their own machine set-up and all of the thinning took place 30 to 40 days after bloom. Figure 3 shows the yield and juice soluble solids of both thinned and un-thinned vines at each of the plots. Data from the Fredonia Vineyard Lab (FVL) is from individual vine measurements. Data from the off-station field plots were from bin weights and bin probe samples taken from whole-treatment rows. There were four thinned and four un-thinned treatment rows at each location.

Figure 3.



At each plot, potential crop was estimated at 30 days after bloom by weighing the fruit removed from a set of sample vines and predicting final crop weight from percent of final berry weight. At the Fredonia Lab and at both plots at the Luke vineyard in PA where the un-thinned crop was about 11 tons/acre to 12 tons/acre, the crop predictions were accurate. At the Militello GDC plot, the harvested crop (17 tons/acre) was lower than what was predicted at 30 days after bloom (22+ tons/acre). It is unclear why the crop prediction was inaccurate, but it has been our experience that when the crop prediction is in excess of 15 tons/acre, the yield potential does not materialize at harvest. Possible causes may be the spontaneous shelling of fruit when the vine is severely overcropped, or the inaccurate estimation of final berry weight on an excessively large crop.

Each plot was harvested at a different time during the harvest season based on the individual grower's schedule and fruit maturity in the plot. Therefore, we would expect differences in the yield-Brix regression lines from each of the plots. Each of the five thinning plots responded positively to the thinning process and the slope of each regression line indicates how well the vines in each plot responded. Interestingly, all of the lines are close to being parallel with each other indicating that the thinning response was similar among all the plots. The average slope from each of the five plots indicates that for every 3.14 equivalent tons/acre removed with thinning, the fruit increased by 1° Brix in 2003.

Extension Response. When the high crop situation became apparent, LERGP research and extension staff worked with area processors to introduce and demonstrate these mechanical crop estimation and thinning techniques to growers for use in their own vineyards. Terry Bates developed a simple one page table for growers to use to help them estimate crop levels based on estimated final berry weight and how many days after bloom the estimate is made (see Table 3). A brief video has also been developed that summarizes the estimation and thinning techniques, and is available for viewing at http://lergp.cce.cornell.edu/Bates/Polebarn_vit.htm. A survey was developed after the growing season was finished to assess the level of adoption of the practices, what specific techniques were used, and growers' intentions for their future use. The survey indicated that approximately 25 percent to 30 percent of the acreage in the region was thinned, and that 35 percent to 40 percent of growers adjusted the crop on some portion of their acreage. The area's largest grape processor estimated that the development and dissemination of this information resulted in the harvest of $3.6 million worth of Concord grapes that otherwise would not have been marketable.

Table 1. **Viticulture results of 1999-2003 Betts' mechanical pruning trial. Yield and juice soluble solids data are from 45 vine bin samples. All other data were collected from sample count vines within the treatment rows. Means with different letters (within a given year) are separated by Duncan's multiple range test at the 0.05% level.**

Year	Treatment	pruning weight	retained nodes	Yield (tons/acre)	^{o}brix	grown periderm	clusters/ vine	clusters/ node	cluster weight (g)	berries/ cluster	berry weight (g)
1999	Hand	2.2	100 d	11.9 ab	15.8 ab	364.3 a	205.5 c	2.1 a	88.4 a	33.8 a	2.6 a
	Betts		122 c	11.3 b	16.2 a	338.9 a	191.6 c	1.6 b	82.0 a	31.7 a	2.6 a
	Arkansas		166 b	11.9 ab*	15.5 b	245.9 b	255.7 b	1.6 b	59.8 b	24.0 b	2.5 a
	Minimal		270 a	12.3 a*	14.6 c	235.1 b	373.1 a	1.4 b	50.0 c	22.4 b	2.2 b
2000	Hand	1.9	100 b	9.2 a	16.1 a	493.6 a	153.1 b	1.5 a	80.6 a	21.9 a	3.7 a
	Betts		111 b	8.5 a	16.1 a	487.8 a	155.5 b	1.4 ab	74.9 a	20.0 b	3.8 a
	Arkansas		143 a	9.8 a	16.0 a	433.6 a	191.1 a	1.3 b	64.0 b	18.2 b	3.5 b
	Minimal		157 a	8.6 a	16.4 a	445.1 a	201.8 a	1.3 b	54.0 c	16.1 c	3.4 c
2001	Hand	1.9	100 c	8.0 bc	16.1 a	455.0 a	153.7 b	1.5 a	63.5 a	17.8 a	3.6 a
	Betts		98 c	7.4 c	16.0 a	434.5 a	140.6 b	1.4 a	61.5 a	17.3 ab	3.6 a
	Arkansas		138 b	8.5 b	16.2 a	408.1 a	192.2 b	1.5 a	53.5 b	15.6 bc	3.4 a
	Minimal		234 a	11.5 a	15.4 b	413.0 a	316.4 a	1.4 a	45.8 c	14.6 c	3.2 b
2002	Hand	2.3	100 c	8.4 ab	16.3 a	357.5 ab	190.1 c	1.9 a	56.4 a	17.1 a	3.3 a
	Betts		117 c	7.9 b	15.8 ab	372.2 a	186.8 c	1.5 b	52.8 a	16.8 a	3.1 b
	Arkansas		198 b	9.2 ab*	15.8 ab	281.9 b	269.0 b	1.4 bc	42.6 b	14.5 a	3.0 c
	Minimal		296 a	9.7 a*	15.4 b	293.3 ab	337.7 a	1.1 c	39.8 b	14.5 a	2.8 d
2003	Hand	2.1	100 c	8.1 a	15.1 c	242.4 a	137.3 c	1.4 a	78.4 a	29.5 a	2.7 ab
	Betts		108 c	6.7 ab	15.5 ab	281.4 a	136.2 c	1.3 a	62.1 b	22.1 b	2.8 a
	Arkansas		155 b	5.3 c*	16.2 a	278.5 a	144.1 b	1.0 b	46.7 c	17.5 c	2.7 ab
	Minimal		262 a	5.4 c*	15.5 bc	276.0 a	198.6 a	0.8 b	39.4 c	15.6 c	2.5 b
99-03	Hand		100 c	9.1 ab	15.9 a	382.5 a	167.9 c	1.7 a	73.5 a	24.0 a	3.2 a
	Betts		111 c	8.4 b	15.9 a	382.9 a	162.1 c	1.5 b	66.6 b	21.6 b	3.2 a
	Arkansas		160 b	9.0 b	15.9 a	329.6 a	209.9 b	1.3 bc	53.2 c	18.0 c	3.0 b
	Minimal		244 a	9.5 a	15.4 b	332.5 a	285.5 a	1.2 c	45.8 d	16.6 c	2.8 c

Table 2. Viticulture results of 1998-2002 Vercant vineyard mechanical pruning trial. Means with different letters (within a given year) are separated by Duncan's multiple range test at the 0.05% level.

Year	treatment	pruning weight (lbs)	retained nodes		yield (tons/acre)		°brix		yield missed (tons/acre)		ripe periderm		clusters/ vine		clusters/ node		cluster weight (g)		berries/ cluster		berry weight (g)	
1998	Hand	0.9	100	b	7.6	b	17.3	a	0.1	b	518	a	154	b	1.6	a	71	a	23	a	3.0	a
1998	Arkansas		185	a	10.2	a	16.8	a	1.0	a	457	a	274	a	1.5	a	59	b	21	b	2.8	b
1998	Vercant		166	a	9.7	a	17.2	a	0.7	a	490	a	242	a	1.5	a	58	b	21	b	2.8	b
1999	Hand	2.0	100	b	11.3	b	16.3	a	0.3	b	368	a	250	b	2.5	a	78	a	28	a	2.8	a
1999	Arkansas		273	a	11.8	b	15.1	b	0.5	ab	240	b	530	a	2.0	b	41	b	16	b	2.5	b
1999	Vercant		293	a	12.9	a	14.9	b	1.0	a	299	b	573	a	2.0	b	42	b	17	b	2.5	b
2000	Hand	2.3	100	b	9.4	b	16.7	a	0.4	a	459	a	178	b	1.8	a	90	a	25	a	3.5	a
2000	Arkansas		174	a	10.4	a	16.1	b	1.1	a	376	c	305	a	1.8	a	61	b	18	b	3.3	b
2000	Vercant		180	a	10.7	a	16.1	b	1.0	a	413	b	307	a	1.7	a	61	b	19	b	3.3	b
2001	Hand	2.8	100	b	6.1	b	16.2	a			470		171	b	1.7	a	63	a	17	a	3.7	a
2001	Arkansas		237	a	8.4	a	15.8	a					354	a	1.5	a	48	b	15	ab	3.3	a
2001	Vercant		244	a	8.2	a	15.8	a					343	a	1.5	a	49	b	14	b	3.5	a
2002	Hand	3.0	100	b	4.6	c	15.8	a	0.2	a	341	a	133	c	1.3	a	55	a	16	b	3.5	a
2002	Arkansas		179	a	7.7	a	15.7	a	0.5	a	227	b	237	b	1.3	a	57	a	18	a	3.1	b
2002	Vercant		178	a	7.4	b	15.9	a	0.4	a	277	ab	276	a	1.5	a	52	a	16	b	3.3	c
98-02	Hand	2.2	100	b	7.8	b	16.4	a	0.2	b	431	a	177	b	1.8	a	71	a	22	a	3.3	a
98-02	Arkansas		209	a	9.7	a	15.9	b	0.6	a	325	c	340	a	1.6	b	53	b	18	b	3.0	b
98-02	Vercant		212	a	9.8	a	16.0	ab	0.6	a	370	b	348	a	1.6	b	52	b	17	b	3.1	b

Table 3. Crop Estimation and Thinning Table.

Dr. Terry Bates: Crop Estimation and Thinning Table: 7/16/2003

	Time of Season														
	20DAB			25DAB			30DAB		40DAB	50DAB		Veraison			Harvest
	% of Final Berry Weight														
Pounds of Fruit Removed in 1/100th of an Acre	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**90**	**100**
10	2.5	2.0	1.7	1.4	1.3	1.1	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5
20	5.0	4.0	3.3	2.9	2.5	2.2	2.0	1.8	1.7	1.5	1.4	1.3	1.3	1.1	1.0
30	7.5	6.0	5.0	4.3	3.8	3.3	3.0	2.7	2.5	2.3	2.1	2.0	1.9	1.7	1.5
40	10.0	8.0	6.7	5.7	5.0	4.4	4.0	3.6	3.3	3.1	2.9	2.7	2.5	2.2	2.0
50	12.5	10.0	8.3	7.1	6.3	5.6	5.0	4.5	4.2	3.8	3.6	3.3	3.1	2.8	2.5
60	15.0	12.0	10.0	8.6	7.5	6.7	6.0	5.5	5.0	4.6	4.3	4.0	3.8	3.3	3.0
70	17.5	14.0	11.7	10.0	8.8	7.8	7.0	6.4	5.8	5.4	5.0	4.7	4.4	3.9	3.5
80 →	20.0	16.0	13.3	11.4	10.0	8.9	8.0	7.3	6.7	6.2	5.7	5.3	5.0	4.4	4.0
90	22.5	18.0	15.0	12.9	11.3	10.0	9.0	8.2	7.5	6.9	6.4	6.0	5.6	5.0	4.5
100	25.0	20.0	16.7	14.3	12.5	11.1	10.0	9.1	8.3	7.7	7.1	6.7	6.3	5.6	5.0
110	27.5	22.0	18.3	15.7	13.8	12.2	11.0	10.0	9.2	8.5	7.9	7.3	6.9	6.1	5.5
120	30.0	24.0	20.0	17.1	15.0	13.3	12.0	10.9	10.0	9.2	8.6	8.0	7.5	6.7	6.0
130	32.5	26.0	21.7	18.6	16.3	14.4	13.0	11.8	10.8	10.0	9.3	8.7	8.1	7.2	6.5
140	35.0	28.0	23.3	20.0	17.5	15.6	14.0	12.7	11.7	10.8	10.0	9.3	8.8	7.8	7.0
150	37.5	30.0	25.0	21.4	18.8	16.7	15.0	13.6	12.5	11.5	10.7	10.0	9.4	8.3	7.5
160	40.0	32.0	26.7	22.9	20.0	17.8	16.0	14.5	13.3	12.3	11.4	10.7	10.0	8.9	8.0
170	42.5	34.0	28.3	24.3	21.3	18.9	17.0	15.5	14.2	13.1	12.1	11.3	10.6	9.4	8.5
180	45.0	36.0	30.0	25.7	22.5	20.0	18.0	16.4	15.0	13.8	12.9	12.0	11.3	10.0	9.0
190	47.5	38.0	31.7	27.1	23.8	21.1	19.0	17.3	15.8	14.6	13.6	12.7	11.9	10.6	9.5
200	50.0	40.0	33.3	28.6	25.0	22.2	20.0	18.2	16.7	15.4	14.3	13.3	12.5	11.1	10.0

Row Spacing determines length of 1/100th of an acre
10.0 feet row spacing = 43.5 feet = 1/100th of an acre
9.5 feet = 45.9 feet = 1/100th of an acre
9.0 feet = 48.4 feet = 1/100th of an acre
8.5 feet = 51.2 feet = 1/100th of an acre
8.0 feet = 54.45 feet = 1/100th of an acre
7.5 feet = 58.1 feet = 1/100th of an acre

Calculation
43, 560 square feet per acre
Divide by row spacing and then
divide by 100 to get 1/100th of an acre

Example:
A grower has 9 foot row spacing and clean picks 48.4 feet at 25 days after bloom. The fruit weighs 80 pounds and the grower estimates that the berries are between 35% and 40% of final berry weight. According to the table, the crop estimate is between 10.0 and 11.4 tons per acre.

Disclaimer:
This table gives the relationship between time of season and % final berry weight on an average year. Year to year variability in weather related berry growth adds error to this table. Information on current year berry growth can be obtained from the Fredonia Vineyard Lab (or) it is strongly suggested that individual growers start collecting berry weight information from their own individual vineyard blocks.

Advancements in Vineyard Assessment and Harvest Technology

Oren Kaye

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Introduction

The past two decades have been a watershed of innovation in the field of viticulture. Many of the emerging technologies have provided viable means to improve grape quality and increase uniformity across a vineyard (Bramley, Lanyon and Panten, 2005a; Bramley et al., 2005b; Bramley and Hamilton, 2004; Bramley, 2005; Davenport et al., 1999; Wample, Mills, and Davenport, 1999). In spite of these advancements, the complexity of the interactions of soil, sunlight, aspect, pathology and physiology cannot be completely mitigated; and even under the best of circumstances, a certain amount of vineyard variability will always exist. Recognizing this limitation, growers and winemakers alike are benefited from understanding the juxtapositions of areas of higher or lower quality in their vineyards. This information can be exploited to add precision to viticultural practices during the growing season or a strategy for the collection and streaming of fruit at harvest.

The convergences of optical and spectroscopic technology with GPS and GIS databases have made it easier to recognize and assess patterns of variability and quality in vineyards. During recent years, developments in spectroscopic instrumentation and chemometric software (Workman & Burns, 2001) have made it possible to rapidly perform multivariate analyses, correlating spectrometric data with quantitative chemical data. These developments have led the way for a much broader use of spectroscopy to measure the concentrations of various substances within a wide range of media (World et al., 2001). In particular, NIR-based instrumentation has been used in different agricultural areas including viticulture (Cozzolino et al., 2004) to indicate plant vegetative status, as well as several fruit maturity indices (Kaye & Wample, 2005).

Analysis using NIR spectroscopy has several desirable characteristics including: non-destructive sampling, rapid data acquisition, portability and sensitivity to a wide range of molecules containing C-H, N-H, S-H and O-H bonds (Ciurczak, 2001). These characteristics, as well as the ability to perform multiple analyses simultaneously, make this technology ideally suited for the intensive sampling required to assess changes in quality parameters within vineyards. GPS-guided statistical analysis of vineyard data has made it possible to accurately interpolate these values across large areas and generate real-time maps based on individual or combinations of different chemical parameters.

Over the past three years, the Viticulture and Enology Research Center at California State University, Fresno, the Research and Development Division of Constellation Wines U.S. and Oxbo International Corp. have engaged in a practical research endeavor to assess the use of these combined technologies to differentially harvest vineyards based on the relative distribution of specific polyphenols and anthocyanins in the grapes prior to harvest. This is not only because these constituents are easily quantified using NIR, but because within the contents of comparable fruit from within the same (or similar) vineyard, the relative concentrations of polyphenols and anthocyanins have been noted to have a positive correlation with the quality and intensity of wine aromas (Francis et al., 1999).

The goal of this research was to:

- use these technologies to assess and compare the spatial dynamics of various quality parameters within vineyards

- interpolate the spatial variability of these parameters to generate 'quality maps' of those vineyards
- harvest the vineyards differentially according to quality maps
- determined if these differences had a measurable impact on the analytical or qualitative characteristics in the wines

Each successive year of the research was conducted on an increasingly larger scale introducing increasingly more difficult logistical challenges. The second and third year of the research was conducted on a commercial scale utilizing a mechanical harvester (Korvan 3016XLR, Oxbo International Corp., Kingsburg, Calif.) which was modified to interpret GIS data and sort the fruit to different gondolas accordingly.

Materials and Methods

1. In 2003 and 2004 (prior to the start of the project), protocols and calibrations were developed for use of a portable NIR spectrometer (Brimrose Corporation, Baltimore, Md.) to measure the Brix, pH, TA and anthocyanin content of whole grape berries in a vineyard. The spectral range used was 1,100 nm to 2,300 nm in transmission mode, with a wavelength increment of 2 nm. The signal to noise ratio was increased by scanning this spectral range 100 times per measurement and averaging all the acquired spectra. After acquisition, the spectral data was converted to absorbance (log (1/T)) values and/or the first derivative values prior to chemometric analysis.

   Calibrations were developed using CAMO Unscrambler 8.0® (Oslo, Norway) chemometric software to perform partial least square analysis (PLS1) of the data sets. All calibrations were validated using cross-validation techniques. The performances of the models were verified by the standard error of cross-validation (SECV) and correlation coefficients (CC). The best calibration models were selected based on their minimum SECV values.
2. In 2005, three commercial (Merlot) vineyards were selected for mapping and analysis. For each vineyard, a grid-like sampling scheme was developed after preliminary assessments of spatial variability using semivariogram analysis (Isaaks & Srivastava,

1989). Semivariogram analysis allows interpretation of spatial dependence between interrelated points by plotting the measured variability of a parameter against distance (m) in a range of vectors.

The semivariogram was calculated as such (Isaaks & Srivastava, 1989):

$$\gamma(h) = \sum_{i=1}^{N(h)} \left[Z(xi) - z(xi + h)\right]^2 / 2N(h)$$

Where Z represents the degree of difference within a pair of data points and N(h) is the number of paired values [Z(xi) and Z(xi+h)] computed in multiple vectors (h) of distance and direction.

Individual attributes of the semivariogram are termed with the numeric parameters: range (r), sill (C1) and nugget effect (C0). The range is indicated by the point where the estimated variance (semivariance) reaches its maximum value. Sill is represented by the difference in the semivariance for patterned (nonrandom) changes in a parameter at the greatest lateral distance between data points.

After final determination of a sampling scheme, the vineyards were again sampled using the NIR spectrometer. At each sampling point, spectra were acquired from five berries randomly selected from noncontiguous positions in each of three clusters, which were randomly selected from alternating locations across a vine. In-field distances and sampling locations were confirmed with a portable GPS receiver (Trimble AgGPS 132 Receiver).

The magnitude of variability for ‘in-field’ predicted data was analyzed by univariate statistics (coefficient of variation (CV)). The spatial relationships were determined by semivariogram analysis (nugget, sill and range) and the Cambardella Index (CI) (Cambardella et al., 1994). The CI confers the level of spatial dependence evident in a dataset. It is equated as: CI = [Co/(Co+C1)]100. CI levels were ranked as follows for spatial dependence : <25= strong, 25–75=moderate and >75: weak.

Knowing the spatial dependence for different parameters in the vineyard, “quality maps” (for °Brix and anthocyanins) were generated using a geo-statistical process known as kriging (Pannatier, 1996). Krigging calculates a weighted value for each sampled datum in an area based on its statistical distance and spatial dependence to each and every other datum in the field. It then employs a weighted linear combination of the data sets to interpolate values for measured parameters. Standard krigging is known as a best linear unbiased estimator (B.L.U.E.) because it attempts to create a mean residual that is equal to zero, minimizing the variance of the errors.

One-ton lots were selectively harvested by hand from each of the three vineyards based on the predicted values for anthocyanins as determined by the quality maps. Vineyards were harvested into two or three tiers (high, low or medium) based on the (maximum) range of anthocyanin values predicted by the NIR. From each wine lot, two 500 g samples were collected to assess relative differences in anthocyanins between the quality tiers. The differences in anthocyanins were measured by the same reference methodology (Iland et al., 2004) used to calibrate the NIR.

Wine was made from each of the different lots using a standard protocol. The wines where then analyzed by standard chemical and organoleptic procedures. Significant differences in wine quality were noted during pre-screening for sensory analysis. The differences were substantial enough to negate the need for further discrimination testing. Nearly all the tasters had a strong and consistent (over time) preference for the wines made from grapes with higher anthocyanin content.

3. In 2006, the experiment was conducted on a commercial scale in a 45-acre block of the Twin Creeks Vineyard near Lodi, Calif. The same or similar analytical and statistical procedures as described above were used to assess the spatial dynamics in the vineyard.

   The vineyard was sampled and mapped several times during the season with the final mapping being conducted approximately 10 days prior to the harvest date. Based on the total range of anthocyanins in the final mapping, high and low quality tiers were delineated based on an arbitrary value near the middle of the range.

   The vineyard was then differentially harvested by a modified mechanical harvester. The modifications to the harvester included dual booms for dropping fruit to two separate gondolas, a bidirectional sorting belt, a GPS receiver and a GPS-guided systems controller which determined the direction of the sorting belt.

The harvester sorted fruit to either the high- or low-quality gondola based on its GPS-determined location within the quality map. The fruit from each tier was delivered to the winery and fermented in 60-ton fermenters under a standardized commercial protocol. At the winery's inspection stand, a 60-pound sample was randomly pulled from each truckload by a Yuba sampler. A subset of this sample was analyzed to measure difference in anthocyanins between the truckloads and the quality tiers.

The wines made from the two tiers, as well as a non-differentially harvested 'control' from the same vineyard, were assessed by both a winemaker using commercial standards and a sensory panel using standard protocols for sensory analysis.

The phenolic constituents (anthocyanins, tannins, and polyphenols) of the wines were measured three times while the wines were being processed. At each interval, the measured differences in the wines were consistent with differences predicted by the quality maps. Additionally, the wines were evaluated (blindly) by both a trained sensory panel and by winemakers using commercial criteria. In both scenarios, significant differences between the wines were noted and overwhelming preference was consistently given to the wine harvested from higher anthocyanin grapes.

4. In 2007, a 159-acre Cabernet Sauvignon vineyard near Madera, Calif., was mapped using a protocol similar to the protocol described above. An 80-acre parcel of the vineyard was mechanically harvested using the same equipment as was used in the Twin Creeks Vineyard in 2006. The 80 acres yielded more than 500 tons of grapes. The grapes were segmented into four different quality tiers (ranges) and streamed to two different wineries accordingly. As before, validation of the mapping was done by assessing difference in anthocyanins and other constituents in the grapes at the inspection stands. Ongoing analysis of the grape samples and the resulting wines has demonstrated that differential harvesting can be a valuable tool for managing the variability in fruit quality across a large vineyard.

Conclusions

The combination of emerging analytical tools with GPS/GIS technology has important implications for the grape and wine industries. When harnessed together, these technologies allow for more intensive sampling of various (vineyard) physiological benchmarks and more meaningful interpretation of the data.

This research has shown that NIR spectroscopy can be used to improve sampling and assessment of vineyards by allowing for larger (more intensive) sample sets across large vineyard areas. The larger sample sets provide more representative information about quality parameters in the field. The experiment has also shown that when spatial dependence is significant, quality parameters can be accurately mapped using GPS-guided spatial statistics and krigging.

In the absence of other information, the concentration of grape anthocyanins (within certain limits) can be indicative of future wine quality. For wine grapes grown under the same (or very similar) conditions, differences in the concentration of grape anthocyanins can be used to segment quality tiers prior to harvest. Within the context of this research, relative differences in total anthocyanin, total phenolics and color of the wines were linearly related to relative differences in the anthocyanin content of the grapes.

Selective and/or differential harvesting (based on a meaningful quality parameter) of wine grapes can significantly impact wine quality. This commercial scale experiment showed that differential harvesting was a viable option even for vineyards which were mechanically harvested. Differential harvesting has the added benefits of:

- Improving sample homogeny of inbound winery trucks
- Maintaining quality threshold for wine grapes assigned to specific wine programs

With or without differential harvesting, GIS has proven itself to be a very powerful tool for understanding the spatial dynamics and possible interactions of a variety of different parameters in vineyards. In addition to helping growers to farm with greater precision, GIS technology aids in transforming data into information. Holistic (across multiple vineyards and multiple seasons) examinations of these ‘information-sets’ is certain to unravel fundamentals science has not yet considered or explored.

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The Challenges of Vineyard Mechanization near the Climatic Limits of Commercial Vine Culture

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Abstract

While major modifications have been made in the culture of grape vines during the 20th century (development of tractors, mechanized pest control, fertilizer application, site preparation for planting, cultivation and most recently harvest), the challenge for the 21st century is mechanization of pruning and other components of crop control (shoot thinning, flower cluster thinning and green-drop thinning).

These will be challenges because of variability inherent in the regions of culture including growing season length and growing season heat accumulation (GDD), variation in meso-climate, site variability, soil variability, cultivar differences and a wide range in crop value.

It is proposed and hoped that describing these challenges will provide an impetus for the research that will bring solutions to the limitations of our cool climate region of culture.

Introduction

Mechanization of aspects of grapevine culture has been with us since the days when engines with horsepower replaced a horse's power to prepare a site for planting, cultivate the vines, spread fertilizer and apply protective sprays in our vineyards. A major milestone in mechanization occurred in the 1960s when efforts in New York led by Shepherdson, Shaulis and Moyer (1968) in agricultural engineering, viticulture and food science, respectively, developed the basis for the huge step forward to mechanized harvest of grapes (Anon., 2002).

In addition to these, innovations have led to laser-based vineyard layout and improved vineyard floor management. Canopy management has been mechanized via employment of leaf pulling fan devices for upright growing, vertically shoot positioned (VSP) trained cultivars with a growth habit characteristic of *Vitis vinifera* L. and some mixed-species cultivars (Howell et al., 2000). A number of horizontal "combing" type shoot positioning devices (Pool et al., 1990) have been employed and evaluated for high, bi-lateral cordon trained, recumbent cultivars characteristic of *V. labruscana* Bailey, and those mixed-species hybrids with a similar growth habit. Hedging devices are also employed with VSP trained vines to control both canopy height and width (Anon., 2007). These tools are well implemented in the mechanized vineyard of cool climate regions. Instead, the current challenges facing producers in these regions are vine balance and crop control, and accomplishing these vineyard goals mechanically.

Innovations by Morris (2006) have offered the promise of 100 percent mechanization of grape production including crop control via mechanized pruning and subsequent crop adjustment. These approaches offer the promise of greatly reduced hand labor at a time when both the cost and shortage of skilled workers have become issues for both production economics and national politics.

The issues associated with vine balance challenges will be dealt with in another presentation at these meetings (Howell and Sabbatini, 2008). The primary impediment to our progress in cropping mechanization in cool/cold climate regions is summated by the term **variability.** Our purpose in this presentation is to inject into this mix of discussions those concerns which are being observed and expressed in the cool/cold, short-season areas of the northern tier of U.S. states and similar regions in Canada.

Materials and Methods

The methods employed here involve those of a review. The issues of interest are most usefully presented as specific examples of previously reported data or as data selected as examples from either recently completed studies or those actively underway.

Data Collection Sites. Data presented were collected from the following Michigan research sites: near Scottdale (Dongvillo Vineyard) and Benton Harbor (Southwest Michigan Research and Extension Center) in Berrien County; Lawton (Mohney and Oxley Vineyards) in Van Buren County; and the Horticulture Teaching and Research Center (HTRC) at Michigan State University in East Lansing in Ingham County.

Cultivars. Cultivars reported include Concord and Niagara of *V. labruscana* Bailey, Pinot noir of *V. vinifera*, and the complex, mixed species cultivar Chambourcin (J. S. 26-205).

Training and Spacing. Training systems, unless otherwise noted, are Hudson River Umbrella (a bi-lateral cordon at the top wire; 6’) for the *V. labruscana* Bailey and Chambourcin, and a modified Guyot system for Pinot noir with the head at the 3’ wire. Row spacings were 10’ between rows and 8’ within-row for Concord and Niagara, 6’ within row for Chambourcin, and 4’ within row for Pinot noir.

Results and Discussion

Variability Limits to Mechanical Crop Control

1. **Seasonal Variability**. In cool regions of the northern tier of the U.S.and the grape production regions of Canada, length of season, as measured by the number of days from last spring to first fall frost vary not only geographically, but also from year-to-year at the same site (see Table 1). In particular, in the two locations reported in Table 1, there were 20 days average difference in frost-free days during the five years analyzed.

   Further, crop control concerns are exacerbated in these cool regions by the reality that crop harvest and leaf loss due to fall freeze kill of leaves occur nearly simultaneously. There is no foliated period post-harvest for crop-stressed vines to recover from carbohydrate depletion (Howell, 2001); therefore, the control of within vine competition for available photoassimilate, which is partitioned to reserves, yield and vine growth, should begin with promoting vine balance (Howell and Sabbatini, 2008).

   Another seasonal variable, the warmth during the growing season, as measured as growing degree days (GDD) (Van Den Brink et al., 1971) is also highly variable (minimum 2,424 GDD to maximum 3,323 GDD in the last five years). This not only has an impact on the selection of cultivars for culture in the region (see Table 1), but also on the frequency with which late season ripening cultivars may not achieve desired ripening characteristics.

   In our region, every spring presents the possibility of crop reduction, based on bud mortality due to either winter cold, spring freeze or poor fruit set. This kind of variability can best be demonstrated with four years of data from Niagara vines at the same site in Michigan (see Table 2). The data show the impact of seasonal differences in both yield and primary bud survival as influenced by either 80 or 120 nodes retained at dormant pruning. The range of crop yield is large: 6.5 t/a and 8.0 t/a for the 80 and 120 node treatments, respectively. The average yield over the five years is 7.56 t/a and 8.82 t/a for those node treatments, respectively.

   Primary bud survival showed that there was some winter mortality even in years when winters were considered mild (1999, 2000). The biggest impact, however, is seen in 2002 when combined winter mortality and two spring freeze episodes reduced primary buds by 59 percent and 42 percent for the 80 and 120 nodes retained treatments. Also noteworthy is the severe crop reduction in 2001, even when node survival was good. This was due to very poor conditions during fruit set.

Most impressive are the 120 node treatment yield data for 2002. The 8.2 t/a yield was quite an acceptable crop, especially in a severe spring freeze situation, and was near the five year average of 8.8 t/a.

2. **Site Variability**. At a particular location, variation in meso-climate (Geiger et al., 1995) can make one portion of a vineyard site strikingly different from another based on differences in slope and aspect. We have all seen the low area in a vineyard showing severe frost damage. This variability can be expressed as differences in meso-climate as well as in vineyard soils, and both must be addressed if mechanization of crop control is to be feasible.
3. **Soil Variability.** Many of the soils employed in vineyard production in the cool, northern tier on North America are the result of glaciations (Heinrich, 1976). These glacial events have resulted in mixed soils ranging from coarse textured sands and gravel sub-soils, heavy clays, muck soils and nearly all the variations among these (White, 2003; Wilson, 1998). Importantly, one can encounter such variability traveling down a row of vines (see Table 3). The data report an average ≈±40 percent variation in pruning weight and yield per contiguous vine along the vineyard row in three cultivars analyzed in two different locations.

   Indeed, soil variability is a key concern as we seek to employ mechanized crop control approaches. This is because a vigorous vine with high production potential is often found adjacent to a low vigor vine with correspondingly low production potential. We observe this every time we visit vineyards in the cool northern U.S. tier of viticulture regions.

   Clearly, employing an approach to cropping that does not consider this variability will result in potentially under-cropped vigorous vines and over-cropped low-vigor vines. Such an approach will make the matter worse as the range of vigor will increase between the two vines.

4. **Cultivar Variation in Production Habit.** Cultivars of *V. vinifera* are commonly productive at basal nodes one to three and are readily adapted to spur pruning (Howell et al., 2000). Sauvignon blanc is a notable exception to this (Personal Communication, M. C. T. Trought, 1996), and the *V. labruscana* cultivars Concord and Niagara are exceptions as well. These latter cases require long-cane pruning (Howell et al., 2000).

   In contrast to these cultivars are mixed-species hybrids which are not only productive at basal nodes, but also at non-count (Wolpert et al., 1983) base buds. Experience with the cultivar Seyval (Smithyman et al., 1997) and unreported work on Chambourcin, de Chaunac and Chancellor suggest that balance cannot be maintained by pruning alone in our short-season grape production region and similar areas where they experience minimal bud mortality in the winter.

5. **Variation in Crop Value.** The means employed to accomplish any vineyard management task is strongly influenced by the value of that crop at market. Thus, a cultivar/location crop valued at $2,000 per ton allows flexibilities in management not acceptable if that crop is valued at $200 per ton.

   In the former case, greater financial flexibility allows for manual, hand-based crop control via pruning and crop adjustment if that labor is indeed available, while the latter case suggests the necessity for these tasks to be mechanized.

Current Status and Future Potential

One might anticipate, based on the above comments, that we are negative regarding the potential of mechanized crop control for grapevines in cool/cold regions. That would be an error. The above information represents the scope of the challenge, not a suggestion of impossibility. Table 4 presents a synopsis of the status of mechanized viticulture in the Great Lakes region. Recent technological breakthroughs regarding soil and sub-soil assessment prior to planting (Anon., 2007) coupled with intelligent selection of rootstocks (Personal communication, P. Cousins, 2005) provide one basis for reducing within vineyard variation resulting from soil variability.

Juice Grapes. The presentation by Dr. Bates and Hans Walter Peterson (2008) points to the current reality that juice grapes in New York and other Great Lakes production areas are currently applying mechanized approaches for crop control of Concord and Niagara production. Those approaches take into account the variability concerns of site, freeze losses and vintage by assessing crop yield potential via estimation at important stages of berry growth (Pool, 2001; Bates, 2003a, b; Howell and Sabbatini, 2008). Based on the timing of berry growth indicating quality of the growing season (as assessed by GDD), the crop may be reduced, if necessary, to a desired level (Bates, 2003a, b; Howell and Sabbatini, 2008).

Importantly, this approach also serves as a hedge against spring freeze episodes, as excess buds (spare parts; Howell et al., 2006) may be retained at pruning (mechanically) and thinned mechanically as needed for the conditions of the vintage. Progressive growers of juice grapes are using this technology now (Bates, 2003a, b).

Wine Grapes. In our variable conditions of culture, mechanization of crop control for wine grapes is a more difficult issue. Crop control for wine grapes can involve a series of efforts. These may include: a) pruning; b) shoot thinning prior to bloom; c) flower-cluster thinning prior to bloom; d) cluster thinning after fruit-set; and finally, the veraison-timed ‘green-drop’. Green-drop is a removal of a specified, ‘least mature’ portion of the crop (based on cluster color status) in the late part of cluster color change (veraison). Green-drop may also employ removal of portions of a cluster, commonly the ‘wing’, for large-clustered cultivars like Malbec (Personal communication, J. Benz, 2003).

a) Pruning. Mechanized pruning of wine grapes is very dependent on training system and cultivar cold-hardiness. Cultivars sufficiently cold hardy to be cordon trained to a VSP (Howell et al., 2000) system and spur-pruned are readily mechanically pruned employing horizontal cutting bars as pre-pruners, allowing removal of vertical canes while retaining spurs that may either be maintained or shortened to desired length by hand.

Importantly, cultivars that require training to multiple trunks (Howell et al., 2006) and/or long cane pruning on VSP systems present challenges. In short, all cold tender *vinifera* cultivars in our climate presently require hand pruning and vine-by-vine assessment of trunk damage due to winter cold (Howell et al., 2006) if economic levels of annual production are to be possibly achieved.

b) Shoot thinning. The removal of non-count shoots arising from cold hardy, mixed species hybrid cultivars trained to Hudson River Umbrella (bilateral cordon at the top wire; 6’; Howell et al., 2000) has been accomplished by employing a brush along the cordon as non-count shoots reach 2-3” length. Hand shoot thinning of *vinifera* cultivars is required in our region since those cultivars commonly lack shoot uniformity along the linear positions on the wire, and blank, shootless areas can occur.

c) Flower cluster thinning. This practice is seldom used for wine grapes as it increases fruit set and subsequent berry number on the cluster. We have observed that the increased fruit set is associated with harvest season cluster rot on tightly bunched clusters.

d) Cluster thinning. As noted above, this practice is often needed for hardy wine grape cultivars with high cluster-weights. The potential to do both cluster and flower cluster thinning exists today using visual technology coupled with global positioning systems (GPS) to not only selectively remove a predetermined number of clusters, but also to control the position of the clusters to be removed.

e) Green-drop. Green-drop is seldom practiced in our region, but may be used in the future. In the short term, this will be accomplished by hand. However, methods as noted for c) and d) above, coupled with leaf plucking, hold potential to identify less mature clusters and remove a selected amount of crop. What is not being addressed and needs attention is whether this removal actually changes the rate of fruit maturity development of the remaining crop. There is much in this area that is based on what Shaulis (Howell, 2007) called “unquestioned answers” that may not be correct.

Conclusions

Present challenges to complete vineyard mechanization in cool climate regions include limitations in mechanized pruning and other crop control methodologies. These limitations are characterized by variation in annual growing season length and growing season heat accumulation (GDD), variation in meso-climate as commonly characterized as site variability, soil variability, differences in cultural methods and growth habit of commercial cultivars, and a wide range in crop value.

While considerable progress has been made with the cold-hardy cultivars Concord and Niagara grown for juice, there has been relatively less progress with wine grapes, whether mixed-species hybrids that have considerable production capability from non-count nodes or *vinifera* cultivars which are marginally cold hardy in the region.

Technological developments are required to accommodate the issues of within-row variation in vine growth and production, and the unique cultural methods required for successful economic culture of cold tender cultivars.

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Table 1. Seasonal variability in frost-free days and growing degree days at two Michigan vineyard sites.

	Growing Season					
Location	2003	2004	2005	2006	2007	Range
	Frost Free Days[1]					
MSU	161	154	166	160	169	15
SWMREC	177	181	176	181	198	22
	Growing Degree Days[2]					
MSU	2424	2467	2936	2592	2960	536
SWMREC	2623	2684	3197	2719	3323	700

[1] Frost Free Days from last 32°F event in the spring until the first 32°F event in the fall.

[2] Growing Degree Days (base 50°F) cumulative, beginning April 1 and ending October 31.

MSU = Michigan State University, East Lansing, Mich. Approximately 90 miles from Lake Michigan.

SWMREC = Southwestern Michigan Research and Extension Center, Benton Harbor, Mich. Approximately 5 miles from Lake Michigan.

Table 2. Annual variability in yield and number of live nodes of Niagara grapevines at Scottdale, Mich. Pruned to 80 and 120 nodes per vine over years 1999-2003. Hudson River Umbrella training system (8' x 10' spacing).

	1999	2000	2001[1]	2002[2]	2003	Range
Nodes	Yield (t/acre)					
80	9.4	7.5	4.1	6.2	10.6	6.5
120	10.9	8.4	4.3	8.2	123	8.0
	Number of live primary buds					
80	65	70	76	33	77	44
120	68	80	100	70	115	47

[1] Yield reduction due to poor fruit-set weather conditions.

[2] Yield reduction due to two spring freeze episodes reducing live primary buds.

Table 3. Examples of within-row, vine-to-vine variation in pruning weight (PWt) and yield/vine for several cultivars and two locations of culture during the 2004 growing season.

Cultivar		Adjacent Vine Location						
Concord[1]								Range
	PWt (lbs.)	2.50	3.25	4.00	4.00	5.50	3.25	3.00
	Yield/vine (lbs.)	25.25	28.00	36.25	22.75	40.00	17.25	22.75
Pinot Noir[2]								
	PWt (lbs.)	3.00	2.25	2.75	2.50	1.75	1.50	1.50
	Yield/vine (lbs.)	9.50	5.50	6.75	11.50	7.50	9.25	6.00
Chambourcin[3]								
	PWt (lbs.)	1.25	1.50	1.75	1.50	1.25	2.25	1.00
	Yield/vine (lbs.)	25.75	35.75	29.75	28.75	35.50	50.00	24.25

[1] 1999, pruned to 65 nodes per vine; adjacent vines, 8'x10' spacing, Hudson River Umbrella (HRU), Horticulture Teaching and Research Center, Michigan State University, East Lansing, Mich.

[2] 1993, clone UCD 9, pruned to 30 nodes per vine; adjacent vines, 4'x10' spacing, low bilateral cordon with vertical shoot positioning (VSP), Southwest Michigan Research and Extension Center (SWMREC) near Benton Harbor, Mich.

[3] 1999, pruned to 20 nodes/vine; adjacent vines, 6'x10' spacing, HRU training, SWMREC.

Table 4. Synopsis of vineyard tasks in northern state vineyards and their status with regard to mechanization.

Vineyard Task	Mechanization Status
I. Vineyard Establishment	
A. Site soil variability assessment	4
B. Vineyard layout	1*
C. Soil preparation for planting	1
D. Planting	2
E. Training years 1-3	3
F. Fruit removal years 1-2 and maybe 3	3
G. Drive posts and spool wire	1
II. Pest Control	
A. Weeds	1
B. Insects	1
C. Diseases	1
III. Fertilizer Application	1
IV. Crop Control	
A. Pruning (reducing bud number)	2
B. Crop estimation	
a. Low value grapes	1
b. High value grapes	4
C. Crop reduction (thinning pre-veraison)	
a. Juice grapes	1
b. Wine grapes	3
D. Crop reduction (green drop)	
a. Juice grapes	5
b. Wine grapes	3
V. Shoot positioning	
a. Juice grapes	2
b. Wine grapes	3
VI. Harvest	
a. Juice grapes	1
b. Wine grapes	2
VII. Cover and uncover graft union	2

*Better technology could be used.

1 = 100% mechanized
2 = Partially mechanized (some hand effort)
3 = 100% hand effort
4 = Technology available, but minimal application
5 = Practice not employed

The Economics of Vineyard Mechanization

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Abstract

Estimates of the economic impact of mechanizing several labor-intensive, pre-harvest operations are presented. Mechanization significantly reduces labor costs. A budgetary exercise demonstrates savings on pruning costs that range from about $90 per acre on vertical shoot positioning (VSP) trellising to roughly $150 per acre on quadrilateral trellising. Savings on shoot and cluster thinning operations are, in most cases, even more dramatic. Two-thirds of the costs of shoot thinning operations can be avoided by mechanizing VSP and lyre trained vineyards, and mechanization removes nearly three-quarters of the shoot thinning costs on quadrilateral trellising. Savings for cluster thinning range from just over 25 percent on VSP to nearly 55 percent on a two-foot lyre. A second and important impact of mechanization comes in the form of reduced production risks. By making it feasible to delay crop adjustments until later in the growing season, mechanization can enable growers to more consistently meet final yield targets. A framework for estimating the economic value of this flexibility is presented along with preliminary estimates of the reduced risk inherent in a mechanized production system. These preliminary estimates suggest that the flexibility afforded by mechanization could be as important as the direct savings in labor costs.

Introduction

This report summarizes recent and ongoing efforts to quantify the economic impact of mechanizing several pre-harvest operations within the framework of the Morris-Oldridge (M-O) system for complete vineyard mechanization. The emphasis of the report is on the value that mechanization can provide to the grower, and the report has two specific goals. The first is to present estimates of the magnitude of cost savings that a commercial wine grape vineyard would expect from the M-O system. These findings have been reported earlier, and in more detail, by Thomsen and Morris (2007) and are summarized in the next section of this report. The second goal is to characterize the economic value of increased flexibility that is inherent in the M-O system. As described by Morris (2005), the lower costs of mechanized operations make it feasible for growers to delay final adjustments to the size of their crop until fairly late in the growing season. This provides an opportunity to compensate for poor conditions early on and thereby be more consistent in meeting final yield targets. An economic model to value this flexibility is outlined in the third section of the report and is followed by preliminary estimates of flexibility value for different trellising systems, crop values and levels of yield risk.

The direct cost savings of the M-O system

Assumptions needed to estimate the costs of mechanized operations were based on information gathered during a visit to French Camp Vineyards (near Shandon, Calif.) during the summer of 2006. French Camp is a large commercial producer of high quality wine grapes and is owned by the Miller family. Hank Ashby, the vineyard manager, adopted the M-O System (vMech^{TM}) for use on some vineyard blocks beginning in 2002 and was able to help develop estimates of technical parameters such as field speeds, field efficiency and labor required to complete a given pre-harvest operation under a mechanized farming scenario. These estimates were used along with prices for inputs and wages that would be typical in the Paso Robles area to develop an estimate of the cost for mechanizing several pre-harvest operations. Similar estimates were developed for the costs of carrying out the same operations without mechanization, that is, under a traditional manual labor-intensive scenario. Again, the hand-labor estimates reflected cultural practices, prices and wages that would be typical of viticulture in the Paso Robles area. A thorough description of this budget study is presented elsewhere (Thomsen and Morris, 2007). It is sufficient to note that the study examined three common trellising systems – VSP, two-foot lyre and quadrilateral systems, and examined the costs of three common pre-harvest vineyard operations – dormant pruning, shoot thinning and cluster thinning.

The main results of the budget exercise are summarized in Table 1. The results show that mechanization can considerably lower the overall cost of each pre-harvest operation examined in the study. Savings on pruning costs range from roughly $90 per acre on VSP to roughly $150 per acre on quadrilateral trellising. Savings on the shoot and cluster thinning operations are, in most cases, even more dramatic. Two-thirds of the costs of shoot thinning operations can be avoided by mechanizing VSP and lyre trained vineyards, and mechanization removes nearly three-quarters of the shoot thinning costs on quadrilateral trellising. Savings for cluster thinning range from just over 25 percent on a VSP to nearly 55 percent on a two-foot lyre.

Mechanization does entail some additional machinery costs. The equipment consists of a tractor (a new 90 HP vineyard tractor was used in preparing the budgets) and a PTO driven implement trailer. The implement trailer is fitted with attachments specific to the operation in question. One set of attachments is used for pruning, another for shoot thinning and another for fruit thinning. The ownership costs reported in Table 1 reflect the costs per acre of recovering the investment in this equipment as well as costs for taxes and insurance. In the hand farming scenario, it is assumed that vineyards are mechanically pre-pruned before a labor crew begins the hand pruning operation. The ownership costs reported in Table 1 under the hand farming scenario reflect the machinery used in this pre-pruning operation.

The increase in ownership cost under mechanization is small when compared to the operating cost that can be avoided. The reduction in operating cost is due primarily to the large reduction in labor requirements. Table 2 shows the labor required for each operation under the hand and mechanized scenarios. Dependent upon the trellising system, mechanization removes, on average, anywhere from 68 to 81 percent of the labor hours required for the three pre-harvest operations considered in the study. As shown in Table 2, mechanization greatly reduces but does not completely eliminate the need for hand labor. After the mechanized pruning operation, a work crew is required to perform some minimal follow-up by hand. Moreover, each mechanized operation requires some support from a ground crew. Dependent upon the operation, members of the ground crew count buds, count shoots per foot of cordon or count and weigh clusters. Measurements provided by the ground crew are used to optimize the operation of the equipment and speed at which the equipment moves down the row. Also, as shown in Table 2, mechanization results in an increase in the amount of machine operator labor. Three machine operators are required for each operation. One person drives the tractor and two operate the implement trailer. In the budgetary exercise, machine operators are paid $2.50 per hour more to reflect their higher skill level.

The bottom line is that the M-O system enables the grower to complete pruning and thinning operations with only a fraction of the hand labor that would be required under traditional vineyard practices. The hand labor that would normally be required is replaced by fewer employees that are trained to efficiently operate the equipment.

The economic value of flexibility from the M-O system

Lower risk is an advantage of mechanization that is not reflected in the above budgets. Management of fruit load is important to quality. Vines are pruned during the winter to achieve the desired balance between fruit yield and quality. However, winter injury, spring frosts, poor fruit set or other factors could reduce fruit load below the level that was intended at the time of the pruning operation (Morris, 2000). To offset this risk, a grower could retain a sufficient number of nodes to achieve some estimate in excess of his or her target tonnage and thereby compensate for poor growing conditions. After risk factors have been resolved, excess tonnage could be removed via a shoot thinning or cluster thinning operation. Insuring against risk in this manner, however, has a price. The price of lower risk comes in the form of a higher likelihood of incurring the costs required to carry out the thinning operations necessary to reduce the crop load. At the high cost of hand operations this price is high and it will generally not be economically feasible to control risk by delaying crop adjustments. At the considerably lower costs of shoot and fruit thinning under the M-O system, risk control by delaying final crop adjustment will likely be of economic importance.

A model can be developed to illustrate the flexibility value inherent in the M-O system. In order to explain the model, let X be a random variable that represents the crop estimate (tons per acre) at the time of the thinning decision, and let μ represent the mean of X. Let V represent the value of the crop estimate in dollars per expected ton, let the final yield target be represented by T and let C be the cost of reducing the estimate through shoot thinning and/or cluster thinning operations.

The economic model reflects two decision points. The first decision point is the dormant pruning operation. This decision determines μ, the mean or expected crop estimate that will be realized later in the season. By retaining a larger or smaller number of nodes, the grower influences the magnitude of this mean. The second decision point relates to whether to thin the crop. This decision is modeled as a binary yes/no type of decision. If, at the time of the thinning decision, the crop estimate is above the yield target ($X > T$), the grower engages in a thinning operation and incurs the cost, C. For simplicity, it is assumed that if the crop is thinned, the grower thins the crop sufficiently to bring the yield forecast into congruence with the final yield target and so the resulting expected profit is $VT – C$. If, however, X is less than the final yield target, no thinning occurs and the expected profit outcome is given by VX.

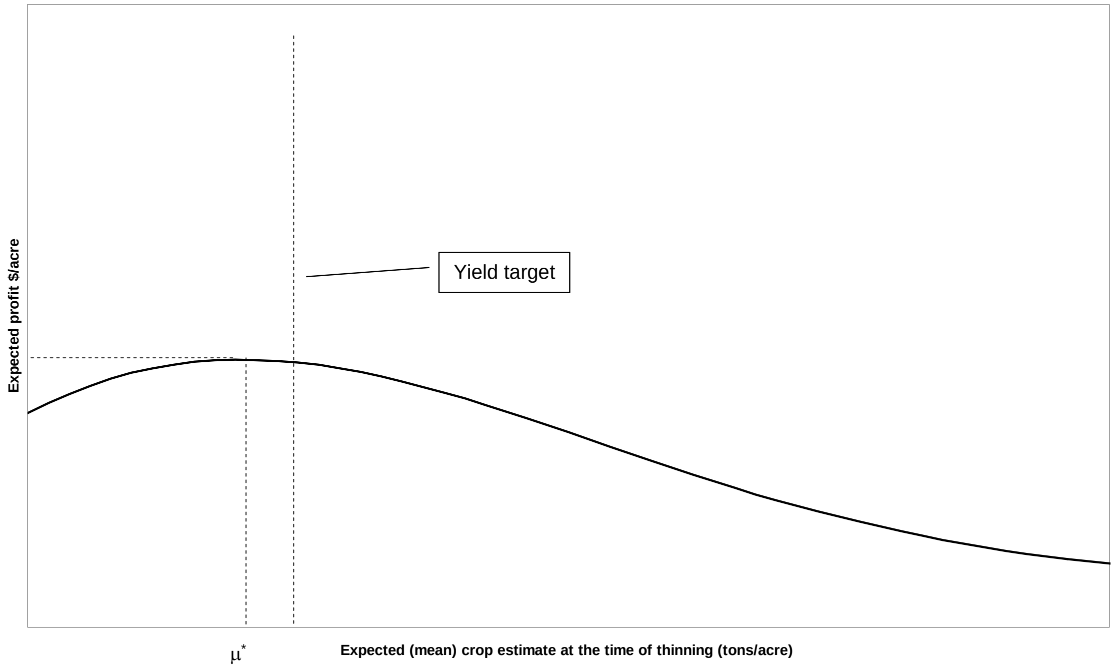

Figure 1. Expected profit and mean crop estimate.

Figure 1 can be used to develop some intuition about the economic tradeoffs inherent in the first decision point. The figure shows the expected profit as a function of μ. As shown in the figure, the expected profit is at its highest point at μ*. If μ is set too high (somewhere to the right of μ^*), expected profit declines because the higher probability of meeting the yield target and associated increase in expected revenue is more than offset by the higher expected costs of thinning operations. Similarly, if μ is set too low (to the left of μ^*), the level of expected profit declines because expected revenue losses from not meeting the target exceed the expected savings in thinning costs. Note from the figure that μ^* may not be equal to the final yield target.

In fact, μ^* could be above or below the final target depending on the costs of thinning, the value of the crop at the thinning stage, and the variance of the crop estimate.

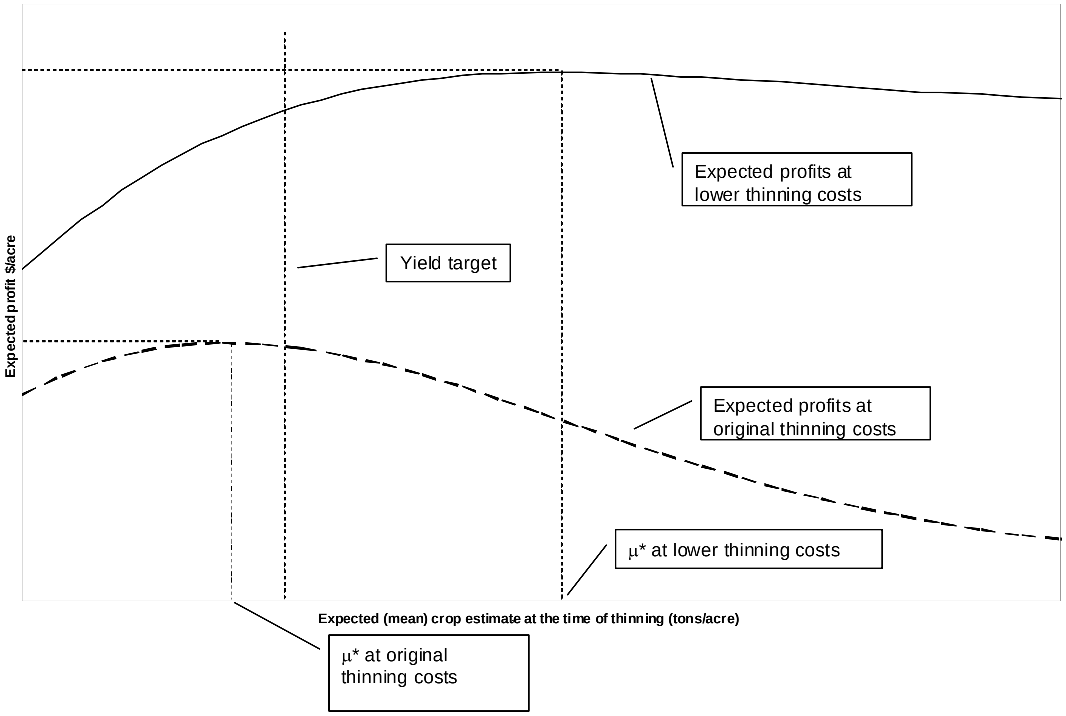

Figure 2. The mean crop estimate depends on thinning costs.

Figure 2 demonstrates how mechanization would impact the expected profit function. By lowering the cost of shoot and cluster thinning, expected profits increase, and as illustrated in the figure, the grower will generally respond to the lower costs by increasing μ^*. In so doing, the grower faces a higher likelihood of needing to reduce the crop load later in the season, but, at the lower costs, this is offset by the higher likelihood of reaching the crop target. In terms of the economic model, an optimizing grower under a mechanized system would choose a higher mean value than would be the case if he or she were operating under a hand-labor system. In other words, $\mu^*_M > \mu^*_H$.

The arguments to this point suggest that the economic impact of mechanization is broader and more complex than the straightforward reductions in labor costs that were shown in the budget exercise summarized above. The cost savings make it feasible to delay the final crop adjustment until later in the season, after many of the most serious risk factors have been removed. In this respect, vineyard mechanization provides the grower with flexibility and the opportunity to more consistently hit crop targets.

So far, the model has only dealt with the mean or the expectation of profits. To better capture the flexibility value of mechanization it is necessary to consider the payoffs that mechanization provides depending on what the crop estimate ultimately turns out to be at the time the thinning decision is made. These payoffs can be described with the aid of Figure 3. In this figure, the horizontal line represents the final crop target. The two lines labeled X_M and X_H show different possibilities of the crop forecast under machine farming and hand farming, respectively. The vertical difference between these two lines represents the additional crop potential under the mechanized scenario and is equal to $\mu_M^* - \mu_H^*$. The probability density function superimposed on the figure represents the likelihood of realizing a crop forecast of the magnitude corresponding to the values read from the X_M and X_H lines. For the sake of illustration, let us assume that X_M and X_H follow a normal distribution. While their means differ, we will make the simplifying assumption that the standard deviation is the same under both hand and machine farmed scenarios.

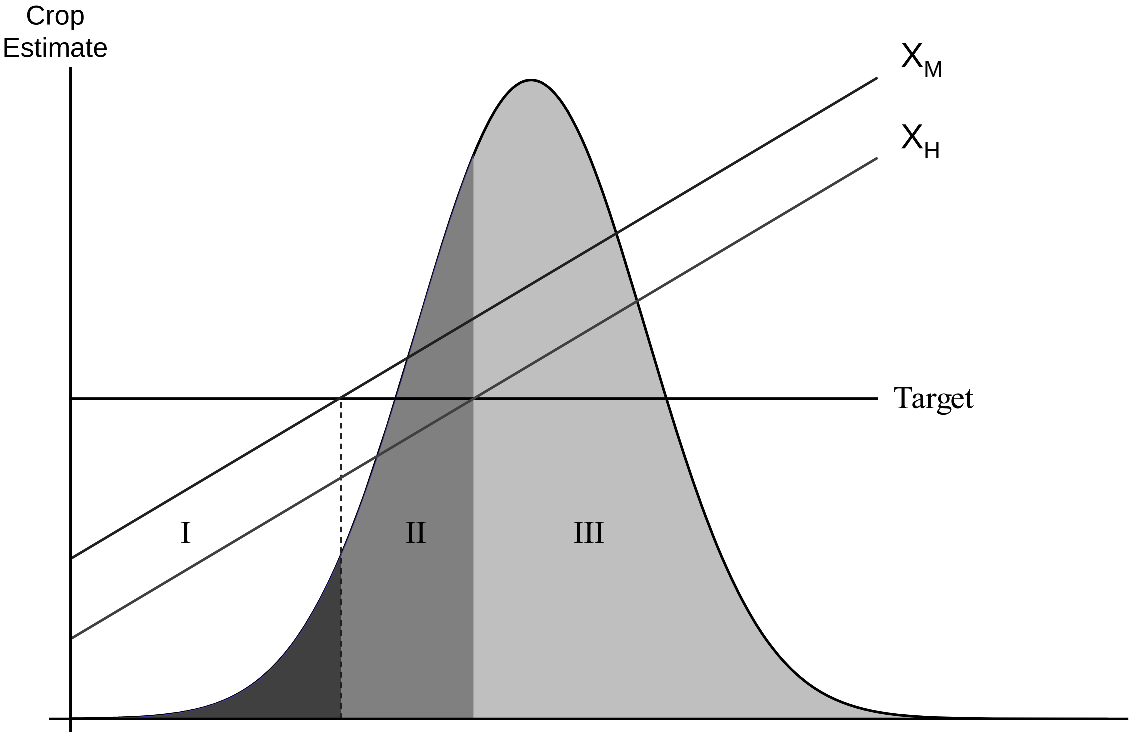

Figure 3. Payoff scenarios depending upon value of the crop estimate.

Figure 3 depicts three types of outcomes that are contingent on the value of the crop estimate. The area labeled “I” represents cases where the crop estimates on both hand and machine farmed vineyards are below the yield target. Consequently, there is no thinning operation, and the payoff to mechanization is simply the augmentation to revenue that results from being closer to the final target. This can be expressed in terms of the model variables as $V(X_M - X_H)$. In the area labeled "II," machine farmed vineyards are above the yield target, the estimated crop load is reduced accordingly and the grower incurs a cost of C_M. However, hand farmed vineyards are below the yield target. The payoff in region II can be expressed as $V(T – X_H) - C_M$. Finally the area labeled "III" reflects situations where both hand and machine farmed vineyards are above target. Consequently, thinning operations occur under both scenarios and the payoff to mechanization consists of the cost savings it provides ($C_H - C_M$). Given the assumptions outlined above, payoffs to mechanization are unambiguously positive in cases that fall in regions I and III. In region II, payoffs to mechanization may be positive or negative depending on whether the revenue enhancement that results from mechanization exceeds the cost of reducing the crop estimate back to the yield target.

An empirical simulation to measure the value of flexibility

A numeric simulation was used to implement the economic model and place a value on the flexibility inherent in vineyard mechanization. The simulation reflects several simplifying assumptions. These are (1) that crop estimates are normally distributed, (2) that variability of the crop estimate is unaffected by whether the vineyard is hand or machine farmed and (3) that the correlation between crop estimates under the hand and machine farmed scenarios is perfect so that the difference in the crop estimates corresponds to the difference in the means. These distributional assumptions are fairly stringent and may depart from reality in several important ways. Consequently, results of the simulation should be taken with some caution. However, the simulations do reflect the essential economic considerations described above and can provide some preliminary insight into the economic consequence of the increased flexibility afforded by mechanization. They can also be used to illustrate how the value of flexibility depends on yield risk and other parameters of the model.

In the simulations, we assumed a target yield of 5.5 tons per acre on VSP and 7.5 tons per acre on quadrilateral and two-foot lyre trellising. The values of C_H and C_M conform to the costs for shoot thinning and one-half of the costs for cluster thinning operations under the hand and machine farmed scenarios as reported above in Table 2. This is to reflect the fact that in some years, shoot thinning alone will be sufficient to bring the crop estimate into congruence with the final yield target and cluster thinning may be unnecessary. We conducted the simulation under several values of the crop estimate ranging from V = \$700, \$800 and \$900 per ton. Several values for the standard deviation of the yield estimate were also used. These were 0.256, 0.51, 0.765 and

1.02 tons per acre and correspond to 95 percent confidence intervals of 0.5, 1, 1.5 and 2 tons above and below the mean crop estimate, respectively.

Results of the simulation exercise are reported in Table 3. Again, given the fairly stringent distributional assumptions, the absolute dollar values should be viewed with some caution. While preliminary, these results are suggestive that the flexibility inherent in mechanization is of considerable economic importance. The flexibility value of mechanization is estimated to be anywhere from $100 per acre to $400 per acre depending on the magnitude of yield risk, value of the potential crop, and trellising system. Values of flexibility are increasing as the value of the crop increases and the results are highly sensitive to the degree of yield risk. The value of flexibility at the highest standard deviation of 1.02 tons per acre is generally 1.5 to 2 times larger than that at the lowest standard deviation of 0.25 tons per acre. When yield risk is high, the results in Table 3 indicate that the flexibility value of mechanization could be of equal or greater importance than the direct cost savings.

Summary

The findings presented in this report suggest that mechanizing pre-harvest operations such as dormant pruning, shoot thinning and cluster thinning is of considerable economic potential. The cost savings from the M-O system are straightforward to estimate and reflect assumptions that conform to implementation of the system in an actual commercial setting. More difficult to estimate is the flexibility value that the system affords. However, preliminary results from the economic model suggest that this flexibility provides significant economic benefits to growers. Future work is focused on better characterizing the distributions of crop estimates under both hand and machine farmed scenarios in order to better value the flexibility inherent in vineyard mechanization.

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Thomsen, M.R. and J.R. Morris. 2007. Economics of Mechanizing Pre-Harvest Vineyard Operations. Wine East Buyer’s Guide, pp. 6-17.

Table 1. Comparison of Costs for Manual and Mechanized Pre-harvest Operations (cost/acre).

	Manual System			Mechanized System		
	Prune	Shoot Thin	Cluster Thin	Prune	Shoot Thin	Cluster Thin
VSP (9 by 6 spacing)						
Equipment Ownership Costs	4.59	NA	NA	12.53	7.20	15.00
Operating Costs	261.84	226.63	214.70	168.65	69.90	141.04
Interest on Operating Capital	11.45	5.36	3.62	7.28	1.65	2.38
Total	277.88	231.99	218.32	188.46	78.75	158.42
Two-foot Lyre (9 by 7 spacing)						
Equipment Ownership Costs	9.17	NA	NA	25.06	14.40	15.00
Operating Costs	413.28	453.26	345.91	277.27	139.80	141.04
Interest on Operating Capital	18.13	10.73	5.84	11.97	3.31	2.38
Total	440.58	463.99	351.75	314.30	157.51	158.42
Quadrilateral (12 by 8 spacing)						
Equipment Ownership Costs	6.45	NA	NA	16.45	10.80	11.25
Operating Costs	334.41	453.26	345.91	182.00	104.85	105.76
Interest on Operating Capital	14.64	10.73	5.84	7.86	2.48	1.79
Total	355.50	463.99	351.75	206.31	118.13	118.80

VSP = vertical shoot positioning

Table 2. Labor Requirements for Manual and Mechanized Operations (hours per acre).

	Manual System			Mechanized System		
	Prune	Shoot Thin	Cluster Thin	Prune	Shoot Thin	Cluster Thin
VSP (9 by 6 spacing)						
Hand Labor	20.18	19.00	18.00	8.48	0.94	0.98
Machine Operator Labor	0.98	NA	NA	2.95	1.69	3.53
Total Labor Hours	21.16	19.00	18.00	11.43	2.63	4.51
Two-foot Lyre (9 by 7 spacing)						
Hand Labor	31.10	38.00	29.00	9.46	1.88	0.98
Machine Operator Labor	1.96	NA	NA	5.89	3.38	3.53
Total Labor Hours	33.06	38.00	29.00	15.35	5.26	4.51
Quadrilateral (12 by 8 spacing)						
Hand Labor	25.54	38.00	29.00	6.21	1.41	0.73
Machine Operator Labor	1.38	NA	NA	3.87	2.54	2.64
Total Labor Hours	26.92	38.00	29.00	10.08	3.95	3.37

VSP = vertical shoot positioning

Table 3. Preliminary Estimates of Flexibility Value ($/acre).

Standard Deviation of the Crop Estimate (tons/acre)	Expected Value ($/ton) of the Crop Forecast		
	700	800	900
	VSP		
0.255	93.84	104.47	117.93
0.510	140.93	157.06	158.97
0.765	161.49	172.56	174.71
1.020	174.77	176.72	177.46
	Two-foot Lyre		
0.255	140.34	170.71	201.13
0.510	233.74	259.04	282.67
0.765	288.20	302.03	313.94
1.020	329.42	355.90	357.26
	Quadrilateral		
0.255	178.25	212.59	243.46
0.510	287.39	314.03	338.76
0.765	344.57	359.10	371.35
1.020	386.83	413.34	414.70

VSP = vertical shoot positioning

Mechanical and Minimal Pruning of Cynthiana Grapes: Effect on Yield Components and Juice and Wine Composition

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Abstract

Cynthiana (*Vitis aestivalis* Michx.), a small clustered premium red wine grape has not been studied for its suitability for mechanical or minimal pruning. Four pruning methods, hand (balanced to 50+10), machine (box cut to 80 nodes), machine+hand (box cut to 110 nodes with hand prune to 80 nodes), and minimal pruning (no pruning) were applied for four years (2002 to 2005). There were only minor differences in vine nutrition and fruit and wine composition among the pruning methods that occurred after the first year. Juice compositional changes occurring during ripening were similar regardless of pruning method. Malic acid content dropped about 55 percent as maturity increased from 19 percent and 22.5 percent soluble solids in all treatments. Minimal-pruned vines overproduced the first year and had poor color and lower soluble solids. This was followed by low yields the second year with yield stabilization by the third year. The 4-year average yield was 10 kg per vine to 11 kg per vine across all pruning methods. Wines produced were similar within year among pruning methods after the first year. No sensory differences were found between wines from hand-pruned vines vs. other methods in any year (wine from minimal-pruned 2002 excluded). After the first year, all pruning methods produced similar fruit, juice and wine. In the final year of the study, all pruning methods had comparable yields and juice composition. Thus, in viticultural areas with sufficient growing seasons, all pruning methods studied may produce high quality grapes.

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Introduction

Dormant pruning by hand is a time-consuming, labor-intensive process used to achieve the desired balance of fruit yield and composition. Hand pruning is the second largest cost factor in vineyard operations behind hand harvesting. Machine farming of grapes reduced costs from 44 percent to 61 percent as compared to hand farming for *Vitis vinifera* grapes (Thomsen and Morris, 2007). Mechanical winter pruning reduced pruning cost by at least 50 percent as compared to hand pruning in other studies (Poni et al., 2004). Shortages of labor and increased labor costs are increasing interest in complete vineyard mechanization systems in the United States (Morris, 2007).

Cultivars respond differently to pruning (Clingeleffer, 1993; Jackson et al., 1984; Poni et al., 2004; Tassie and Freeman, 1992). Spur length and climate can affect bud fruitfulness in *V. vinifera* cultivars (Clingeleffer, 1993; Jackson et al., 1984). Low-fruitful cultivars like Croatina respond very successfully to mechanical pruning followed by hand finishing (Poni et al., 2004), and conversion of these traditionally long-cane-pruned vines to short-cane pruned provides balanced growth and ripening.

Minimal pruning is a system involving no pruning, except mechanical skirting (summer trimming of shoots at approximately 60 cm above vineyard floor) to aid mechanical harvest. This system increases yield and produces numerous small clusters with delayed fruit maturity (Clingeleffer, 1993; Jackson and Lombard, 1993; Possingham, 1996; Tassie and Freeman, 1992). Clingeleffer (1996) concluded from 20 seasons of Australian minimal-pruning trials on *V. vinifera* that vines have the capacity, through balanced growth and self-regulation, to maintain their shape, productivity and fruit quality.

The effects of machine and minimal pruning on fruit, juice and wine composition have not been established for Cynthiana. The aims of this research were to compare and evaluate the effects of hand, machine, machine+hand and minimal pruning on Cynthiana grapes and wines and to examine the effect of grape maturity on juice composition.

Materials and Methods

This manuscript is a companion paper to Main and Morris 2008; detailed materials and methods can be found in that paper. Vineyard treatments were established in a 14-year-old

Cynthiana block located at the Arkansas Agricultural Research and Extension Center, Fayetteville, Ark. (lat. 36°10′N, long. 94°17′W) in a north-south row orientation. Vines were trained to a bilateral cordon 1.8 m in height. Spacing was 1.8 m x 2.75 m (vine X row) with two drip emitters per plant for irrigation.

Bird netting was applied over the row and fixed under the irrigation line at veraison each year. Shoots were skirted on non-minimal treatment vines at 30 cm above the vineyard floor to facilitate application of bird netting. The hand- and minimal-pruned Cynthiana grapes required approximately 185 days and 193 days, respectively, to reach maturity after bud break.

Pruning Methods. Four pruning methods were applied in six replications of four-vine plots for four consecutive years (2002 to 2005) as follows:

1. Hand-pruned vines were balance-pruned, utilizing 3- to 4-node spurs with some one-node spurs for wood renewal, to 50+10 with an 80-node upper limit.
2. Machine-pruned vines were box cut with a gasoline-powered hedge trimmer to retain 70 to 80 nodes. The box cut retained 2- to 3-node spurs on top and sides of the cordon.
3. Machine+hand-pruned vines were machine pruned to a box cut to retain 100 to 110 nodes with follow-up hand-pruning to 70 to 80 nodes. The box generally had four node spurs on the top and sides. The hand follow-up consisted of spur thinning to achieve a better distribution of spurs along the cordon.
4. Minimal-pruned vines were not pruned during dormancy but skirted 60 cm above the ground at veraison.

Mechanical pruning was in a “box cut” style. In this style of pruning, vertical cuts are made on the sides of the cordon and horizontal cuts are made on the top and the bottom of the cordon. The horizontal cut below the cordon was made close to the cordon to leave short spurs with only basal buds.

A random 200-berry sample was collected across the four-vine plots for each pruning method and replication when average soluble solids were approximately 19 percent, 21 percent and 22.5 percent. A hot-press method was used to determine fruit composition. This hot-press method expresses more of the compounds that are available during wine fermentation by extracting more color, acids, and minerals from the skins (Threlfall et al., 2006). Cluster weight, clusters per vine, and yield per vine were determined by counting clusters and weighing grapes from each vine at harvest. Berries per cluster were calculated as (cluster weight/berry weight).

Wine production. Wines were produced in 2002, 2003 and 2004 as detailed in Main and Morris, 2008. Wine was produced from two 40-kg lots from each pruning method. During production, the pectinolytic enzyme Lallzyme EXV, the yeast Saccharomyces cerevisiae strain BRL97 and bacteria Oenococcus oeni MBR® strain Lalvin 31 (all from Lallemand, Inc., Montreal, Canada), were used. The musts were fermented at 21°C, and the fermentation cap was mixed two times per day. Before and during fermentation, pH was adjusted to pH 3.6 using tartaric acid to maintain wine quality. After seven days of fermentation, the must was pressed. After malolactic fermentation, wine pH was adjusted to pH 3.55 with tartaric acid, and the wines were cold stabilized and then filtered with a 1-µm filter. One hundred mg/L of sulfur dioxide (SO_2) was added at bottling, and wines were transferred to 750-mL bottles and closed with SupremeCorq 45-mm closures (Supreme Corq, LLC., Kent, WA).

Sensory analysis. Wines were evaluated by Vinquiry, Inc., Napa, Calif., using triangle tests. Three of the four pruning methods were compared in 2002, and all four methods were compared in 2003 and 2004. Wines had been in the bottle for approximately one year when evaluated. Details of the sensory analysis can be found in Main and Morris, 2008.

Experimental design and statistical analysis. The experiment was a completely randomized block with four pruning methods in four-vine plots with six replications over four seasons (2001 to 2005) with three sampling dates. Wines from the different pruning methods were made in duplicate for three years. There were significant differences in years that resulted in significant year x treatment interactions primarily related to the minimal-pruning treatment in years one and two. Data for the third sample date were therefore analyzed and reported as pruning treatments by year. Data for 2004 and 2005 were averaged to examine the influence of maturity on pruning treatments. JMP software (version 6.0, SAS Institute Inc., Cary, N.C.) was used for analysis of variance and either Student's t or Tukey's Honestly Significant Difference tests at the $p \leq 0.05$ level of significance were used to separate means of pruning treatments. FIZZ sensory analysis management software was used for sensory statistical analysis.

Results and Discussion

Vine nutritional status was measured in plant petioles at veraison (see Table 1). There were few differences in petiole mineral content between pruning treatments within year. Potassium did not differ among pruning treatments in any year. Phosphorus and magnesium differed among pruning treatment only in 2004. The numerical differences were generally small, and year to year patterns associated with pruning treatments were not apparent. The values for N, P, K and Ca were within or slightly higher than the normal range (Dami et al., 2005). The values for Mg were either low or at the low end of the normal range even though two to three foliar magnesium sprays were applied during the growing season and soil magnesium was adequate (Main and Morris, 2008). Minor elements manganese, iron, zinc, copper and boron were also within the normal ranges for each element with no apparent relationship to pruning method (data not shown).

Fruit was sampled when soluble solids were approximately 19 percent, 21 percent and 22.5 percent. Data was averaged for 2004 and 2005, when fruit yields had stabilized, to examine the effects of fruit maturity on juice composition (see Table 2). There were significant increases or decreases for measured variables between each sampling date regardless of pruning method for all variables except tartaric acid, which remained constant, and berry weight. Berry weight differed with sampling date only on the hand-pruned vines. This was probably associated with desiccation and shriveling that took place on all berries regardless of treatment. Malic acid decreased by about 55 percent in all pruning treatments between the first and third sampling dates and contributed the most to the reduction in titratable acidity. Both pH and potassium increased with sampling date but potassium showed no correlation with pH (data not shown). There were few differences between pruning methods at a given sampling date. Soluble solids were lower in the minimal pruning treatment than in the other pruning treatments at sample date one, but the difference closed by sample date two. The same was true for total red pigments. Berry weight was lower in the minimal treatment than the hand or machine+hand treatment at all sample dates for this two-year average.

The remainder of the tables compare the data on a year-by-year basis at harvest but also show an average across years. The averages are presented to provide a feel for longer term trends. However, they do not provide statistically relevant results due to significant pruning method by year interactions. Minimal pruning had the greatest impact on yield and yield components among the pruning methods (see Table 3). During the first year, minimal-pruned vines appeared to be overcropped at 13.9 kg/vine and fruit was not as mature when harvested even though it was harvested one week after the other treatments. In the second year, the minimal-pruned vines had reduced yield in response to the high crop load from the previous year. A yield increase during the first year after implementation of minimal pruning is normal, with yield stabilization occurring in subsequent years (Clingeleffer, 1996; Jackson and Lombard, 1993). Yield appears to be stable in minimal-pruned vines by the third year, and the vines produced fruit of similar composition to the other pruning methods. Minimal-pruned vines had three times as many shoots as hand-pruned vines (data not shown). The shoots on minimal-pruned vines were shorter and smaller in diameter than the shoots from the other pruning methods, which was consistent with reports on minimal pruning of *V. vinifera* cultivars (Sommer and Clingeleffer, 1993; Clingeleffer, 1996; Jackson and Lombard, 1993, Possingham, 1996). Overall, yield components were similar within year and on average for hand-, machine+hand- and machine-pruned vines. There was little difference in berry weight among pruning methods. Minimal-pruned vines had lower berry weights than hand-pruned vines in 2002 and 2004 and appear lower on average. Minimal pruning reduced berry weight in other cultivars as compared to traditional pruning (Sommer and Clingeleffer, 1993; Clingeleffer, 1996; Reynolds and Wardle, 2001). Cluster weight was lower, and clusters per vine were higher in minimal-pruned vines than hand-pruned vines which was consistent with other reports (Sommer and Clingeleffer, 1993; Clingeleffer, 1993; Jackson and Lombard, 1993; Possingham, 1996). Minimal-pruned vines had a four-year average of 35 percent more clusters than the hand-pruned vines.

Minimal-prune vines appeared to have slightly higher yields than vines pruned with the other methods. The minimal-prune vines had yields of 11.6 kg/vine in year four, with a four-year average of 11.2 kg/vine (19.9 t/ha equivalent). By comparison, the four-year average yield for hand-pruned vines was 10.1 kg/vine (17.95 t/ha equivalent). The hand-pruned yield observed in this experiment was higher than the 7.7 kg/vine average obtained when vines were pruned to 60 buds (Main and Morris, 2004). The average yield increase for minimal-pruned vines vs. hand-pruned vines was about 10 percent. This was much lower than the 25 percent to 50 percent increase reported for some *V. vinifera* cultivars (Clingeleffer, 1993; Possingham, 1996).

Commercial yields of Cynthiana range from about 3.5 to 13 t/ha which is much lower than observed in this experiment. Therefore, it would appear that in grape growing areas with a sufficient growing season (185 to 195 days) commercial yields of Cynthiana could be increased while retaining good fruit composition by applying any of the pruning and management conditions used in this study. However, the vineyard location in this experiment provided a 30+ day foliated postharvest period. This foliated postharvest period may assist in vine recovery by increasing carbohydrate reserves which may for ripening of a larger crop (Howell, 2001). Mechanical grape harvesting would be advisable for the croploads used in this study due to the large number of small clusters per vine.

An issue that needs to be explored before minimal pruning can be recommended for Cynthiana vines relates to an observation not reflected in the data. In most years, a portion of the clusters hanging in the lower 0.75 m of the minimal-prune canopy suffered from late-season bunch stem necrosis. Bunch stem necrosis is a physiological disorder that begins in the peduncle. There are several theories about the cause of bunch stem necrosis that range from mineral deficiency to vine vigor, but the exact cause is unknown (Pickering et al., 2007). These clusters, in large quantity, could potentially affect quality of wine produced from mechanically harvested fruit. The bunch stem necrosis may have been in part due to the 60 cm skirting at veraison. This would have shortened some fruit bearing shoots. Skirting of the minimal pruned vines during the dormant season may alleviate this issue and should be explored.

Juice Composition. Fruit composition differences among pruning treatments were usually minor, were not recurrent with year, and therefore did not appear to be associated with pruning method (see Table 4). The higher yield on minimal-pruned vines in 2002 resulted in lower soluble solids (21.3 percent). Soluble solids were not different among pruning methods for other years. Malic acid was similar among pruning methods after the first year. Tartaric acid did not differ among pruning methods in any year (data not shown). Total red pigments were similar in all years except 2002 when the juice from the minimal-prune method had lower values than juice from the other pruning methods. Total red pigments in juice and wine was lower in 2002 and 2005 than in the other years; both these years had temperatures above 35°C during veraison or a temperature spike that occurred during or slightly before veraison. By contrast, the exceptional color year of 2004 had only a few days where the maximum temperature reached 33°C. Red color accumulation is cultivar dependent, and warm temperatures during the growing season reduces red color development in some cultivars (Jackson and Lombard, 1993). Decreased red color has been previously associated with warm veraison periods in Cynthiana (Main and Morris, 2004).

Wine Composition. Wine pH was adjusted with tartaric acid to pH 3.55 before cold stabilization and did not differ among treatments. Total red pigment was substantially lower in the 2002 wines from the minimal-prune vines (see Table 5). This color discrepancy did not appear in later years. Tartaric acid did not differ among treatment wines and was a reflection of the cold stabilization process. Malic acid content was reduced to the same level in all wines by the malolactic bacteria. The lactic acid levels in the wines were similar, as would be expected, since the malic acid levels of the juice were all similar. Ethanol was lower in wine from the minimal-prune treatment in 2002, reflecting the lower sugars obtained in the grapes that year.

The results of sensory discrimination testing of the wines using triangle tests are shown in Table 6. Only wines from three pruning methods were evaluated in 2002 because wine from minimal-pruned vines obviously had less color. The panel of expert wine judges could only differentiate wine from machine vs. machine+hand wine in 2003. They could not differentiate any other wine pair in other years at the 5 percent level of significance.

Conclusions

Cynthiana vines that were machine pruned with or without hand follow-up produced fruit yield, fruit composition and wines that were similar to hand-pruned vines. Therefore, the use of machine pruning either alone or in conjunction with hand pruning is a viable option for Cynthiana production in regions with a long (185+ day) growing season. Minimal pruning also produced fruit and wine composition similar to hand-pruned fruit after the vines stabilized in fruit production. Further testing is needed in viticultural areas with a shorter growing season.

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Table 1. Effect of pruning methods on minerals in Cynthiana petioles sampled at veraison (2003 to 2005).

Pruning method[1]	Year			3 year Average	Normal range[2]
	2003	2004	2005		
	Nitrogen (%)				0.9-1.3
Hand	1.46 a[3]	1.43 a	1.33 ab	1.41	
Machine+hand	1.41 ab	1.44 a	1.36 a	1.40	
Machine	1.37 ab	1.38 ab	1.30 ab	1.35	
Minimal	1.36 b	1.48 a	1.28 b	1.37	
	Phosphorus (%)				0.16-0.29
Hand	0.38	0.50 a	0.44	0.44	
Machine+hand	0.49	0.54 a	0.43	0.48	
Machine	0.46	0.51 a	0.44	0.47	
Minimal	0.53	0.42 b	0.46	0.47	
	Potassium (%)				1.5-2.5
Hand	2.14	2.77	2.31	2.41	
Machine+hand	2.14	2.99	2.26	2.46	
Machine	2.06	2.92	2.46	2.48	
Minimal	2.25	2.63	2.31	2.40	
	Calcium (%)				1.2-1.8
Hand	2.47 a	1.61 b	2.14	2.07	
Machine+hand	2.18 ab	1.49 b	2.19	1.95	
Machine	2.25 ab	1.63 b	2.20	2.03	
Minimal	2.00 b	2.22 a	2.40	2.20	
	Magnesium (%)				0.26-0.45
Hand	0.29	0.20 b	0.27	0.25	
Machine+hand	0.27	0.18 b	0.26	0.24	
Machine	0.28	0.17 b	0.27	0.24	
Minimal	0.24	0.24 a	0.29	0.26	

[1] Hand = balance to 50+10; machine = box cut to 80 nodes; machine+hand = box cut to 110 nodes with hand pruning to 80 nodes; and minimal = no pruning

[2] Dami et al., 2005

[3] Means within column and year with the same or no letter(s) are not significantly different at p≤0.05

Table 2. Effect of sampling date on juice composition in Cynthiana grapes (average of 2004 and 2005 growing seasons).

Pruning Method [1]	SD [2]	Soluble solids (%)	pH	Titratable acidity (g/L)	Total red pigments (AU)	Tartaric acid (g/L)	Malic acid (g/L)	Potassium (mg/L)	Berry weight (g)
Hand	1	19.8 Ca[3]	3.47 C	14.2 A	59 Ca	7.3	9.6 A	2574 C	1.21 Aa
Hand	2	21.1 B	3.63 B	11.1 B	8 Bab	7.2	6.3 B	2722 B	1.19 Aa
Hand	3	22.5 A	3.80 A	9.2 C	131 A	7.9	4.2 C	2961 A	1.15 Ba
Machine +hand	1	19.4 Ca	3.47 C	14.5 A	60 Ca	7.3	10.0 A	2622 C	1.17 a
Machine +hand	2	20.8 B	3.62 B	11.2 B	89 Bab	7.2	6.4 B	2747 B	1.17 a
Machine +hand	3	22.3 A	3.79 A	9.6 C	129 A	7.7	4.5 C	2961 A	1.15 a
Machine	1	19.6 Ca	3.49 C	14.1 A	58 Ca	7.3	9.7 A	2540 C	1.17 ab
Machine	2	21.3 B	3.64 B	11.0 B	97 Ba	7.1	6.3 B	2728 B	1.16 a
Machine	3	23.2 A	3.82 A	8.9 C	140 A	7.8	4.0 C	2966 A	1.12 ab
Minimal	1	18.6 Cb	3.47 C	13.8 A	43 Cb	6.8	9.6 A	2513 C	1.09 b
Minimal	2	20.6 B	3.63 B	10.8 B	77 Bb	6.8	6.5 B	2666 B	1.06 b
Minimal	3	22.5 A	3.82 A	8.9 C	119 A	7.6	4.2 C	2867 A	1.02 b

[1] Hand = balance to 50+10; machine = box cut to 80 nodes; machine+hand = box cut to 110 nodes with hand pruning to 80 nodes; and minimal = no pruning

[2] Sample date – each date is seven to 10 days apart with a goal of sampling at average soluble solids of 19 percent, 21 percent and 22.5 percent.

[3] Within a column, no letters or the same letter(s) indicate the means are not significantly different at $p \leq 0.05$. Uppercase letter(s) are mean separations between sample dates and within a pruning method (i.e. within Hand). Lowercase letters(s) are mean separations across all pruning methods within a sample date (i.e. all SD 1).

Table 3. Effect of pruning methods on yield components of Cynthiana grapevines (2002 to 2005).

Pruning method [1]	Year 2002	2003	2004	2005	4-year average [2]
	Berry weight (g)				
Hand	1.19 a [3]	1.05	1.21 ab	1.08	1.13
Machine+hand	1.18 a	1.04	1.33 a	1.02	1.13
Machine	1.18 a	1.18	1.18 bc	1.05	1.11
Minimal	0.96 b	1.04	1.06 c	0.98	1.01
	Cluster weight (g)				
Hand	66 a	62 a	68 ab	71 a	66
Machine+hand	64 ab	61 a	74 a	69 a	67
Machine	58 b	53 b	57 bc	69 a	59
Minimal	40 c	49 b	43 c	53 b	46
	Clusters/vine				
Hand	145 b	185	122 b	164 b	154
Machine+hand	151 b	196	139 b	174 ab	165
Machine	162 b	229	111 b	163 b	167
Minimal	348 a	189	241 a	220 a	250
	Yield (kg/vine)				
Hand	9.5 b	11.4 ab	8.2 b	11.6	10.2
Machine+hand	9.5 b	12.1 a	7.9 b	12.0	10.4
Machine	9.4 b	12.1 a	7.7 b	11.3	10.1
Minimal	13.9 a	9.2 b	10.2 a	11.6	11.2

[1] Hand = balance to 50+10; machine = box cut to 80 nodes; machine+hand = box cut to 110 nodes with hand pruning to 80 nodes; and minimal = no pruning

[2] Statistics are not available across years or for 4-year average due to interactions between years.

[3] Means within column and year with the same or no letter(s) are not significantly different at $p \leq 0.05$.

Table 4. Effect of pruning methods on Cynthiana grape juice composition (2002 to 2005).

	Year				
Pruning method [1]	2002	2003	2004	2005	4-year average [2]
	Soluble solids (%)				
Hand	22.5 a [3]	20.3	23.3	22.0	21.9
Machine+hand	22.1 a	20.3	23.0	21.9	21.7
Machine	22.7 a	20.9	23.9	22.5	22.2
Minimal	21.3 b	20.3	23.4	21.9	21.7
	pH				
Hand	3.59	3.64	3.70 b	3.90	3.70
Machine+hand	3.56	3.61	3.69 b	3.89	3.68
Machine	3.60	3.62	3.75 a	3.90	3.72
Minimal	3.59	3.67	3.73 ab	3.91	3.73
	Titratable acidity (g/L) [4]				
Hand	12.5 a	9.4	10.3	7.9 b	10.1
Machine+hand	13.1 a	9.7	10.8	8.1 ab	10.5
Machine	12.6 a	9.8	10.3	8.2 a	10.2
Minimal	11.0 b	9.6	9.8	8.3 a	9.7
	Malic acid (g/L)				
Hand	6.9 ab	4.6	4.6	3.9	5.0
Machine+hand	7.4 a	4.8	4.9	3.7	5.2
Machine	6.8 ab	4.8	4.7	4.1	5.2
Minimal	5.9 b	5.2	4.5	4.1	5.3
	Total red pigments (AU)				
Hand	96 a	128	151	105	121
Machine+hand	94 a	130	146	115	118
Machine	108 a	143	165	105	125
Minimal	74 b	137	135	111	112

[1] Hand = balance to 50+10; machine = box cut to 80 nodes; machine+hand = box cut to 110 nodes with hand pruning to 80 nodes; and minimal = no pruning

[2] Statistics are not available across years or for average of years due to interactions between years.

[3] Means within column and year with the same or no letter(s) are not significantly different at $p \leq 0.05$.

[4] Expressed as tartaric acid

Table 5. Effect of pruning methods on color, organic acids, and ethanol content of Cynthiana wine.

Pruning method[1]	Year 2002	 2003	 2004	3-year average[2]
	Total red pigment (AU)			
Hand	43 a[3]	64 ab	131 b	79
Machine+hand	44 a	58 b	116 c	73
Machine	45 a	66 ab	136 a	83
Minimal	26 b	72 a	132 b	77
	Tartaric acid (g/L)			
Hand	2.1	2.5	2.2	2.3
Machine+hand	2.1	2.5	2.3	2.3
Machine	2.1	2.5	2.3	2.3
Minimal	2.1	2.6	2.3	2.3
	Malic acid (g/L)			
Hand	0.5	0.3	0.4 b	0.4
Machine+hand	0.5	0.3	0.5 a	0.4
Machine	0.5	0.3	0.4 b	0.4
Minimal	0.4	0.3	0.4 b	0.4
	Lactic acid (g/L)			
Hand	4.7	3.1 b	3.5	3.7
Machine+hand	4.6	3.3 ab	3.4	3.7
Machine	4.7	3.4 a	3.4	3.7
Minimal	4.3	3.4 a	3.4	3.7
	Ethanol (%)			
Hand	12.0 a	11.1	12.2 a	11.7
Machine+hand	12.1 a	11.2	11.3 b	11.6
Machine	12.0 a	11.0	12.2 a	11.7
Minimal	10.3 b	11.2	12.6 a	11.4

[1] Hand = balance to 50+10; machine = box cut to 80 nodes; machine+hand = box cut to 110 nodes with hand pruning to 80 nodes; and minimal = no pruning

[2] Statistics are not available across years or for average of years due to interactions between years.

[3] Means within column and year with the same or no letter(s) are not significantly different at $p \leq 0.05$.

Table 6. Sensory results from triangle testing of Cynthiana wine produced from different pruning methods.

Year and pruning method [1] comparison	Correct responses out of 24	Probability of result by chance (%)
2002 [2]		
Hand vs. Machine+hand	10	25.4
Hand vs. Machine	10	25.4
Machine+hand vs. Machine	2	99.9
2003		
Minimal vs. Hand	9	40.6
Minimal vs. Machine+hand	11	14.0
Minimal vs. Machine	11	14.0
Machine vs. Hand	10	25.4
Machine vs. Machine+hand	14 *	1.0
Machine+hand vs. Hand	12 **	6.8
2004		
Minimal vs. Hand	9	40.6
Minimal vs. Machine+hand	9	40.6
Minimal vs. Machine	9	40.6
Machine vs. Hand	8	33.5
Machine vs. Machine+hand	12 **	6.8
Machine+hand vs. Hand	10	25.4

[1] Hand=balance to 50+10, machine=box cut to 70 to 80 nodes, machine+hand = box cut to 110 nodes with hand pruning to 70 to 80 nodes, and minimal=no pruning

[2] Wines made from the 2002 minimal pruning treatment were not included due to obviously less color.

* Significant at the 5 percent level of significance

** Significant at the 10 percent level of significance

Initial Impact of Pruning and Fruit Thinning Applications on Growth and Composition of Concord and Sunbelt Grapes

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Abstract

Balanced dormant hand pruning was compared to minimal and machine box-cut pruning with either no fruit thinning, thinning at 39 days to 45 days post bloom or thinning at veraison on *Vitis labruscana* Bailey grape cultivars, Concord and Sunbelt. Although this was the first year that the pruning and thinning treatments were applied to this vineyard, pruning methods impacted yield components more than the time of fruit thinning. There were no differences between juice quality components (sugars, acids, color and phenolics) for pruning or thinning treatments on either cultivar. In terms of percent difference as compared to hand pruning in both cultivars, minimal pruning decreased berry weight and cluster weight and increased clusters/vine. Minimal pruning Sunbelt and Concord grapevines without thinning increased yield/vine. In both cultivars, minimal and machine pruning increased nodes retained. Ravaz indices for hand-pruned Concord and Sunbelt vines were 14 and 20, respectively. The Ravaz indices for the machine-pruned Concord vines were 14 to 20 and Sunbelt vines were 17 to 24. All treatments achieved the target soluble solids level of 18 percent to 19 percent. Delaying harvest by approximately one week for the minimally-pruned treatments without thinning was required to achieve the target soluble solids level.

Introduction

Decreasing availability and increased cost of hand labor has increased grower interest in mechanized systems for vineyard operations. Since hand pruning is labor intensive, machine and minimal (unpruned vines) pruning have been incorporated into vineyards to reduce labor costs (Clingeleffer, 1988; Mitchell, 1993; Morris, 1996) and time spent pruning (Poni et al., 2004). Although machine and minimal pruning can be cost effective, the initial and long-term impacts of these pruning systems on grape yield and composition are of concern.

Mechanically pruned Concord (*Vitis labruscana* Bailey) vines sustained higher yields with similar quality grapes than could be achieved by balance pruning (Keller et al., 2004). Mechanical pruning non *V. labruscana* vines produced higher yields initially (first two years) but less difference in yields the following years as compared to dormant hand pruning (Reynolds and Wardle, 1993; Sims et al., 1990), indicating the ability of the vines to adjust to pruning methods (Clingeleffer, 1993; Reynolds and Wardle, 1993; Sims et al., 1990). Minimal pruning applied over 17 seasons on *V. vinifera* vines showed that the vines have the capacity to maintain productivity and fruit quality (Clingeleffer, 1993).

Successful implementation of minimal or mechanized pruning in vineyards often requires hand follow-up or fruit thinning to achieve desired fruit maturity and quality (Clingeleffer, 1992; Fendinger et al., 1996; Fisher et al., 1996a, 1996b; Morris, 1996; Petrie and Clingeleffer, 2006; Poni et al., 2004; Reynolds and Wardle, 2001; Smith et al., 1996) or skirting (cutting the lower section of the vine to aid vineyard operations) (Clingeleffer, 1988; Reynolds and Wardle, 2001).

Hand pruning during dormancy controls crop level for *V. labruscana* Bailey cultivars, but pruning is done before natural crop reduction (e.g., spring freezes, hail storms, poor fruit set) occurs. In a "balanced cropping" method, more nodes can be retained at dormant pruning, and then shoot and fruit thinning can be used for later crop adjustment. Yield prediction is required to establish thinning parameters for balanced cropping (Clancy, 2002; Fisher et al., 1996; Petrie et al., 2003). Maintaining long term records for each vineyard site is essential to establish yield predictions. Yield prediction can be accomplished using historical data including berry or cluster size at different growth stages (50 percent final berry weight, lag phase, veraison and harvest) (Morris et al., 1980; Morris, 2004; Morris, 2005; Pool et al., 1996; Price, 1988).

Mechanical pruning was most effective in Concord grapes when node, shoot or fruit adjustments followed pruning to prevent over-cropping (Morris and Cawthon, 1980, 1981). Mechanical thinning reduced crop level to the target yield and improved fruit quality in *V. vinifera* vines (Petrie and Clingeleffer, 2006). Crop adjustments of mechanically pruned Concord grape vines resulted in lower yields with higher fruit soluble solids than mechanical pruning alone (Smith et al., 1996; Zabadal et al., 2002). Mechanical pruning over a six-year period did not reduce or alter berry composition in *V. rotundifolia* compared to hand pruning and mechanical pruning plus hand pruning (Andersen et al., 1996).

Timing of thinning operations can vary from bloom to veraison. Pool et al. (1993) recommended machine thinning of Concord 20 days to 30 days following bloom. Berry weight greater than one gram was required for efficient machine thinning of Concord (Pool et al., 1996). Dokoozlian and Hirschfelt (1995) recommended cluster thinning prior to berry softening in *V. vinifera* grapes.

Demand for juice and juice products has increased (Morris and Striegler, 2005) due to public knowledge of health benefits associated with grape product consumption. Outside of California, the primary red juice grape is Concord (*V. labruscana* Bailey) but as an alternative, Sunbelt (*V. labruscana* Bailey) 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).

This study was designed to examine the initial impact of pruning and time of fruit thinning on the growth and composition of Concord and Sunbelt grapes. This is the first detailed comparison of these cultivars involving pruning and fruit thinning treatments and harvest dates.

Materials and methods

Experimental design and statistical analysis. Seven crop adjustment treatments were evaluated on Concord and Sunbelt grapes. The treatments were: dormant pruning 50+10 with a maximum of 80 nodes (HAND), minimal pruning with no thinning (MIN-NT); minimal pruning with fruit thinning at 39 days to 45 days post bloom (MIN-PBT), minimal pruning with fruit thinning at veraison (MIN-VT); machine pruning to 120 nodes with no thinning (MACH-NT); machine pruning to 120 nodes with fruit thinning 39 days to 45 days post bloom (MACH-PBT); and machine pruning to 120 nodes with fruit thinning at veraison (MACH-VT).

Treatments were applied to single vine plots in a complete randomized block design with three replications. Treatments (HAND, MACH-NT and MIN-NT) were also applied to additional vines for yield and fruit thinning determinations. Data were analyzed using Statistical Analysis Systems (SAS) (version 8.2; SAS Institute, Cary, N.C.) ANOVA procedure. The significance of the separations of mean values was determined using Tukey's Test for Differences at $p \leq 0.05$.

Vineyard. Two-year-old Concord and Sunbelt vines were planted in the spring of 2000 at the University of Arkansas Agricultural Research and Extension Center vineyards, Fayetteville, Ark. (lat. 36°10´N, long. 94°17´W). Vines were trained to a double curtain (DC) 1.8-m high bilateral cordon with 2.4 x 3.0 m vine spacing and 0.9 m between foliage canopies. The vines were well established and in their fifth leaf at the beginning of the experiment. Soil was a Captina silt loam (fine-silty, siliceous, active, mesic Typic Fragiudults) with pH 6.8. The vines were drip irrigated. The vineyard floor was sod with a one meter weed-free zone under the vines maintained with pre- and post-emergent herbicides.

In 2004, two post bloom applications of 370 kg/ha of 13-13-13 fertilizer were applied on 25 May and 8 June. The minimal pruned vines received an additional application of ammonium nitrate equivalent to 73 kg/ha nitrogen on 24 June. Fertilizer was applied under the drip emitters to simulate fertigation. All vines were dormant pruned to approximately 80 nodes in the year before the study began. Bloom and veraison dates are listed in Table 1.

Fruit thinning and harvest parameters. The fruit thinning treatments were applied 39 days to 45 days post bloom (MACH-PBT and MIN-PBT) and at veraison (MACH-VT and MIN-VT) (see Table 1). Fruit was removed by cutting a specified weight of clusters that were randomly selected from each vine.

Several minimal-pruned Concord vines had excessive (1,200) nodes. Based on previous research on Concord (Morris and Main, 2007, unpublished data), it was evident the high node numbers would not produce fruit of acceptable quality, and to ensure vine survival the maximum number of nodes allowed was 850. The Sunbelt minimal-pruned vines had lower node numbers (500 to 600) and were not adjusted.

The machine pruning treatments were applied using gas-powered hedge trimmers to create a box-cut with box dimensions of approximately 20 cm x 30 cm for Concord and 25 cm x 35 cm for Sunbelt. The box related to the cordon such that approximately 10 cm was above the cordon and 5 cm was to the DC middle. After mechanical pruning, nodes were counted and box dimensions were shortened, if necessary, to obtain 120 nodes.

To calculate projected yield and determine the amount of fruit to remove from treatments, all of the fruit from two representative extra vines of HAND, MACH-NT, and MIN-NT treatments were removed and the number of clusters/vine, total weight of fruit removed/vine, and berry weights were determined. The target yield for thinning treatments was a yield equivalent to the projected yield of the HAND treatment. Yield was extrapolated from fruit weight of each vine multiplied by the number of vines/acre at 2.4 m x 3.0 m vine spacing. Targeting yield based on fruitfulness of the hand-pruned vines allows climatic conditions from the previous year that are reflected in the current year’s bud fruitfulness to be extrapolated to all treatments. All vines were skirted at veraison to 40 cm above the vineyard floor to facilitate vineyard operations. Each vine was harvested at a soluble solids level of approximately 17 percent for Concord and 18 percent for Sunbelt. Cluster weight and yield at harvest were determined by counting clusters and harvesting individual vines.

Grape sampling and preparation. Treatments were sampled weekly during the growing season to monitor pruning and fruit-thinning treatments by berry weight and composition. Twenty five berries per cultivar, treatment and replication were randomly collected from clusters within the vine each week during the growing season and weighed to determine berry weight. When total soluble solids reached approximately 10 percent, the samples were further analyzed for pH, soluble solids, and titratable acidity. For these analyses, the berry samples were homogenized (Oster, Osterizer Model 848-31N, Jarden Rye Corp., N.Y.) for five seconds on the lowest speed. This low homogenization speed over a very short time did not break the seeds. At harvest, a final 100-berry sample was taken from each treatment, placed in polyethylene bags, sealed and frozen at -29°C.

Sample preparation of frozen berries. Frozen grapes were held at -29°C for two months. Final berry weights at harvest were determined by counting and weighing the frozen berries. The bags containing the frozen grapes were held at room temperature (25°C) for 18 hours prior to analysis. After thawing, each sample of grapes was removed from the bag and placed in a 1 L blender container. The grapes were homogenized and the must was poured into a 250 mL beaker. The must treatments were placed in a hot water bath set at 80°C. Samples were lightly stirred at 10 minute intervals, and the temperatures were monitored. When the samples reached 71°C (approximately 20 minutes), the beakers were removed from the water bath. The samples were then squeezed through cheesecloth until 150 mL of juice was collected. A pectolytic enzyme, Scottzyme Pec5L (Scott Laboratories, Petaluma, Calif.), was added at 100 µL/150 mL to each sample. The samples were then cooled to room temperature. Forty five mL of juice from each sample was centrifuged at 13,250 relative centrifugal field or g-number for 15 minutes and used for analysis.

Compositional analyses. Grape juice pH was measured with a Beckman model 250 pH meter (Beckman Coulter, Inc. Fullerton, Calif.) with an electrode standardized by three point calibration (pH 1.68, 4.0 and 7.0 buffers). Titratable acidity (tartaric acid in g/L) was measured by placing 5 mL of juice into 125 mL of degassed, deionized water and titrating with 0.1 N NaOH to an endpoint of pH 8.2 (Iland et al., 2004). Total soluble solids (percent) were measured using a Bausch & Lomb Abbe Mark II refractometer (Scientific Instrument, Keene, N.H.).

Color and phenolics of the juice were determined using a Unicam Helios Beta UV-VIS spectrophotometer (ThermoSpectronic, Cambridge, United Kingdom) (Iland et al., 2004; Zoecklein et al., 1995). Absorbance was read at 520 nm to measure red-colored pigments in the juice. Color density was defined as the intensity of color (yellow/brown [420 nm] + red [520 nm]). Absorbance (280 nm x dilution factor – 4) of the sample diluted with HCL provided a measure of the phenolic material (Iland et al., 2004). Spectrophotometric measurements were standardized to a 1-cm cell.

Other harvest parameters. Dormant pruning weights were taken on hand and machine pruned vines, and the Ravaz index (kg fruit/kg dormant cane prunings) for each vine was calculated (Bravdo et al., 1984; Ravaz, 1903). The Ravaz index indicates vine balance: a value of five to 10 for V. vinifera cultivars indicates the vine is balanced, a value greater than 12 indicates overcropping, while a value less than three indicates excessive vine size (Smart and Robinson, 1991). Nodes retained/vine, yield (g)/node [(Vine yield (kg)/nodes retained) x 1000], and clusters/shoot (clusters per vine/nodes retained) were also calculated.

Results and Discussion

Weekly berry weight measurements were used to determine when 60 percent to 75 percent of final berry weight for thinning was reached and to monitor growth (see Figure 1 and Figure 2). Grape berry growth occurs as a double sigmoid curve (Coombe, 1976; Coombe and McCarthy, 2000). The initial phase of berry growth is a result of cell division and cell expansion, then as this growth slows the phase is termed ‘lag’. Lag phase is not a physiological growth stage, but an artificial designation between the two growth periods of grape berry development. The lag phase was determined as the time between sampling dates where there was no statistical difference between the berry weight (data not shown) and the least change in berry weight which was usually 0 to 0.1 g increase or a decrease between sampling dates.

The average lag phase period among treatments in Concord and Sunbelt occurred 54 and 57 days post bloom, respectively. Other research has shown that lag phase occurs about 50 days to 60 days post bloom (Price, 1988; Nitsch et al., 1960). Lag phase period was not only dependent on the cultivar but also the pruning and thinning treatments. The range of lag phase for Concord

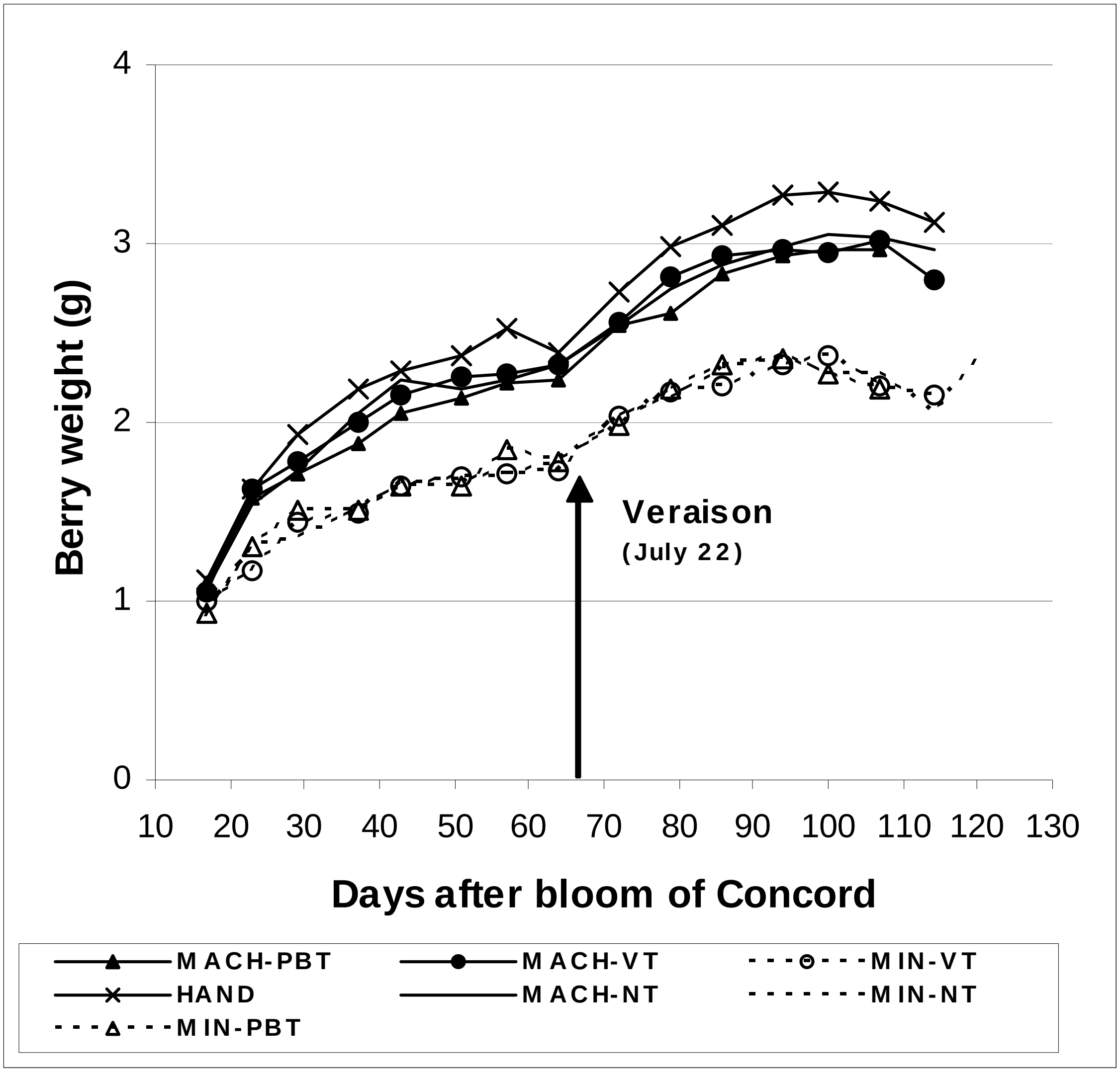

Figure 1. Effect of pruning and fruit thinning on berry weight of Concord grapes. MIN-NT=minimal with no fruit thinning; MIN-PBT= minimal with fruit thinning 39 days post bloom; MIN-VT=minimal with fruit thinning at veraison; MACH-NT=machine (box-cut) with no fruit thinning; MACH-PBT=machine with fruit thinning 39 days post bloom; MACH-VT=machine with fruit thinning at veraison; and HAND=balanced prune 50+10 with a maximum of 80 nodes.

was 43 days to 64 days post bloom. The range of lag phase for Sunbelt was 43 days to 70 days post bloom.

The berry weights of Concord and Sunbelt demonstrated the effect of pruning and fruit thinning treatments during the growing season (Figure 1 and Figure 2). At the initial sample date for both cultivars, there were no differences in berry weights between the HAND treatment and machine or minimal pruning treatments. In Concord and Sunbelt after veraison, the HAND treatment had higher berry weights than the minimally-pruned treatments. The berry weight in *V. vinifera* grapes at lag phase is generally 50 percent of the berry final weight (Hellman and

Casteel, 2003). However, in this study the lag phase for Concord occurred at 74 percent to 80 percent berry weight and for Sunbelt at 75 percent to 83 percent. Nitsch et al. (1960) showed that the lag phase occurred at 65 percent of the final berry weight in Concord.

Regardless of pruning or fruit-thinning treatment the target soluble solids were obtained for Concord (17 percent) and Sunbelt (18 percent) (see Table 2). The MIN-NT treatment was usually the last treatment harvested regardless of cultivar. Smith et al. (1996) found that thinning minimally pruned Concord vines reduced yield (from 37 t/ha to 22 t/ha) and increased soluble solids (14.8° to 17°Brix) as compared to non-thinned vines when harvested on the same date. The Concord grape juice industry usually uses 15 percent soluble solids as the lower level of acceptable quality and pays a premium for each percent increase in soluble solids up to 18 percent (Morris and Striegler, 2005). In Concord, grape flavor and acidity generally decreases above 18 percent soluble solids, reducing quality. Sunbelt grapes taste best at 16 percent soluble solids and higher, and flavor often begins to deteriorate at soluble solids levels over 19 percent (personal observations).

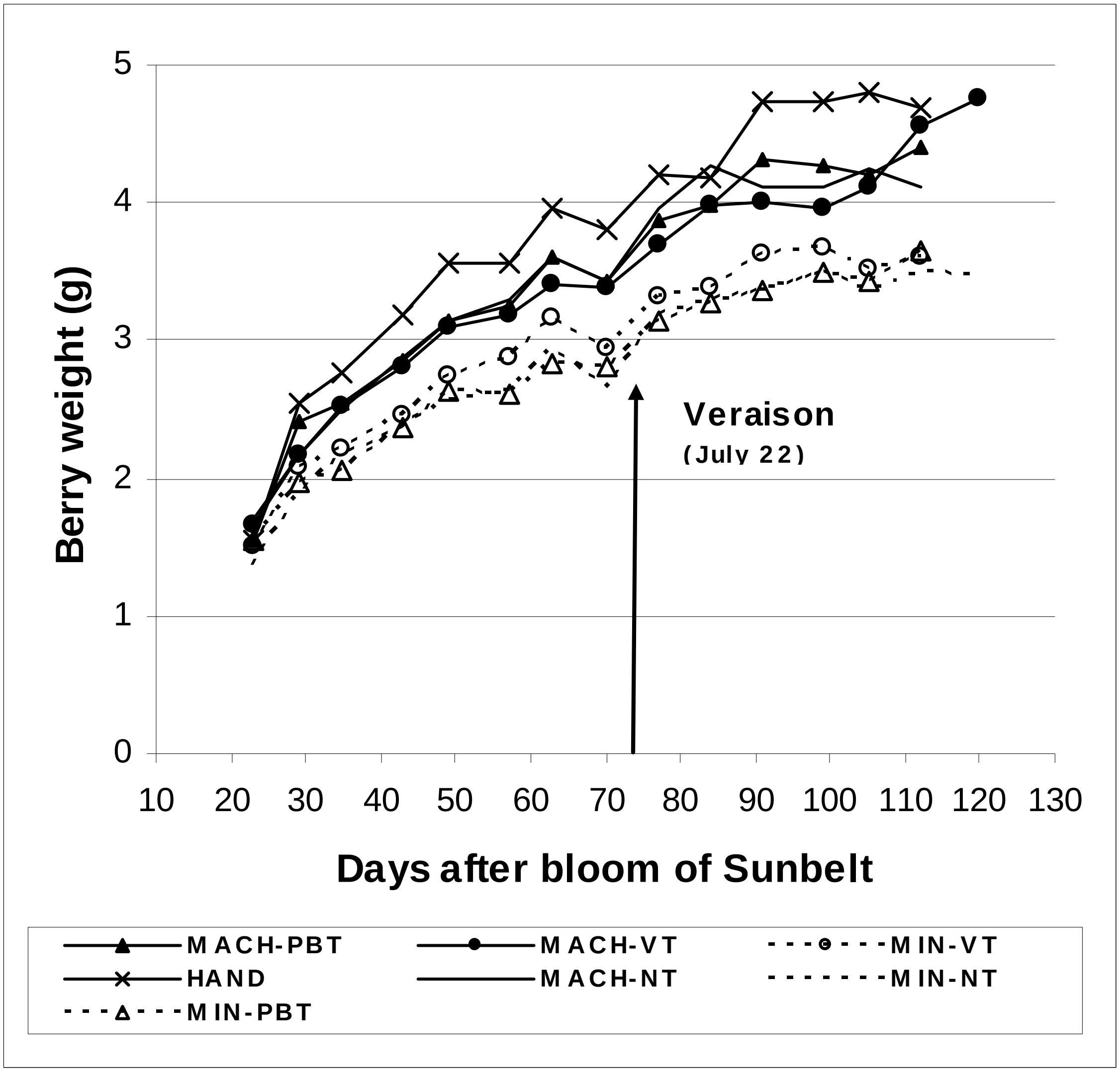

Figure 2. Effect of pruning and fruit thinning on berry weight of Sunbelt grapes. MIN-NT=minimal with no fruit thinning; MIN-PBT= minimal with fruit thinning 45 days post bloom; MIN-VT=minimal with fruit thinning at veraison; MACH-NT=machine (box-cut) with no fruit thinning; MACH-PBT=machine with fruit thinning 45 days post bloom; MACH-VT=machine with fruit thinning at veraison; and HAND=balanced prune 50+10 with a maximum of 80 nodes.

Juice composition was measured in juice processed at harvest (see Table 2). Statistical comparisons were made between hand and machine pruned treatments and hand and minimal pruned treatments separately. There were no differences between total soluble solids, pH, titratable acidity, color density, red color and total phenolics of the juice from grapes in either cultivar or pruning/thinning treatment. Previous studies (Morris and Cawthon, 1980, 1981) have shown differences in fruit composition due to canopy management treatments, but the treatments were harvested on the same date when one treatment was mature (i.e. by calendar date).

The harvest period was generally longer for Concord than for Sunbelt (see Table 1). The range indicates the time from the initial harvest of a treatment and replication to the last harvested treatment and replication. The pruning method had more of an impact on when target soluble solids levels were achieved than the time of thinning. MIN-NT treatments were usually the last treatment harvested (6 days after the initial harvest of the HAND and machine treatments). Treatments and replications were harvested when the target soluble solids level was achieved. It is important to note that the target fruit composition could be achieved under high fruit load conditions in Arkansas which may be partially due to the 30 or more days from harvest of the HAND treatments until frost that allows time for additional ripening and building of vine carbohydrate reserves.

Fruit thinning adjustments were targeted to achieve the same yield in fruit-thinned vines as in the hand-pruned vines. Therefore, yield (kg/vine) was similar even though clusters/vine, cluster weight (g), final berry weight (g), yield (g)/node, and clusters/shoot may have differed (see Table 3). Minimal pruning Sunbelt without fruit thinning increased yield/vine as compared to HAND pruning. In Concord and Sunbelt, minimal pruning increased clusters/vine and decreased cluster weight, berry weight, yield (g)/node, and clusters/shoot as compared to HAND pruning.

The percentage change in yield/vine, clusters/vine, cluster weight and berry weight of the pruning treatments as compared to HAND pruning were calculated (see Table 4). Minimal pruning without thinning Concord and Sunbelt grapevines increased yield/vine as compared to HAND pruning. Minimal and machine pruning Concord and Sunbelt increased clusters/vine and decreased cluster weights and berry weights as compared to HAND pruning. As compared to hand pruning in both cultivars, minimal pruning had higher clusters per vine (146 percent to 306 percent) than machine pruning (9 percent to 30 percent). As compared to hand pruning in both cultivars, minimal pruning had lower cluster weights (-54 percent to -70 percent) and berry weights (-19 percent to -23 percent) than cluster weights (-5 percent to -22 percent) and berry weights (-2 percent to -8 percent) from the machine-pruned vines.

In both cultivars, nodes retained of the machine and minimal-pruning treatments were higher than the HAND-pruning treatments (see Table 5). Concord and Sunbelt HAND-pruning treatments had Ravaz indices of 14 to 20, respectively. Previous research on non-irrigated hand-pruned Concord vines and machine-pruned vines with no thinning had Ravaz indices of 6.2 and 19, respectively (Morris and Cawthon, 1980). Although the Ravaz index for *V. vinifera* indicated a value greater than 12 was over cropped (Smart and Robinson, 1991), target soluble solids levels were achieved with the higher reported Ravaz indices of the machine-pruning treatments for Concord (14-20) and Sunbelt (17-24).

Conclusions

The yield performance of the cultivars was similar with respect to their response to the pruning and thinning treatments. Although this was the first year that the pruning and thinning treatments were applied to this Concord and Sunbelt vineyard, the timing of the thinning did not impact harvest components as much as the pruning treatments. Although the harvest period was generally longer for Concord than for Sunbelt, MIN-NT treatments were usually the last treatment harvested (10 days after the initial harvest of the HAND and/or machine treatments) within each cultivar. Regardless, the target soluble solids level for each cultivar was reached for all treatments.

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

Cultivar	Bud break	Bloom	Target yield (t/ha) [1]	Post bloom thinning	Average lag phase	Veraison thinning	Harvest period [2]
Concord	27 March	16 May	37.4	24 June (39 d post bloom)	54 d post bloom	22 July (67 d post bloom)	31 Aug to 13 Sept (107 to 120 d post bloom)
Sunbelt	25 March	10 May	28.9	24 June (45 d post bloom)	57 d post bloom	22 July (73 d post bloom)	30 Aug to 7 Sept (112 to 120 d post bloom)

[1] The target yield for thinning treatments was the projected yield of the hand-pruned vines (balanced prune 50+10 with a maximum of 80 nodes).

[2] Range indicates initial harvest of hand- and machine-pruned treatments to last harvest of minimal-pruned treatments based on the soluble solids goal for Concord and Sunbelt at 17 percent and 18 percent, respectively.

Table 2. Effect of pruning and fruit thinning on the development of Concord and Sunbelt grapes frozen for analysis.

Cultivar	Pruning	Fruit thinning	Soluble solids (%)	pH	Titratable acidity[2] (g/L)	Color density (AU)	Red color (AU)	Total phenolics (AU)
Concord	Hand[1]	None	18.2 a[3]	3.66 a	7.46 a	17.2 a	11.1 a	61.3 a
	Machine	None	18.9 a	3.64 a	7.07 a	12.9 a	7.85 a	52.4 a
	Machine	27 d post bloom	18.6 a	3.61 a	7.28 a	14.1 a	9.02 a	54.4 a
	Machine	Veraison	18.6 a	3.65 a	7.23 a	14.7 a	9.16 a	57.7 a
P value			NS	NS	NS	NS	NS	NS
	Hand	None	18.2 a	3.66 a	7.46 a	17.2 a	11.1 a	61.3 a
	Minimal	None	19.0 a	3.48 a	7.29 a	11.8 a	7.47 a	49.5 a
	Minimal	27 d post bloom	18.4 a	3.58 a	7.06 a	13.1 a	8.35 a	51.4 a
	Minimal	Veraison	18.7 a	3.64 a	6.89 a	14.8 a	9.31 a	55.6 a
P value			NS	NS	NS	NS	NS	NS
Sunbelt	Hand	None	18.9 a	3.42 a	8.97 a	19.0 a	13.6 a	61.8 a
	Machine	None	18.7 a	3.45 a	8.84 a	21.7 a	15.5 a	67.2 a
	Machine	29 d post bloom	18.9 a	3.40 a	8.68 a	22.5 a	16.4 a	67.8 a
	Machine	Veraison	19.1 a	3.43 a	8.78 a	24.1 a	17.4 a	71.5 a
P value			NS	NS	NS	NS	NS	NS
	Hand	None	18.9 a	3.42 a	8.97 a	19.0 a	13.6 a	61.8 a
	Minimal	None	18.6 a	3.41 a	8.25 a	24.3 a	17.7 a	78.9 a
	Minimal	29 d post bloom	18.7 a	3.39 a	8.35 a	25.0 a	18.1 a	71.5 a
	Minimal	Veraison	18.9 a	3.44 a	8.79 a	25.6 a	18.4 a	75.8 a
P value			NS	NS	NS	NS	NS	NS

[1] Balanced pruning 50+10 with a maximum of 80 nodes.

[2] Titratable acidity expressed as tartaric acid.

[3] Means within cultivar, column, and pruning method as compared to hand-pruned vines having the same letters are not significantly different by Tukey test.

NS = Not significant

Table 3. Effect of pruning and fruit thinning on yield components of Concord and Sunbelt.

Cultivar	Pruning	Fruit thinning	Yield (t/ha)	Yield (kg/vine)	Clusters per vine	Cluster wt (g)	Berry wt (g)	Yield (g)/node	Clusters per shoot
Concord	Hand[1]	None	38.8 a[2]	28.9 a	275 b	105 a	3.03 a	369 a	3.50 a
	Machine	None	40.1 a	29.9 a	319 ab	93.9 a	2.91 a	249 a	2.66 a
	Machine	39 d post bloom	39.9 a	29.7 a	339 ab	88.0 a	2.97 a	248 a	2.83 a
	Machine	Veraison	39.3 a	29.3 a	358 a	82.2 a	2.94 a	276 a	3.37 a
	P value		**NS**	**NS**	*	**NS**	**NS**	*	**NS**
	Hand	None	38.8 a	28.9 a	275 c	105 a	3.03 a	369 a	3.50 a
	Minimal	None	45.9 a	34.1 a	1117 a	31.0 b	2.44 b	52.0 b	1.73 b
	Minimal	39 d post bloom	36.6 a	27.2 a	857 ab	31.8 b	2.37 b	40.2 b	1.27 b
	Minimal	Veraison	34.6 a	25.8 a	799 b	33.5 b	2.32 b	34.2 b	1.10 b
	P value		**NS**	**NS**	***	***	**	***	**
Sunbelt	Hand	None	27.7 a	20.6 a	158 a	131 a	4.53 a	327 a	2.49 a
	Machine	None	26.5 a	19.7 a	184 a	111 a	4.19 a	165 b	1.54 b
	Machine	45 d post bloom	31.0 a	23.0 a	185 a	125 a	4.25 a	226 ab	1.82 ab
	Machine	Veraison	25.4 a	18.9 a	172 a	109 a	4.28 a	184 b	1.67 ab
	P value		**NS**	**NS**	**NS**	**NS**	**NS**	**	*
	Hand	None	27.7 b	20.6 b	158 c	131 a	4.53 a	327 a	2.49 a
	Minimal	None	40.3 a	30.0 a	555 a	54.8 b	3.58 b	53.9 b	0.99 b
	Minimal	45 d post bloom	34.9 ab	25.9 ab	422 b	61.6 b	3.58 b	61.1 b	1.00 b
	Minimal	Veraison	33.8 ab	25.2 ab	389 b	64.8 b	3.48 b	47.3 b	0.73 b
	P value		*	*	***	***	**	***	***

[1] Balanced pruning 50+10 with a maximum of 80 nodes

[2] Means within cultivar, column, and pruning method as compared to hand-pruned vines having the same letters are not significantly different by Tukey test.

NS = Not significant

* = Significant at p≤0.05

** = Significant at p≤0.01

*** = Significant at p≤0.001)

Table 4. Percentage change in yield components from pruning method and fruit thinning as compared to hand pruning [1] Concord and Sunbelt.

Cultivar	Pruning	Fruit thinning	Yield (kg)/vine	Clusters/vine	Cluster wt (g)	Berry wt (g)
Concord	Machine	None	3.5	16	-11	-4.0
	Machine	39 d post bloom	2.8	23	-22	-2.0
	Machine	Veraison	1.4	30	-16	-3.0
	Minimal	None	18.0	306	-70	-19.5
	Minimal	39 d post bloom	-5.9	212	-70	-21.8
	Minimal	Veraison	-10.7	191	-68	-23.4
Sunbelt	Machine	None	-4.4	16	-15	-7.5
	Machine	45 d post bloom	11.7	17	-17	-6.2
	Machine	Veraison	-8.3	9	-5	-5.5
	Minimal	None	45.6	251	-58	-21.0
	Minimal	45 d post bloom	25.7	167	-53	-21.0
	Minimal	Veraison	22.3	146	-51	-23.2

[1] Balanced pruning 50+10 with a maximum of 80 nodes

Table 5. Average pruning weights (PWT), nodes retained and Ravaz index [1] in Concord and Sunbelt grapes.

		Concord				Sunbelt			
		2003	2004			2003	2004		
Pruning	Fruit thinning[2]	PWT (kg/ vine)	Nodes retained	PWT (kg/ vine)	Ravaz index	PWT (kg/ vine)	Nodes retained	PWT (kg /vine)	Ravaz index
Hand [3]	None	2.02 a[4]	79 b	2.20 a	14.0 a	1.07 a	63 b	1.08 a	19.9 a
Machine	None	1.51 a	120 a	1.57 a	19.5 a	1.10 a	120 a	1.21 a	16.9 a
Machine	39-45 d post bloom	2.04 a	120 a	2.14 a	14.1 a	0.89 a	103 a	0.97 a	24.3 a
Machine	Veraison	1.96 a	107 a	1.95 a	17.0 a	1.01 a	104 a	0.98 a	23.8 a
P value		NS	***	NS	NS	NS	**	NS	NS
Hand	None	2.02	79 b	2.20 a	14.0	1.07 a	63.3 b	1.08 a	19.9
Minimal	None	-	662 a	-	-	-	575 a	-	-
Minimal	39-45 d post bloom	-	733 a	-	-	-	428 a	-	-
Minimal	Veraison	-	754 a	-	-	-	535 a	-	-
P value			***				***		

[1] kg fruit/kg dormant pruning

[2] Fruit thinning for Concord and Sunbelt was 39 and 45 d post bloom, respectively.

[3] Hand=balanced prune 50+10 with a maximum of 80 nodes

[4] Means within cultivar, column, and pruning method as compared to hand-pruned vines having the same letters are not significantly different by Tukey test.

NS = Not significant

** = Significant at $p \leq 0.01$

*** = Significant at $p \leq 0.001$)

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