CROP LOAD ADJUSTMENT IN *VITIS VINIFERA* L. CV. RIESLING

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Cluster thinning is practiced to reduce grapevine crop load and advance ripening parameters, such as soluble solids, which may or may not lead to higher quality wine. It is often implemented in the field with little or no specificity, and its practicality has been questioned because of increased production costs and lost yields. A new analytical model was introduced that combines grapevine yield and cost data with an assessment of wine quality and willingness to pay (WTP). The model was applied to two separate but concurrent field studies whereby crop levels of 1 (low), 1.5 (medium), and 2 (high) clusters per shoot established by cluster thinning (CT) were compared to non-thinned (control) Riesling vines over a three year period in the Finger Lakes of New York. In both studies CT enhanced soluble solids accumulation and had effects on yield components mostly consistent with previous literature. Consumer wine sensory trials revealed that lower cropped vines (crop load below 5) produced wines with different aromatic attributes and lower likability ratings than wines from higher crop levels. The reduced financial net returns experienced by grape growers at lower vine crop levels could only be offset by substantial increases over base market price for grapes. However, consumer WTP trended inversely with grower net returns indicating per-bottle price increases could not be used to offset the financial losses associated with CT. Despite enhancements to fruit maturity, the extreme application of CT is not a justifiable component of a sustainable viticulture program for viticultural, enological, wine quality, and financial reasons.

BIOGRAPHICAL SKETCH

Trent Leon Preszler grew up on a cattle ranch in South Dakota and attended Iowa State University, where he won the Udall Scholarship and was a national finalist for the Truman Scholarship. During his junior year he was a research assistant at the National Institutes of Health, and his work there was later published as a book chapter by Oxford University Press. He graduated in 1998 with highest honors, Phi Beta Kappa, with a B.S. in Global Science Policy and Bioethics, and delivered the student speech at graduation. After graduation, Trent was a summer intern in The White House Office of Science & Technology Policy, and then studied overseas for a year as a Rotary Foundation Ambassadorial Scholar. In 1999, he earned a postgraduate Diploma in the Biodiversity and Taxonomy of Plants through a joint program between The University of Edinburgh, U.K. and the Royal Botanic Garden.

In 2002, Trent completed a M.S. in Agricultural Economics at Cornell University, where his thesis research focused on the marketing of New York-grown wines in New York City. His research won the Outstanding Thesis award from Cornell's Department of Agricultural, Resource, and Managerial Economics. From 2003 to 2008 he worked in various capacities at Bedell Cellars, a 100-acre estate vineyard and winery on the North Fork of Long Island, NY. Beginning in 2008 he returned to Cornell as a doctoral student in the Department of Horticulture, where he was President of the Society for Horticulture Graduate Students and studied under the direction of Dr. Justine E. Vanden Heuvel. In Spring 2010, he was an Instructor in the John S. Knight Institute for Writing in the Disciplines at Cornell, where he developed and taught a new Freshman Writing Seminar entitled "Wine Culture."

Today, Trent is Chief Executive Officer of Bedell Cellars, and serves on the Board of Directors of five non-profit organizations: WineAmerica, the New York Wine and Grape Foundation, Long Island Sustainable Winegrowing, the Long Island Gay, Lesbian, Bisexual and Transgender Services Network, and the Iowa State University Honors Program Alumni Board.

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CHAPTER 1

A MODEL TO ESTABLISH ECONOMICALLY SUSTAINABLE CLUSTER THINNING PRACTICES[1]

Abstract

Cluster thinning is practiced to reduce grapevine crop load and advance ripening parameters, such as soluble solids, which may or may not lead to higher quality wine. It is often implemented in the field with little or no specificity, and its practicality has been questioned because of increased production costs and lost yields. New analytical methods are introduced that combine commonly available yield and cost data with estimated parameters for grape quality and willingness-to-pay. The result is a tailored economic model that allows growers to calculate their optimal yields and prices within a rigorous, quantitative decision-making framework.

Introduction

Growers of premium winegrapes face a common dilemma between the potentially incompatible demands of simultaneously increasing yield and increasing quality. These two goals may seem irreconcilable because of a historically tenuous belief that lower yields lead to better wine. The Ravaz index, which is the crop load ratio of fruit weight per unit pruning weight (Ravaz 1911), is one of the most important indicators of vine physiological balance (Smart 1995). Yet, the Ravaz index is primarily useful to the extent that its measurements can be predictably calibrated with fruit and/or wine quality at both low and high boundaries of acceptability—a range between 5 and 10 (Bravdo et al. 1984, 1985). This principle has been subject to dozens of investigations on various cultivars grown in warm and dry (Chapman et al. 2004, Keller et al. 2005) and cool and wet (Reynolds et al. 2007) growing conditions. However, the existence of a crop load metric to indicate vine balance by itself does not necessarily enhance

[1] Preszler, T., T.M. Schmit, and J.E. Vanden Heuvel. 2010. A model to establish economically sustainable cluster-thinning practices. Am. J. Enol. Vitic. 61:140-146.

decision-making acuity among grape growers, particularly in regions where prices are not directly based on fruit quality.

The most common method of reducing crop load is through cluster thinning (CT). When a commercial grower thins clusters after yield estimation to intentionally reduce crop load, it is generally done with the basic premise that the lost revenue from lower yields will be recaptured through increased prices resulting from changes desired by the buyer, such as higher soluble solids or increased flavor. Typically, CT is used to advance ripening in red cultivars or in regions with shortened growing seasons (Jackson and Lombard 1993, Keller et al. 2005, Reynolds 1989). However, CT can be used to advance the timing of fruit maturity or increase soluble solids in white cultivars as well, including Riesling in southern Australia (McCarthy 1986) and western Canada (Reynolds 1989, Reynolds et al. 1994), Chardonnay Musqué in eastern Canada (Reynolds et al. 2007), Seyval blanc in the northeastern United States (Edson et al. 1993, 1995, Reynolds et al. 1986), Chasselas in southwestern Switzerland (Murisier and Ziegler 1991), and Trebbiano in northern Italy (Arfelli et al. 1996). Yield components are also affected by CT, and some field studies have shown that the average cluster weight at harvest is higher for thinned vines compared to non-thinned control vines, including Gewürztraminer (Reynolds and Wardle 1989), Riesling (Reynolds 1989, Reynolds et al. 1994), and Seyval blanc (Edson et al. 1993, Kaps and Cahoon 1989, Reynolds et al. 1986).

Since vine yield is generally the major economic consideration of grapegrowing, and there are costs associated with the implementation of CT, grape growers are generally reluctant to apply this cultural practice. While the need for balancing vines with respect to fruit production and economic return has been identified repeatedly (Reynolds et al. 1994, 2007, Jackson and Lombard 1993, Lakso and Eissenstat 2005), little guidance is available for helping grape growers justify the cost versus benefit of CT. The cost of CT in Spain was recently determined to be $520 to $650 per hectare by hand and $220 per hectare by machine, but the impact of lower yields on net returns was not examined (Tardaguila et al. 2008). In an experiment of Cabernet Sauvignon at four different crop load levels, CT was reported as economically profitable only when vines were substantially overcropped, stressed, or when environmental conditions did not allow for optimal ripening (Nuzzo and Matthews 2006); however, no economic or quantitative analysis was presented to support this statement.

There is a lack of data relating to costs of production and net returns in the viticultural literature, and published crop load studies in particular, making it difficult to thoroughly evaluate the economic sustainability of the CT treatments imposed under experimental conditions. Furthermore, no model has been published that positions yield or crop load within a quantitative decision-making framework. This study provides a computationally straightforward model for growers to use in maximizing returns through the determination of minimum farm-level prices for grapes at varying yield levels, conditional on the existing market. The economic tradeoffs of CT practices are analyzed by identifying potential changes in yields, output prices, and input costs. Thus, a more thorough understanding of the implications of CT is developed in a format that growers can use to potentially gain negotiating leverage with prospective grape buyers. Additionally, the model determines the optimal level of CT to apply given the relationship between improved grape characteristics from CT and the willingness-to-pay by grape buyers. The methods can be tailored to any viticultural situation and use basic economic and yield data that are readily available to vineyard managers. The main goal is to enhance decision-making acuity with respect to crop load management and CT practices.

Materials and Methods

In order to assess the appropriateness of implementing CT, a grower must consider the associated costs and benefits, including lost yield and associated revenue from thinned clusters and production costs for implementing CT. As such, an approach that considers net returns (i.e., gross revenue minus variable costs of production) with and without CT practices is essential. Variable production costs include labor, materials, chemicals, fuel, and maintenance costs and may vary depending on the type of CT practice. Fixed costs of production, such as depreciation and other costs of capital, are assumed to be constant whether or not a vineyard implements CT; as such, their inclusion is unnecessary for the approach described here.

The benefits of CT are expected to arise from harvested grapes that will command higher prices from grape buyers because of improvements in grape characteristics such as advanced maturity, higher soluble solids, and enhanced flavors. We broadly define these effects as CT "quality" effects that may influence grape value and, thereby, offered purchase prices. Also underlying this assumption is that higher quality grapes lead to improved wine quality. The grower model variables and parameters described below are summarized in Table 1.1.

Table 1.1 Summary of cluster thinning (CT) economic model variables and parameters.

Abbrev	Units	Value	Equation	Description	Source
Q_0	t/ha	9.63		Expected grape yield without CT	NASS (2006)
P_0	\$/t	1,323		Expected grape price without CT	FLGP (2008)
C_0	\$/ha	5,930		Variable production costs without CT	White (2008)
NR_0	\$/ha	computed	1	Net returns without CT	
Q_x	t/ha	computed	4	Expected grape yield at CT level x	
P_x	\$/t	computed	$(NR_x+C_x)/Q_x$	Expected grape price at CT level x	
β_1	\$	371		Fixed CT production costs	White (2008)
β_2	\$	62		Variable CT production costs	Based on White (2008)
C_x	\$/ha	computed	6	Additional production costs of CT	
NR_x	\$/ha	computed	2	Net returns at CT level x	
P_x^*	\$/t	computed	7	Min. price needed by grower at CT level x	
x	#	variable		Number of clusters removed per shoot	
$\bar{X}$	#	3.25		Average no. of clusters per shoot w/o CT	Inferred
φ	%	5.0		Cluster yield compensation factor per unit change in CT and harvest	Based on Reynolds (2007)
WTP_x	\$	computed	8	Grape buyer willingness-to-pay at CT level x	Assumed
x^*	#	computed	13	Optimal level of CT given WTP	

Assumptions

Three general assumptions are necessary to establish a framework for the grape-pricing model with CT practices. First, the grower is assumed to produce grapes from a given set of inputs, including land resource endowments. Second, the grower's implicit price for a specific quantity of grapes is determined endogenously within the model and is dependent on the yield and canopy management practices used, as well as existing market conditions. Third, the grower faces a multi-tiered pricing schedule based on crop yield and quality parameters related to the adjustment of crop load by CT.

CT model specification for yield and price

To begin, Q_0 is defined as the grower's expected grape yield (t/ha) under existing canopy management practices without CT. For a given vintage, the grower expects to receive a price of P_0 ($/t) and incurs variable production costs of C_0 ($/ha). As such, net returns per hectare without CT (NR_0) can be expressed as:

$$NR_0 = P_0 Q_0 - C_0 \tag{1}$$

To maximize net returns, a grower must allocate resources to produce the amount of grapes where marginal revenue (P_0) is equal to marginal cost ($\partial C_0/\partial Q_0$).

Further, the average number of clusters per shoot before CT is defined as $\bar{X}$, and x represents the number of clusters removed from each shoot at the time of CT ($0 < x < \bar{X}$). Now Q_x, C_x, and P_x are defined as the expected yield, variable production cost, and grape price at CT level x, respectively, where $Q_x < Q_0$, $C_x > C_0$, and $P_x > P_0$. Expected net returns with CT at level x (NR_x) can then be expressed as:

$$NR_x = P_x Q_x - C_x \tag{2}$$

Given that the grower knows Q_0, Q_x, P_0, C_0, and C_x for any given x, then the minimum grape price per tonne (P_x^*) that would induce grower adoption of CT at level x can be computed by setting equation 1 equal to equation 2 and solving for P_x. Thus, P_x^* represents the price that leaves the grower indifferent between adopting CT or not, and, at realized prices greater than P_x^*, grower returns are increased by adopting CT. Solving for price (P_x^*) yields:

$$P_x^* = [P_0 Q_0 + (C_x - C_0)]/Q_x \tag{3}$$

Equation 3 can be further defined by incorporating the yield and cost effects associated with CT.

Allowance for yield compensation

Since the demand for carbon assimilates by reproductive growth of the grapevine (relative to vegetative growth) increases after berry set, CT can lead to a yield compensation response in cluster weight (Reynolds et al. 2007). Accordingly, the proportional CT yield response can be defined as:

$$Q_x = Q_0\left(1 - \frac{(1-\varphi)x}{\bar{X}}\right) \tag{4}$$

where $x/\bar{X}$ represents the proportional decrease in yield by CT and is offset by any compensating growth in the remaining clusters (φ) between the time of CT and harvest. If the change in yield is defined as $\Delta = Q_0 - Q_x$, then, as expected, $\frac{\partial\Delta}{\partial x} > 0$ (i.e., the more severe the CT, the larger the overall yield impact) and $\frac{\partial\Delta}{\partial\varphi} < 0$ (i.e., the larger the compensating cluster weight response to CT, the lower the overall yield response to CT per hectare).

Incorporation of variable costs

As mentioned above, CT also incurs production expenses associated with the additional labor and other costs required for its execution. Accordingly, the marginal cost of CT per hectare (MC_x), that is, the increase in costs relative to the no CT scenario, can be expressed as:

$$MC_x = \beta_1 + \beta_2 x \tag{5}$$

where β_1 is the cost component of CT that does not change with the level of x and β_2 is any additional costs of CT that vary with the level of x. Most primary labor costs would not be expected to vary substantially with the level of clusters thinned (i.e., these costs would be contained within β_1). However, other costs may vary proportionally with the level of x, such as hauling and machinery costs or secondary labor costs if the complete CT treatment requires multiple passes through the vineyard (i.e., these costs would be contained within β_2). Accordingly, the total variable costs with CT can now be defined as:

$$C_x = C_0 + \beta_1 + \beta_2 x \tag{6}$$

for all values of x (clusters removed) greater than zero and less than $\bar{X}$ (clusters present before CT), i.e.,$\forall\, x \in (0, \bar{X})$.

Minimum price estimation model

Substituting equations 4 and 6 into equation 3 yields the final CT minimum price equation:

$$P_x^* = [P_0 Q_0 + (\beta_1 + \beta_2 x)] \Big/ \left[Q_0 \left(1 - \frac{(1-\varphi)x}{\bar{X}} \right) \right] \tag{7}$$

which is the minimum price per tonne required for a grower to adopt CT at a particular level x, that is, $NR_x^* = NR_0 \; \forall \; x \in (0, \bar{X})$.

Equation 7 leads to several observations. First, the required CT price premium $(P_x^* - P_0)$ increases with the level of overall market prices $\left(\frac{\partial(P_x^* - P_0)}{\partial P_0} > 0\right)$; that is, at higher existing market prices, the price premium required to switch to CT increases, all else held constant. Second, minimum prices required are positively related to the level of CT costs $\left(\frac{\partial P_x^*}{\partial(\beta_1 + \beta_2 x)} > 0\right)$. Third, minimum prices required are inversely related to the level of existing yields $\left(\frac{\partial P_x^*}{\partial Q_0} < 0\right)$; that is, vineyards with higher yields would adopt CT at lower price premiums, all else held constant. Finally, minimum prices required are positively related to the level of CT used $\left(\frac{\partial P_x^*}{\partial x} > 0\right)$ and are inversely related to the level of compensating cluster weight effects $\left(\frac{\partial P_x^*}{\partial \varphi} < 0\right)$.

As discussed above, the price premium for adopting CT is essentially a reflection of the improvement in grape characteristics that would lead to higher-value wines. Growers who are considering CT need to determine the expected price at which CT for a given level of *x* is economically feasible. Consequently, computing expected prices using equation 7 provides growers with essential information when negotiating higher crop prices with buyers in situations where CT is practiced.

Model specification for CT effects and willingness-to-pay

While computing minimum grower prices required to adopt CT practices is a valuable first step for growers, the additional value of CT fruit that is assumed by buyers may not result in grower prices that would induce CT (i.e., . $P_x \geq P_x^*$ is not guaranteed). As such, additional information is required to understand changes in offered prices as a reflection of improved grape characteristics from CT. The final key to determining the optimal level of CT (x^*) is in quantifying the additional value relationship (or willingness-to-pay) assumed by buyers, conditional on the level of CT, *x*. While this relationship is often complicated because of differences in tastes and preferences, it is nevertheless required to determine optimal grower practices.

Willingness-to-pay (WTP) approaches are often used in estimating the demand for new or developing products or in determining the "added value" for agricultural products differentiated by various characteristics (Lusk and Hudson 2004). As such, if a buyer's WTP for grapes is differentiated for quality as determined by a grower's CT practices, then the buyer's WTP for each tonne of grapes can be expressed as a function of the level of grower CT:

$$WTP_x = a_0 + a_1 x + a_2 x^2 \tag{8}$$

It follows that WTP_x is the buyer's offered price given CT at level *x* (i.e., $a_0 > 0$, $a_1 > 0$, and $a_2 < 0$), and a_0 equals the expected grower price per tonne with no CT (i.e., $WTP_0 = a_0 + a_1 0 + a_2 0 = a_0 \equiv P_0$). Given these parameters, an increase in CT leads to an increase in WTP, but at a decreasing rate $\left(\frac{\partial WTP}{\partial x} > 0 \text{ and } \frac{\partial^2 WTP}{\partial x^2} < 0\right)$, that is, as the level of CT increases, the marginal gains in expected grower prices are reduced. The maximum WTP can be estimated by differentiating equation 8 with respect to *x*, setting that expression equal to zero, and solving for *x*:

$$x_{WTP}^* = -a_1/2a_2 \tag{9}$$

The level of *x* that maximizes grower net returns (x^*), however, will also depend on the cost and yield effects of CT such that $x^* < x_{WTP}^*$.

Overall CT calibration model

Given equation 8, grower net returns are now a function of the buyer's WTP, or

$$NR_x^{WTP} = WTP_x Q_X - C_x \tag{10}$$

Substituting equations 4, 6, and 8 into equation 10, the grower determines the level of *x* that maximizes net returns, or

$$\max_x NR_x^{WTP} = (a_0 + a_1 x + a_2 x^2)\left(Q_0\left(1 - \frac{(1-\varphi)x}{\bar{X}}\right)\right) - (C_0 + \beta_1 + \beta_2 x) \tag{11}$$

The first-order necessary condition for a maximum implies that $\frac{\partial NR_x^{WTP}}{\partial x} = 0$. Taking the derivative of equation 11 with respect to *x*, setting the expression equal to zero, and rearranging terms results in

$$3a_2(1-\varphi)x^2 - \big(2a_2\bar{X} - 2a_1(1-\varphi)\big)x - \left(a_1\bar{X} - a_0(1-\varphi) - \frac{\beta_2\bar{X}}{Q_0}\right) = 0 \tag{12}$$

Given that all of the parameters in equation 12 are assumed fixed, it is simply a representation of a quadratic equation and can be solved for *x* by using the well-known quadratic formula (Chiang 1984). Doing so results in the final equation defining the optimal number of clusters removed per shoot (x^*):

$$x^* = \frac{1}{3}\left(\frac{\bar{X}}{(1-\varphi)} - \frac{a_1}{a_2} + \sqrt{\frac{\bar{X}^2}{(1-\varphi)^2} + \frac{\left(a_1 - \frac{3\beta_2}{Q_0}\right)\bar{X}}{a_2(1-\varphi)} + \frac{(a_1^2 + 3a_0a_2)}{a_2^2}}\right) \tag{13}$$

As expected, the optimal level of CT (x^*) is directly related to base yields $\left(\frac{\partial x^*}{Q_0} > 0\right)$, base clusters per shoot $\left(\frac{\partial x^*}{\bar{X}} > 0\right)$, and cluster weight compensation effects $\left(\frac{\partial x^*}{\varphi} > 0\right)$, and is inversely related to marginal CT costs $\left(\frac{\partial x^*}{\beta_2} < 0\right)$. While a complicated expression, all right-hand-side parameters in equation 13 are assumed known by the grower, given the model specifications outlined. The substitution of these parameter values results in the grower's optimal level of CT, which is a comprehensive assessment of all factors related to price, yield, quality, and WTP.

Results and Discussion

The methods described here demonstrate that a vineyard manager with access to appropriate cost and yield information can now determine (1) the minimum price per tonne of grapes that must be received in order to adopt CT practices and maintain net returns and (2) the optimal CT level given information about the quality effects of CT as reflected by WTP responses from buyers.

Riesling case study and input parameters

A hypothetical Riesling vineyard in the Finger Lakes region of New York can illustrate the model. This exercise is particularly salient given that informal surveys have shown wide variation in grower-level yields of Finger Lakes Riesling and equally divergent cost structures and quality goals. Although the case is based on the production system for an important *Vitis vinifera* cultivar in New York, the CT model could also be applied more broadly to interspecific hybrid cultivars or even *Vitis labruscana*, which may undergo CT in certain growing situations.

Input parameters were obtained either from published sources or were assumed (Table 1.1). The existing yield level before CT (Q_0) was set to 9.63 t/ha (4.30 T/A) based on recent average industry yields for Riesling on suitable sites in the Finger Lakes (NASS 2006). In a 2008 survey, reported grape prices varied widely and reflected, at least in part, differences in grape composition and quality. Prices for Finger Lakes Riesling grapes ranged from $1,323 to $1,929/t ($1,200 to $1,750/T); however, as noted, some "premium prices" may not have been included (FLGP 2008). To accommodate this range in prices, the expected grape price before CT (P_0) was set at the low end of the range, or $1,323/t ($1,200/T).

Total variable production costs of ~$6,178/ha ($2,500/A) were reported for maintaining a mature Riesling vineyard in the Finger Lakes based on grower interviews and recommended best management practices (White 2008). Assumed production practices included a flat-cane vertical shoot-positioned system and conducting shoot thinning, shoot positioning, leaf pulling, summer hedging, and spraying for disease and insect control throughout the growing season. Since some CT costs were also included in this estimate, we reduce somewhat our assumed total variable production costs without CT (C_0) to $5,930/ha ($2,400/A).

The average number of clusters set on each shoot before CT ($\bar{X}$) can vary widely depending on a vine's genotype, age, light environment, and availability of nutrients and growth hormones (Mullins et al. 1992). For the purposes of this analysis, $\bar{X}$ was set at 3.25 based on an informal survey of several different Riesling vineyard sites in the Finger Lakes. For the additional production costs of CT expressed in equation 5 ($MC_x = \beta_1 + \beta_2 x$), the parameters were set at β_1 = $371/ha ($150/A) irrespective of the number of clusters removed, and β_2= $62/ha ($25/A) for each cluster removed (based on White 2008). In a field experiment of Chardonnay Musqué over a four year period, average yield compensation effects in the remaining fruit after CT ranged between -7% and +16% across years and treatments and varied significantly with the timing of thinning (Reynolds et al. 2007). As such, the level of yield compensation after CT (φ) for this example application was set within this range, at 5%. However, model sensitivity analysis reveals that the final results are relatively insensitive to this parameter given the much larger yield impact directly from CT.

Minimum price model computation

The assumed input parameters described above were entered into equation 7 to compute the minimum price required to adopt CT across a range of CT levels (Figure 1.1), with CT practices (x) assumed from 0 to 2 clusters removed per shoot. Also shown are the associated yield levels (t/ha), variable production costs ($/t), and net returns ($/t), as defined above. Recall that at the derived minimum price, the grower is indifferent between adopting and not adopting CT. As such, grower net returns ($/ha) remain constant across all levels of x when evaluated at the minimum price ($6,820/ha). Net returns per tonne increase with the higher per tonne price requirements, but are offset because of lower yields and higher production costs.

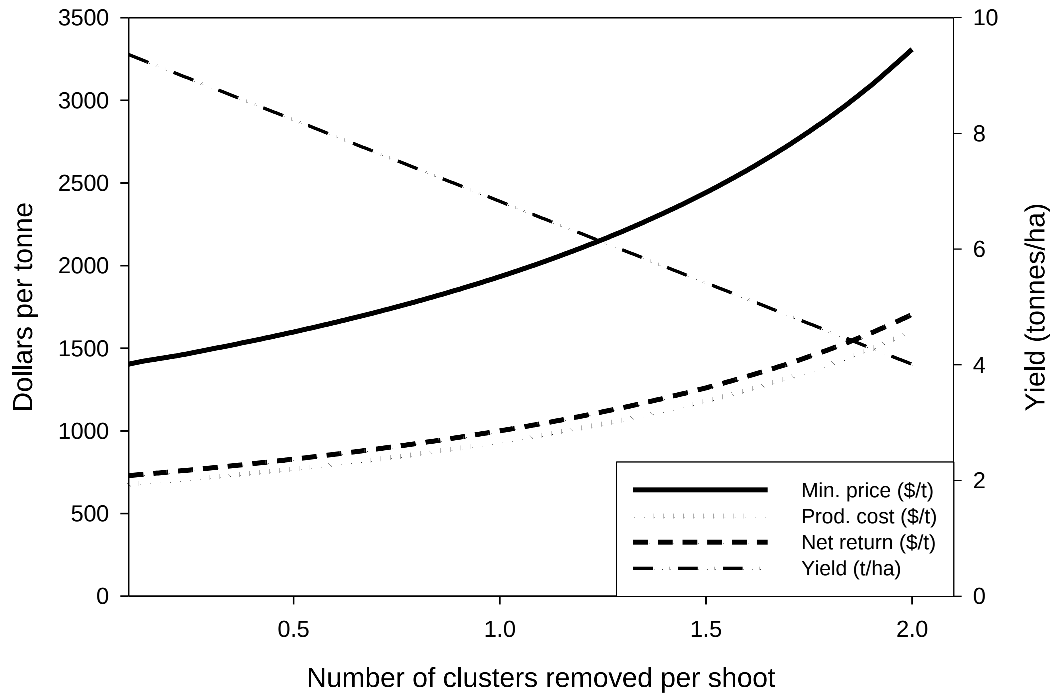

Figure 1.1 Minimum grape prices per tonne necessary for grower to maintain net returns across a range of CT levels, with associated yields and costs, as estimated by the CT economic model.

The model, although somewhat complicated in its mathematical derivation, ultimately produces very clear and straightforward answers for the grower seeking more efficient crop load management practices. The hypothetical grower of Finger Lakes Riesling grapes, when considering the option of reducing crop load by removing one cluster per shoot, would need to be paid $1,933/t ($1,753/T) for grapes instead of the base price of $1,323/t ($1,200/T) to maintain the same level of net returns (Figure 1.1). This represents a sizable price increase (46%); however, this is the level required to compensate for the lost grape volume and additional production costs of CT. This same metric, when expressed on a per hectare basis, shows that the grower needs to be paid $13,183/ha instead of $12,750/ha ($5,335/A instead of $5,160/A) to account for higher production costs. Accordingly, this per hectare price involves significantly less total fruit: a decrease from 9.64 to 6.82 t/ha (4.30 to 3.04 T/A).

Optimal level of CT

To identify the optimal level of CT, growers need information pertaining to the expected increase in value (i.e., price) of the grapes managed under CT practices. The WTP function (equation 8) provides for such a framework, but requires data to estimate the underlying parameters (usually through regression analysis). Since such data does not currently exist, we provide assumed WTP parameters to facilitate application and interpretation of the model.

The generated WTP function is based on assumed WTP parameters of $a_0 = P_0 = 1{,}323$, $a_1 = 1{,}213$, and $a_2 = -303$ (the equivalent U.S. units are 1,200, 1100, and -275, respectively) (Figure 1.2). These parameters were assigned such that for lower levels of CT, WTP prices are above the minimum price requirements (i.e., adoption of CT is economically feasible), but for higher levels of CT, WTP prices are below the minimum price requirements (i.e., CT is not economically feasible). Since the WTP prices are assumed to increase, but at a decreasing rate, this implies that as the level of CT increases, the marginal increases in WTP prices decrease and, at higher levels of CT, will not cover the increasing costs of CT.

By design, the WTP price is maximized at $x = 2$ clusters removed per shoot (see equation 9), and this level of CT is not affected by grower cost or yield effects of CT. Similarly, net returns per tonne are maximized at $x = 1.2$ clusters removed (Figure 1.2), where the additional production costs of CT are considered, but yield effects are not. The maximum WTP price was set to describe the WTP linkages back to the grower level. Indeed, no existing research or literature has estimated this relationship, either directly or indirectly.

After considering the assumed WTP function, additional input parameters (Table 1.1) were substituted into equation 13 to determine the optimal level of CT for growers. In this case, using an empirical example of a Finger Lakes Riesling vineyard results in an optimal CT level of $x^* = 0.73$. This computation maximizes grower net returns per hectare and considers all salient aspects of CT decisions: higher grape prices from increases in grape quality, higher production costs associated with CT, and lost revenue from the thinned clusters.

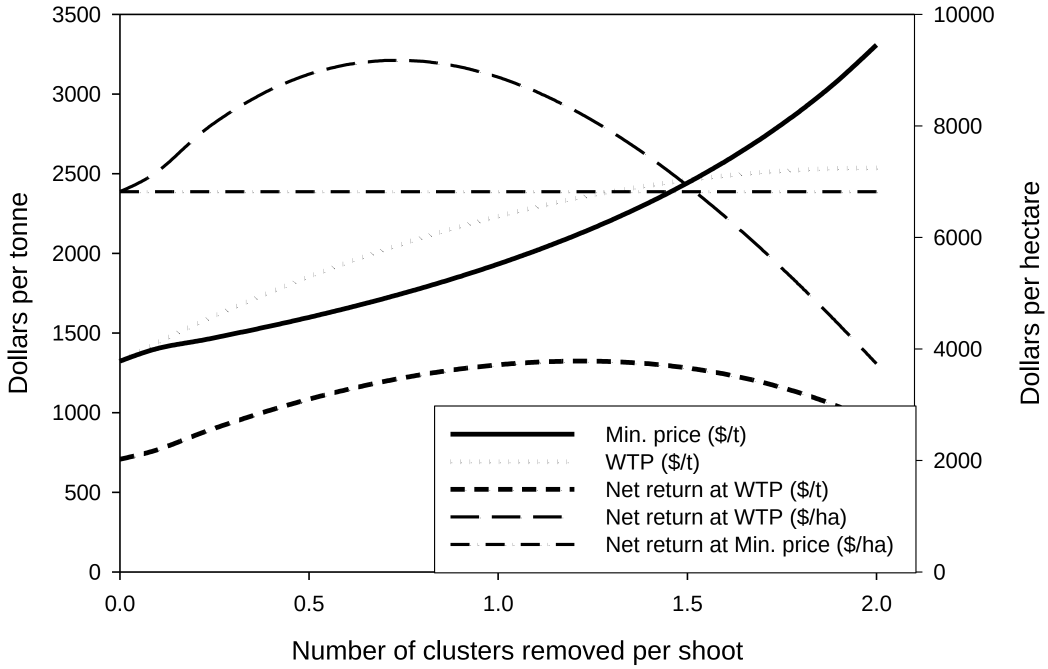

Figure 1.2 Grower net returns per hectare as a function of level of CT and assumed willingness-to-pay for grape quality effects from CT, as estimated by the CT economic model.

Grower use of model

The model recognizes the importance of determining optimal production practices based on specific, measurable parameters. Pricing schedules for growers competing in a market with other producers must be based on a thorough understanding of such parameters. While other market factors can also influence prices received, the model allows growers to interpret the value of their own grapes as well as changes in values when alternative production practices are considered to increase grape quality. Such information should be extremely valuable in making sound production adjustments and in communications with potential buyers, based on existing market conditions. Computation of the crop load economic metrics can be performed using basic yield and price data readily available to any vineyard manager. An Excel spreadsheet that automates the data processing is available from the corresponding author.

Considerations for training systems and regions

This model is designed to enhance decision making acuity among winegrape growers who use CT to reduce crop load or advance fruit maturity. It is suitable for application to vineyard operations in warm and cool climates, for red and white grapes of any commercially grown species (e.g., *Vitis vinifera*, *Vitis* sp., *Vitis labruscana*), and for any canopy training system. In addition, the model can be tailored constructively in appellations where yield and cost structures vary widely among individual producers. Although the model is robust enough to reveal opportunities for greatly enhanced efficiency, its accuracy is dependent upon the accuracy of the input parameter data used for its computations. This underscores the importance of detailed record-keeping and a data-driven management philosophy in vineyard operations.

Additional applications

The model described here not only is useful in a single-producer competitive market but also can be generalized to establish uniform pricing or optimal yields for cooperative grower organizations, as long as data for cost and yield input parameters are adjusted accordingly. The response curves generated could be used in strategic planning for vineyard operations to streamline the annual budget planning process across functional areas of the vineyard, winery, and sales operation. Other vineyard management aspects that could be improved by these production optimality metrics include disease and pest pressure control, non-CT canopy management practices, and the calibration of equipment usage versus hand-labor requirements.

Directions for future research

This model can be expanded further to include and interpret delayed effects on fruit quality valuations and vine health, which may span numerous more complicated physiological factors over time, as the long-term effects of CT practices become apparent. Additionally, optimal crop load management practices could be defined in context with wine quality and consumer response to wines made from grapes at different crop load levels. It would be instructive to evaluate changes in crop load indices, long-term vine health, and links between grape and wine prices based on changes in both grape and wine-quality parameters, including those related to wine flavor chemistry. Long term data collection through viticultural field research, winemaking, flavor chemistry analysis, and consumer WTP response surveys would be necessary to enhance the model's specificity toward particular wine styles. The development of a more complex utility-theoretic behavioral choice framework based on specific wine styles could equally serve grower, winery, and consumer objectives for quality improvement and economic sustainability.

Conclusion

New analytical methods use commonly available vineyard data for yields and costs to reveal previously overlooked viticultural and economic efficiencies. When applied to sample data, this tailored economic model demonstrated that growers can determine their required price at a given yield, and their optimal yield at a given WTP price. These metrics allow growers to take a more active role in the competitive environment of grape contract pricing and make specific, quantitatively justified CT decisions in the field. The ultimate goal of establishing such a model is to enhance the decision making acuity of growers with respect to grapevine crop load management, while simultaneously strengthening the economic sustainability of vineyard operations. It would be helpful if publications relating to CT provide as much detail as possible about production costs, yields, prices and grape quality parameters so that this model can be applied to the data and economic comparisons can be made between different crop load levels.

REFERENCES

Arfelli, G., R. Zironi, B. Marangoni, A. Amati, and M. Castellari. 1996. The effects of cluster thinning on some ripening parameters and wine quality. Acta Hortic. 427:379-385.

Bravdo, B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. 1984. Effect of crop level on growth, yield and wine quality of a high yielding Carignane vineyard. Am. J. Enol. Vitic. 35:247-252.

Bravdo, B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. 1985. Effect of crop level and crop load on growth, yield, must and wine composition, and quality of Cabernet Sauvignon. Am. J. Enol. Vitic. 36:125-131.

Chapman, D.M., M.A. Matthews, and J.X. Guinard. 2004. Sensory attributes of Cabernet Sauvignon wines made from vines with different crop yields. Am. J. Enol. Vitic. 55:325-334.

Chiang, A.C. 1984. Fundamental methods of mathematical economics, 3rd edition. McGraw-Hill/Irwin, New York.

Edson, C.E., G.S. Howell, and J.A. Flore. 1993. Influence of crop load on photosynthesis and dry matter partitioning of Seyval grapevines I. Single leaf and whole vine response pre- and post-harvest. Am. J. Enol. Vitic. 44:139-147.

Edson, C.E., G.S. Howell, and J.A. Flore. 1995. Influence of crop load on photoshynthesis and dry matter partitioning of Seyval grapevines III. Seasonal changes in dry matter partitioning, vine morphology, yield, and fruit composition. Am. J. Enol. Vitic. 46:478-485.

FLGP (Finger Lakes Grape Program). 2008. Grape harvest prices. Cornell University Cooperative Extension, Penn Yan, New York.

Jackson, D.I. and P.B. Lombard. 1993. Environmental and management practices affecting grape composition and wine quality – a review. Am. J. Enol. Vitic. 44:409-430.

Kaps, M.L. and G.A. Cahoon. 1989. Berry thinning and cluster thinning influence vegetative growth, yield, fruit composition and net photosynthesis of ‘Seyval blanc’ grapevines. J. Am. Soc. Hortic. Sci. 114:20-24.

Keller, M., L.J. Mills, R.L. Wample, and S.E. Spayd. 2005. Cluster thinning effects on three deficit-irrigated Vitis vinifera cultivars. Am. J. Enol. Vitic. 56:91-103.

Lakso, A.N., and D.M. Eissenstat. 2005. Crop load – physiology, modelling and relationships to root growth in grapevines. In Proceedings of the Twelfth Australian Wine Industry Technical Conference, pp. 38-44. Australian Society of Viticulture and Oenology, Melbourne.

Lusk, J.L. and D. Hudson. 2004. Willingness-to-pay estimates and their relevance to agribusiness decision making. Rev. Ag. Econ. 26:152-169.

McCarthy, M.G. 1986. Influence of irrigation, crop thinning, and canopy manipulation on composition and aroma of Riesling grapes. M.Sc. Thesis, University of Adelaide, Australia.

Mullins, M.G., A. Bouquet, and L.E. Williams. 1992. Biology of the grapevine. Cambridge University Press, Cambridge.

Murisier, F. and R. Ziegler. 1991. Effets de la charge en bourgeons et de la densité de plantation sur la potentiel de production, sur la qualité du raisin et sur le developpement vegetatif. Essais sur Chasselas. Rev. Suisse Vitic. Arboric. Hortic. 23:277-282.

NASS (National Agricultural Statistics Service). 2006. New York fruit tree and vineyard survey. New York State Department of Agriculture and Markets, Albany.

Nuzzo, V. and M.A. Matthews. 2006. Response of fruit growth and ripening to crop level in dry-farmed Cabernet Sauvignon on four rootstocks. Am. J. Enol. Vitic. 57:314-324.

Ravaz, M.L. 1911. L’effeuillage de la vigne. Ann. l’École Nat. Agric. Montpellier 11:216-244.

Reynolds, A.G. 1989. ‘Riesling’ grapes respond to cluster thinning and shoot density manipulation. J. Am. Soc. Hortic. Sci. 114:364-368.

Reynolds, A.G. and D.A. Wardle. 1989. Impact of various canopy manipulation techniques on growth, yield, fruit composition, and wine quality of Gewürztraminer. Am. J. Enol. Vitic. 40:121-129.

Reynolds, A.G., C.G. Edwards, D.A. Wardle, D.R. Webster, and M. Dever. 1994. Shoot density affects ‘Riesling’ grapevines I: Vine Performance. J. Am. Soc. Hortic. Sci. 119:874-880.

Reynolds, A.G., J. Schlosser, D. Sorokowsky, R. Roberts, J. Willwerth, and C. De Savigny. 2007. Magnitude of viticultural and enological effects II: Relative impacts of cluster thinning and yeast strain on composition and sensory attributes of Chardonnay Musqué. Am. J. Enol. Vitic. 58:25-41.

Reynolds, A.G., R.M. Pool, and L.R. Mattick. 1986. Effect of shoot density and crop control on growth, yield, fruit composition, and wine quality of ‘Seyval blanc.’ J. Am. Soc. Hortic. Sci. 111:55-63.

Smart, R. 1995. Smart thinking, on viticulture: Two golden rules of viticulture. Australian and New Zealand Wine Industry Journal 10:38-39.

Tardaguila, J., P.R. Petrie, S. Poni, M.P. Diago, and F. Martinez de Toda. 2008. Effects of mechanical thinning on yield and fruit composition of Tempranillo and Grenache grapes trained to a vertical shoot-positioned canopy. Am. J. Enol. Vitic. 59:412-417.

White, G.B. 2008. Cost of establishment and production of vinifera grapes in the Finger Lakes region of New York – 2007. Cornell University Department of Applied Economics and Management Extension Bulletin 2008-05.

CHAPTER 2

EFFECTS OF CLUSTER THINNING ON ECONOMIC SUSTAINABILITY, YIELD COMPONENTS, FRUIT COMPOSITION, AND WINE AROMA IN RIESLING

Abstract

Crop levels of 1 (low), 1.5 (medium), and 2 (high) clusters per shoot established by cluster thinning (CT) were compared to non-thinned (control) Riesling vines over a three year period. In 2008, yields ranged from 5.2 t/ha in low crop to 12.4 t/ha in control and in 2009 from 4.0 to 9.3 t/ha respectively, and in both years yield reflected cluster number. By 2010, yield and crop load (yield/pruning weight) did not differ among treatments and mirrored the differences in yield. Cluster weight was unaffected by CT in 2008 and 2009 but in 2010 control clusters weighed 63% less than low crop. There were more berries per cluster in low crop compared to control in 2009 and 2010 only. There was little or no CT effect on berry size, pH, TA, pruning weight, cluster light exposure or bud cold hardiness. Soluble solids at harvest ranged from 18.2°Brix in control to 22.3 in low crop in 2008, from 18.9 to 22.1 Brix respectively in 2009, and from 20.5 to 22.0 Brix in 2010. A consumer wine aroma sorting trial revealed that the low crop wine, and the low and medium crop wines, differed in aromatic attributes from the other treatments in 2008 and 2009, respectively. Grower financial net return per hectare ranged from $2,832 in low crop to $16,055 in control in 2008, from -$115 to $8,596 respectively in 2009 and from $1,938 to $4,242 respectively in 2010. The only way financial losses associated with CT could be recouped would be with up to 150% increases over base market price for grapes, and it more market price data is needed to ascertain whether enhancements to fruit maturity would merit such a price increase.

Introduction

The belief that low yielding grapevines produce higher quality wines has a foothold among wine critics in the popular press, and in fact grapevine yield restrictions have long been codified by law in the quality appellations of some European countries (Johnson and Robinson 2001). In many regions, wine producers face a dilemma trying to maximize both grapevine yields and wine quality simultaneously (Keller et al. 2008). Balancing these two objectives requires a quantitative and holistic approach to understanding all aspects of yield management, including financial returns and vine balance.

The Ravaz Index or crop load (yield/pruning weight) is one of the most important indicators of vine balance (Ravaz 1911) and its usefulness is enhanced when measurements are calibrated with fruit and/or wine quality. Crop load between 5 and 10 is thought to be ideal for quality winemaking (Bravdo et al. 1984, 1985), a principle subject to numerous investigations on various cultivars in warm (Chapman et al. 2004; Keller et al. 2005) and cool (Reynolds et al. 2007) climates. But the crop load metric does not encompass the full spectrum of decision making among grape growers, especially in regions where grape prices are pegged to other parameters besides soluble solids at harvest.

Commercial growers commonly reduce crop load by cluster thinning (CT) assuming it will improve fruit composition and/or wine aromas, or enhance consumer perception of quality, either of which may enable the grower to recoup lost revenue through higher prices. Cluster thinning has demonstrated positive effects on the timing of fruit maturity or soluble solids accumulation in red cultivars such as Cabernet Sauvignon (Nuzzo and Matthews 2006), Pinot Noir (Reynolds et al. 1994b), and Merlot (Bowen et al. 2011), and in white cultivars such as Riesling (McCarthy 1986; Reynolds 1989; Reynolds et al. 1994a), Chasselas (Murisier and Zielger 1991), and Trebbiano (Arfelli et al. 1996). Wines made from lower cropped vines exhibited increased herbaceousness in Chardonnay Musqué (Reynolds et al. 2007) and more vegetal aromas in Cabernet Sauvignon (Chapman et al. 2004). There were no CT effects on consumer perception of wine quality in studies of Gewürztraminer at one cluster per shoot (Reynolds and Wardle 1989), Sangiovese at three crop levels (Filippetti et al. 2007), and Cabernet Sauvignon at ~30% crop reduction (Ough and Nagaoka 1984), however CT reduced consumer quality ratings in Sauvignon Blanc (Gal et al. 1996; Naor et al. 2002). In the aforementioned studies, no economic analyses were conducted to link yield and quality with changes in grower financial returns.

Significant increases in canopy density, vine size, pruning weight, cluster weight, and/or berries per cluster have been reported in cluster-thinned Gewürztraminer (Reynolds and Wardle 1989) and Riesling (Reynolds 1989; Reynolds et al. 1994a). Conversely, CT reduced cluster weight and berries per cluster in Pinot Noir (Howe et al. 2002) and Chardonnay Musqué (Reynolds et al. 2007). Both pH and titratable acidity (TA) have shown little or no response to CT in Riesling (Reynolds et al. 1994a).

The need for balancing fruit production and economic returns has been identified repeatedly (Jackson and Lombard 1993; Keller et al. 2008; Lakso and Eissenstat 2005; Reynolds et al. 1994b, 2007), but few quantitative tools exist to help growers calculate costs and benefits of CT. There are two primary costs associated with CT: skilled human labor and lost revenue from reduced yield. The cost of CT in Spain was determined to be \$520 to \$650/ha by hand and \$220/ha by machine, but the impact of lower yields on net returns was not examined (Tardaguila et al. 2008). Other reports have stated CT is economically feasible only as a “band-aid” solution when vines are over-cropped or when environmental conditions impede ripening (Keller et al. 2005; Nuzzo and Matthews 2006), but no economic analyses were presented to support these statements. There is little data in viticulture literature relating to production costs and financial net returns, making it difficult to evaluate the economic sustainability of varying crop levels imposed under experimental conditions.

A model published by this research group was the first to position grapevine yield within a quantitative economic decision making framework (Preszler et al. 2010). In this study, the model is applied to viticultural and sensory data from a field trial of varying crop levels in a mature commercial Riesling vineyard. The goal is to elucidate the effects of CT on yield components, fruit composition, wine similarities or differences, and financial net returns, and by doing so, enhance decision making acuity among winegrape growers using or considering CT.

Materials and Methods

Vineyard site and experimental design

This field experiment was conducted from 2008-2010 at a commercial vineyard on the east side of Cayuga Lake in King Ferry, NY, in the Finger Lakes AVA (42.38°N, 76.38°W, 213 m elevation), on a soil type classified as Cazenovia series with a silt loam structure (USDA-NRCS soil maps). Vines were *Vitis vinifera* L. cv. Riesling cl. 239, grafted on 3309C rootstock, planted in 1998 in an east-west row orientation on a westward facing slope, with 1.5 m spacing between vines and 3.0 m between rows. Vines were cane pruned and trained to the Pendelbogen vertically shoot-positioned system. The vineyard was managed by the cooperating commercial grower according to the standard viticultural and disease control practices for *V. vinifera* in the Finger Lakes region.

The research plot spanned three adjoining vineyard rows and the experiment was designed with a non-thinned control plus three CT treatments: 1.0 (low crop), 1.5 (medium crop), and 2.0 (high crop) clusters retained per shoot. Treatments were arranged in a randomized complete block with four replicates. Each CT treatment was nine contiguous vines, the outer two serving as guard vines and the inner seven used for data collection, for a total of 112 experimental units. When at least two-thirds of the vines reached or exceeded Eichorn-Lorenz (E-L) stage 9 (two or three leaves unfolded), secondary shoots were removed by hand and in 2008 primary shoots were thinned to 27 per vine, the lowest density counted before thinning. In 2009 and 2010, primary shoots were thinned to 36 per vine, the lowest density counted, to control excessive vigor. Cluster thinning treatments were applied when at least two-thirds of the vines had reached or exceeded E-L stage 31 (pea-sized berries). Clusters located distally nearest the shoot apex were removed first, and the basal clusters were left intact.

Canopy characterization

Grapevine canopy characteristics relating to light environment and vegetative growth were recorded on a per vine basis when at least two-thirds of the vines had reached or exceeded E-L stage 35 of shoot development (early berry ripening, veraison). Enhanced Point Quadrat Analysis (EPQA) was used to quantify the light environment according to a previously specified methodology (Meyers and Vanden Heuvel 2008). A thin rod was inserted through the fruiting zone perpendicular to the row direction, at 20 cm intervals, and the rod's sequential contact with leaves, clusters, and wires were recorded. Photon flux measurement was performed using a ceptometer (Decagon, model AccuPAR LP-80, Pullman, WA) for each vine between 11:00 and 14:00 hr EST on the same day as insertion data was collected. The ceptometer measurements were obtained by holding the probe (90 cm long with 80 photosensors) within the vine fruit zone and parallel to the row while simultaneously holding a photosynthetically active radiation sensor above the canopy, which was connected to the integrated controller. For each vine, 10 measurements were made over a period of 10 seconds, and the mean value for above- and within-canopy photon flux was recorded. The resulting data was analyzed by EPQA and CEM Tools, version 1.7 (available free of charge from Jim Meyers, jmm533@cornell.edu) to calculate occlusion layer number (OLN), the number of shade-producing contacts; cluster exposure layer (CEL), the number of shading layers between clusters and the nearest canopy boundary; and cluster exposure flux availability (CEFA), the percentage of above-canopy light that reaches clusters.

Harvest and yield components

Vegetative and yield component data were collected on a per vine basis. Harvest date was based on a 22 Brix threshold determined using the average soluble solids of a random berry sampling from the low crop vines, as measured by a temperature compensating Brix scale (0-30) refractometer (Leica Inc., Buffalo, NY). Experimental vines were harvested by hand in consort with the harvest schedule of the cooperating commercial grower on 9 Oct 2008, 7 Oct 2009, and 13 Oct 2010. Clusters were snipped, counted, and weighed with a hanging scale accurate to 0.01

kg (Salter Brecknell, model SA3N340, Fairmont, MN) to determine yield per vine, total yield, and average cluster weight. A subsample of 100 berries was collected randomly in duplicate from each treatment replicate and weighed to determine average berry weight.

Differential thermal analysis and pruning

The low-temperature exotherm (LTE_{50}) at which 50% of buds are killed through freezing was measured by differential thermal analysis (DTA). A freezing chamber design and methodology was used (Mills et al. 2006) that incorporated a computer-controlled freezing and data acquisition module, environmental test chamber (Tenney Thermal Product Solutions, model BTC, New Columbia, PA), digital temperature controller (Watlow Electric Manufacturing, model 942, St. Louis, MO), multimeter datalogging system (Keithley Instruments, model 2701, Cleveland, OH), and output computer (Dell Optiplex, model 745, Round Rock, TX).

Four vines were selected from each CT treatment replicate and in February each year one cane was cut from each data vine, weighed, and brought to the lab for same-day DTA data collection. Canes collected for study were in an exterior canopy position, were representative of the approximately modal cane diameter for the vine, and exhibited uniformly dark periderm (Wolf and Cook 1992). Buds were excised from the second through sixth nodes on each cane leaving 2 mm of surrounding tissue intact. Ten buds from each CT treatment replicate were randomly assigned and loaded into each thermoelectric module (TEM) on the freezing tray and the chamber temperature was reduced from 4°C to -40°C and back to 4°C at a rate of 4°C/hr (Mills et al. 2006). Signals (mV) produced by the heat of fusion upon freezing of the buds were detected by the TEMs and output was recorded every 15 seconds in Excel (Microsoft, Redmond, WA). Median LTEs were determined for each TEM and then averaged to derive a single mean LTE for each treatment replicate (Wolf and Cook 1992).

On or around 15 March in each year vines were pruned to three remaining canes with 40 nodes per vine and the prunings were weighed on a per vine basis with a hanging scale accurate to 0.01 kg (Salter Brecknell, model SA3N340, Fairmont, MN). Cane weights collected earlier for

DTA were added back into the pruning weights for each vine and crop load (yield/pruning weight) was calculated for each vine.

Winemaking and basic juice chemistry

Grapes from all field replicates were combined with like CT treatments and brought to the Cornell Orchards Teaching Winery for processing on the day of harvest. All fruit underwent identical processing. Grapes from each treatment were whole-cluster pressed in a 40 L stainless steel hydraulic bladder press (Gino Pinto, model Zambelli Hydro 40 Inox, Hammonton, NJ), and duplicate 200 mL juice samples were collected from each treatment and frozen at -20°C for later analysis. Juice was treated with 50 mg/L sulfur dioxide added as potassium metabisulfite and allowed to settle for 12 hr. at 4°C. After pressing and settling, the juice was racked according to treatment into duplicate 19 L glass carboys for a total of eight fermentation lots. Carboys were chaptalized to the same level of soluble solids, 22 Brix, if necessary, and juice was inoculated with 0.25 g/L *Saccharomyces cerevisiae* strain R-HST yeast (Lallemand Inc., Toulouse, France) previously rehydrated in GoFerm (Lallemand) according to manufacturer's instructions. Carboys were moved to a 16°C room and stirred daily. FermAid K (Lallemand) was added (0.15 g/L) at inoculation and again when wines reached 10 Brix. Wines fermented until residual sugar was measured at less than 0.5% using Clinitest tablets (Bayer, West Haven, CT), were racked into clean carboys, adjusted to 40 mg/L free sulfur dioxide, and moved to a 2°C storage room for approximately four months. Wines did not undergo any acid adjustments or malolactic fermentation and were screened for faults by an expert panel prior to being bottled manually using standard 750 mL green glass bottles and natural corks, and then stored at 16°C. Wine aroma consumer sorting trials were conducted approximately one year after bottling.

Fruit composition data were collected as composite samples on a per replicate basis with duplicate analytical replicates. Juice soluble solids content was analyzed from previously frozen samples with a temperature compensating Brix scale (0-30) refractometer (Leica Inc., Buffalo, NY). Juice pH was measured with a benchtop pH meter (VWR SympHony, model SB80P1, Radnor, PA) and TA was measured by titrating a 50 mL aliquot of juice against 0.10 M NaOH to pH 8.2 using an automatic titrator (Mettler Toledo, model DL22, Columbus, OH).

Wine aroma sorting trial

Wines made in 2008, 2009 and 2010 were evaluated for aromatic similarities approximately one year after bottling by an aroma sorting panel consisting of faculty, staff and students at Cornell University who consume white wine at least once per month and were between 21 and 55 years of age. In each year of the study respectively 60, 40 and 48 people participated in the trial and were seated in a room illuminated with fluorescent lighting and separated by white partitions. Wines were served in 30 mL aliquots at room temperature in clear tulip-shaped (ISO) 220 mL wine glasses covered with petri dish lids. Wines from all three CT treatments and non-thinned control were poured in duplicate for a total of eight glasses per panelist presented simultaneously. Each glass was coded with a random three digit identification number and the presenting order of wines was randomized. Panelists were asked to sort wines into groups based on the wines' aromatic properties, using only their own sorting criteria and sensory experience of the aromas, without tasting. To minimize imposed researcher bias, panelists were not trained in advance and there was no predetermination or rating of attributes that would discriminate among wines (Lawless and Heymann 1998).

After the free sorting task was complete, wines placed in the same group were given a similarity rating of 1 and wines placed in different groups were assigned a similarity rating of zero. The number of times each pair of samples was sorted into the same group was summed across panelists to create a similarity square matrix for each year which was analyzed by the multidimensional scaling (MDS) statistical methodology (Kruskal 1964) in SAS Version 8.0 (Cary, NC). Sorting data was summed across all panelists rather than inspecting for possible sub-segments because more data points per stimulus pair correlates to a more precise fit to the data by MDS (Giguère 2007). MDS is a perceptual mapping technique used to structure data and reveal patterns of similarity among samples when underlying attributes are not well understood (Lawless and Heymann 1998; Schiffman et al. 1981). This statistical tool represents multivariate information in geometric maps corresponding closely to the input matrix, thus more frequently paired samples are placed close to each other while objects with stronger negative correlations are set farther apart (Nestrud and Lawless 2010). MDS has been widely applied in food science and sensory studies (Lawless and Glatter 1990; Tang and Heymann 2002) and to classify wine aroma in Chardonnay (Lee and Noble 2006) and Cabernet Sauvignon (Preston et al. 2008).

The appropriate dimensionality of MDS configurations was determined by calculating the squared correlation (RSQ), a direct measure of the proportion of variance accounted for by MDS, and badness-of-fit (i.e., stress value) at varying levels of dimensionality for the aroma sorting matrix (Schiffman and Knecht 1993). An RSQ between 0.90 and 1 and a stress value between 0 and 0.15 indicate a good fit of the model to the data and significance of the consensus plot (Wilkinson 1990). Analysis in two dimensions created a model with RSQ and stress value within the acceptable ranges for significance, and adding a third dimension provided little reduction in stress, little increase in RSQ, and made visual interpretation of the output configuration more difficult. Thus the analysis was completed under two dimensions, which is the most common and readily interpretable level (Giguère 2007) also used in prior MDS studies of wine aroma (Lee and Noble 2006; Preston et al. 2008).

Economic analysis

Input parameter data for yield (t/ha) before and after CT, fixed and variable production costs ($/t) before and after CT, and Riesling market price ($/t) were entered into a previously described CT economic model (Preszler et al. 2010). Calculated output parameters were actual net returns ($/t) and constant net returns expressed as the minimum grape price ($/t) that must be received in order to adopt CT practices at varying levels. The model assumes net returns per tonne increase with higher per tonne price requirements, but are offset due to lower yields and higher production costs.

Statistical analysis

The SAS software version 8.0 (SAS, Cary, NC) was used to analyze viticulture and juice data for statistically significant differences. Data was analyzed using SAS General Linear Model procedure (GLM Proc) and means were separated using the Fisher's Least Significant Difference (LSD) test at the 5% significance level. A *p*-value equal to or less than 0.05 was necessary for results to be reported as significant. Canopy light environment data were analyzed using EPQA and Canopy Exposure Mapping (CEM) Tools, version 1.7 (Cornell University, Ithaca, NY). Consumer wine aroma sorting trial data were analyzed using the MDS Proc in SAS. Microsoft Excel was used for basic descriptive statistics. Economic data were analyzed using a previously published model (Preszler et al. 2010).

Results

Reproductive growth and fruit composition

Yield per vine and hectare was reduced by CT in 2008 and 2009 but no significant differences existed in 2010. Yields in 2008 ranged from 5.7 kg/vine in the control vines to 2.4 kg/vine in low crop, corresponding to 12.4 and 5.2 t/ha respectively, or a 58% decrease in yield from CT. In 2009, yields ranged from 4.3 kg/vine in control to 1.9 kg/vine in low crop, corresponding to 9.3 and 4.0 t/ha respectively, or a 57% decrease. In 2010 yields ranged from 3.0 kg/vine in control to 2.5 kg/vine in low crop, corresponding to 6.5 and 5.3 t/ha respectively, with no significant differences among treatments. In 2008 and 2009 there was no CT effect on cluster weight and yield differences were due to the number of clusters per vine after thinning. In 2010 clusters in the control weighed 63% less than low crop and cluster weight differed among low, medium and high crop treatments. Berry count per cluster in 2010 was separated into two groups: low (49.0) and medium (43.6) in one, and high (30.8) and control (31.5) in another. There was little or no CT effect on berry weight in any year. In 2008 soluble solids ranged from 18.2 Brix in control up to 22.3 Brix in low crop. In 2009 soluble solids ranged from 18.9 Brix in control up to 22.1 Brix in low crop, while medium and high crop did not differ from one another. In 2010 soluble solids did not differ among medium, high, and control treatments. Juice acid levels at harvest were highest in 2009 but CT had little or no effect on pH and TA in any year.

Table 2.1 Yield components and fruit composition of Riesling grapevines in the Finger Lakes, NY, from 2008 to 2010. Cropping treatments were imposed by cluster thinning to varying crop levels at E-L stage 31.[a] Yield data are shown at harvest. Each value is an average of four field replicates ± standard error.

	Clusters/shoot			Clusters/vine		
Crop Level[b]	2008[c]	2009	2010	2008	2009	2010
Low	1.0 ± 0.01 d	1.0 ± 0.03 c	1.0 ± 0.01 c	27.4 ± 0.37 d	35.5 ± 1.06 c	37.1 ± 0.29 c
Medium	1.6 ± 0.01 c	1.5 ± 0.02 b	1.6 ± 0.01 b	43.1 ± 0.36 c	55.2 ± 0.72 b	56.4 ± 0.22 b
High	2.0 ± 0.11 b	2.0 ± 0.05 a	2.0 ± 0.06 a	54.9 ± 2.85 b	70.8 ± 1.87 a	70.5 ± 2.08 a
Control	2.5 ± 0.11 a	2.1 ± 0.12 a	2.0 ± 0.18 a	67.8 ± 2.88 a	74.0 ± 4.21 a	73.0 ± 6.48 a
	Cluster weight (g)			Berries/cluster		
Crop Level	2008	2009	2010	2008	2009	2010
Low	88.9 ± 1.21 a	52.8 ± 2.96 a	66.1 ± 1.66 a	50.7 ± 1.32 a	34.2 ± 1.26 a	49.0 ± 0.82 a
Medium	80.6 ± 3.25 a	45.9 ± 2.75 a	54.8 ± 5.34 b	45.8 ± 1.28 a	29.2 ± 1.39 b	43.6 ± 3.47 a
High	83.1 ± 1.82 a	50.8 ± 3.35 a	39.6 ± 3.11 c	49.6 ± 3.41 a	32.7 ± 2.86 ab	30.8 ± 2.32 b
Control	84.3 ± 3.97 a	58.3 ± 4.65 a	40.5 ± 2.82 c	52.2 ± 3.87 a	41.9 ± 2.93 a	31.5 ± 1.89 b
	Berry weight (g)			Yield/hectare (t)		
	2008	2009	2010	2008	2009	2010
Low	1.76 ± 0.04 a	1.54 ± 0.05 a	1.35 ± 0.06 a	5.2 ± 0.08 d	4.0 ± 0.15 c	5.3 ± 0.14 a
Medium	1.76 ± 0.06 a	1.57 ± 0.03 a	1.25 ± 0.06 a	7.5 ± 0.31 c	5.5 ± 0.30 b	6.7 ± 0.66 a
High	1.69 ± 0.10 a	1.56 ± 0.05 a	1.29 ± 0.02 a	9.8 ± 0.41 b	7.8 ± 0.73 a	6.0 ± 0.59 a
Control	1.63 ± 0.04 a	1.39 ± 0.02 b	1.29 ± 0.04 a	12.4 ± 1.00 a	9.3 ± 1.01 a	6.5 ± 1.01 a
	Yield/vine (kg)			Pruning weight/vine (kg)		
	2008	2009	2010	2008	2009	2010
Low	2.4 ± 0.04 c	1.9 ± 0.07 c	2.5 ± 0.06 a	0.87 ± 0.09 a	0.66 ± 0.04 a	0.75 ± 0.08 a
Medium	3.5 ± 0.14 b	2.5 ± 0.14 b	3.1 ± 0.31 a	0.78 ± 0.05 a	0.56 ± 0.08 ab	0.63 ± 0.13 a
High	4.6 ± 0.19 a	3.6 ± 0.34 a	2.8 ± 0.28 a	0.75 ± 0.04 a	0.53 ± 0.06 ab	0.66 ± 0.07 a
Control	5.7 ± 0.46 a	4.3 ± 0.47 a	3.0 ± 0.47 a	0.67 ± 0.04 a	0.44 ± 0.05 b	0.53 ± 0.07 a
	Crop load (yield/pruning weight)			Soluble solids (Brix)		
	2008	2009	2010	2008	2009	2010
Low	2.9 ± 0.32 d	2.9 ± 0.17 d	3.4 ± 0.27 b	22.3 ± 0.14 a	22.1 ± 0.10 a	22.0 ± 0.04 a
Medium	4.5 ± 0.39 c	4.7 ± 0.64 c	5.5 ± 1.14 ab	20.8 ± 0.08 b	21.0 ± 0.17 b	21.0 ± 0.11 b
High	6.1 ± 0.45 b	7.1 ± 0.97 b	4.3 ± 0.09 ab	20.0 ± 0.09 c	20.3 ± 0.26 b	20.9 ± 0.11 b
Control	8.7 ± 0.80 a	9.9 ± 0.76 a	5.8 ± 0.80 a	18.2 ± 0.03 d	18.9 ± 0.13 c	20.5 ± 0.21 b
	pH			Titratable acidity (g/L)		
	2008	2009	2010	2008	2009	2010
Low	3.64 ± 0.04 a	2.65 ± 0.02 a	2.81 ± 0.01 b	7.0 ± 0.48 a	13.5 ± 0.11 a	8.3 ± 0.04 a
Medium	3.52 ± 0.04 b	2.69 ± 0.02 a	2.89 ± 0.01 a	7.1 ± 0.36 a	13.4 ± 0.22 a	8.4 ± 0.08 a
High	3.48 ± 0.03 b	2.68 ± 0.05 a	2.82 ± 0.02 b	7.3 ± 0.10 a	13.2 ± 0.18 a	8.5 ± 0.12 a
Control	3.42 ± 0.02 b	2.62 ± 0.01 a	2.84 ± 0.03 b	7.3 ± 0.13 a	13.4 ± 0.19 a	8.3 ± 0.06 a

[a]Eichorn-Lorenz stage 31 of shoot development, when at least two-thirds of berries reached pea-size, about six mm diameter
[b]Low: 1 cluster/shoot remains; Medium: 1.5 clusters/shoot remain; High: 2 clusters/shoot remain; Control: non-thinned
[c]Analysis of variance was conducted through the General Linear Model (GLM) Procedure in SAS. Within year columns, means followed by different letters are significantly different at $p \leq 0.05$ by Fisher's least significant difference (LSD) test.

Vegetative growth and canopy characterization

Pruning weight of low crop vines was higher than the control in 2009 only. Crop load differed among CT treatments in 2008 ranging from 2.9 in low crop to 8.7 in control and in 2009 ranging from 2.9 to 9.9 respectively. In 2010 low crop load was significantly lower than control but all other treatments were statistically equivalent. Low and medium crop load remained generally consistent all three years, but crop load in the high crop vines was 6.1 in 2008 and 7.1 in 2009 and fell to 4.3 in 2010. Likewise crop load in the control vines was 8.7 in 2008 and 9.9 in 2009 but fell to 5.8 in 2010. Bud cold hardiness as measured by mean LTE_{50} of buds sampled in February was not affected by CT in any year (Table 2.2). Neither OLN nor CEFA were significantly affected by CT in any year (Table 2.3). When compared to the control, CEL increased in low crop by 47% in 2008, indicating more shading layers between clusters and their nearest canopy boundary as CT increased. There was no difference among treatments for CEL in 2009 and 2010.

Table 2.2 Mean low temperature exotherm (LTE in °C) of buds sampled in February from Riesling grapevines in the Finger Lakes, NY, from 2008 to 2010. Each value is an average of four field replicates.

Crop Level[a]	LTE_{50} 2008[b]	LTE_{50} 2009	LTE_{50} 2010
Low	-22.2 a	-22.8 a	-23.7 a
Medium	-22.3 a	-22.9 a	-23.2 a
High	-22.6 a	-23.3 a	-22.8 a
Control	-22.7 a	-23.2 a	-22.7 a

[a]Low: 1 cluster/shoot remains; Medium: 1.5 clusters/shoot remain; High: 2 clusters/shoot remain; Control: non-thinned
[b]Analysis of variance was conducted through SAS GLM Proc. and within year columns means followed by different letters are significantly different at $p \leq 0.05$ by Fisher's LSD.

Wine aroma sorting

Calculated RSQ and stress values for MDS consensus plots indicated an acceptable fit of the two-dimensional model to the aroma sorting data all three years, and panelists reported significant differences among crop levels all three years. In 2008 low crop was separated as the only wine above zero on the first dimension, while medium and high crop aromas more closely resembled the control since those three samples were all below zero in the first dimension (Figure 2.1). In 2009 low and medium crop aroma clustered together as the only two wines above zero in both the first and second dimensions, while high crop and control were in separate groups (Figure 2.2). In 2010 data plots were spaced relatively equidistant in all four quadrants thus panelists discerned differences between aromas of all crop levels (Figure 2.3).

Table 2.3 Canopy characterization of Riesling grapevines in the Finger Lakes, NY, from 2008 to 2010, by Enhanced Point Quadrat Analysis (EPQA) metrics.[a] Cropping treatments were imposed by cluster thinning to varying crop levels at E-L stage 31.[b] Data shown were collected at E-L stage 35.[c] Each value is an average of four field replicates ± standard error.

	OLN[f]			CEL[g]			CEFA[h]		
Crop Level[d]	**2008[e]**	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Low	2.62±0.12a	2.84±0.23a	2.54±0.12a	0.91±0.06a	0.94±0.15a	0.94±0.15a	0.32±0.02a	0.25±0.05a	0.25±0.05a
Medium	2.75±0.37a	2.90±0.07a	2.74±0.25a	0.82±0.14a	0.85±0.06a	0.71±0.14a	0.34±0.03a	0.26±0.03a	0.36±0.07a
High	3.14±0.21a	2.98±0.18a	2.86±0.26a	0.86±0.09a	0.83±0.13a	0.84±0.26a	0.35±0.05a	0.30±0.02a	0.30±0.07a
Control	3.18±0.20a	3.17±0.31a	2.84±0.23a	0.62±0.07b	0.77±0.05a	0.63±0.06a	0.37±0.04a	0.32±0.04a	0.37±0.03a

[a]Meyers and Vanden Heuvel 2008
[b]Eichorn-Lorenz stage 31 of shoot development, when at least two-thirds of berries reached pea-size, about six mm diameter
[c]Eichorn-Lorenz stage 35 of shoot development, when at least two-thirds of berries reached early ripening phase, or veraison
[d]Low: 1 cluster/shoot remains; Medium: 1.5 clusters/shoot remain; High: 2 clusters/shoot remain; Control: non-thinned
[e]Analysis of variance was conducted through SAS GLM Proc and within year columns means followed by different letters are significantly different at $p \leq 0.05$ by Fisher's LSD.
[f]Occlusion Layer Number: a measure of the overall shade-producing biomass (clusters and leaves) density of a canopy
[g]Cluster Exposure Layer: the number of occlusion (shading) layers between clusters and their nearest canopy boundary
[h]Cluster Exposure Flux Availability: percentage of the available above-canopy photon flux that reaches clusters

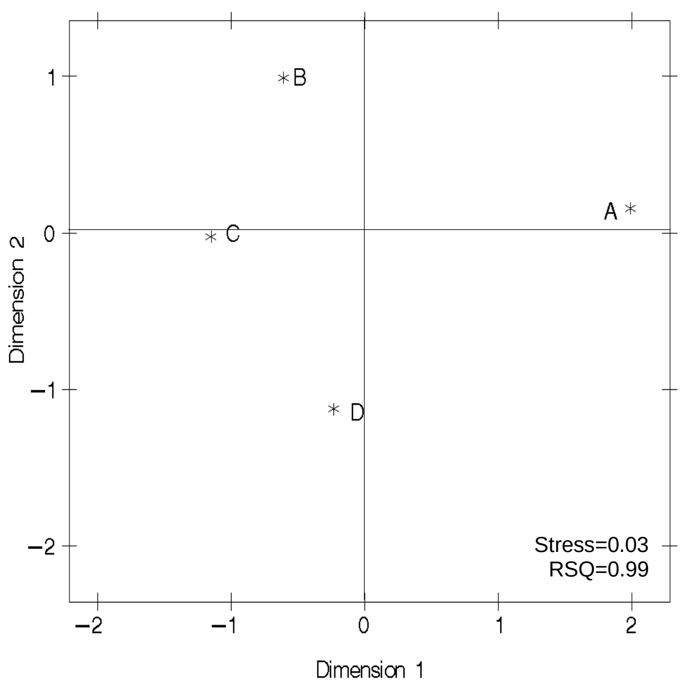

Figure 2.1 Two-dimensional consensus plot output from multidimensional scaling analysis of aroma similarity of Riesling wines made in 2008 from low (A), medium (B), high (C), and control (D) crop vines averaged over responses of 60 panelists.

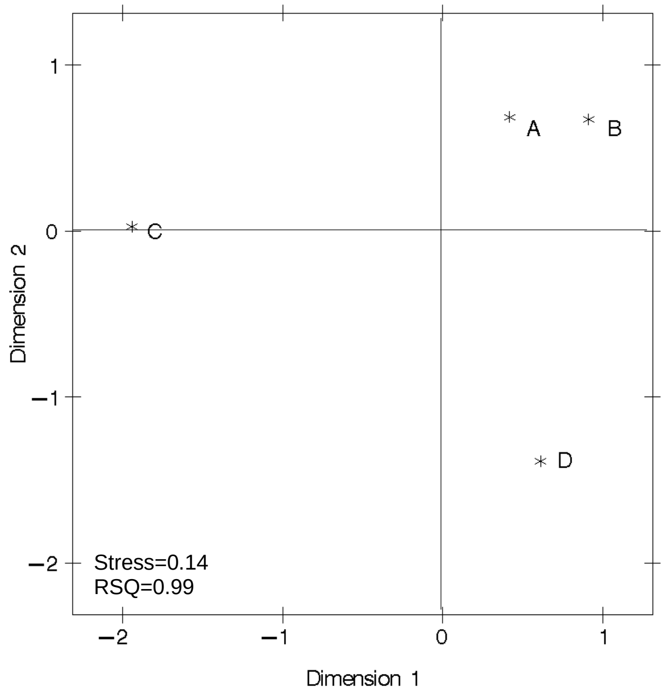

Figure 2.2 Two-dimensional consensus plot output from multidimensional scaling analysis of aroma similarity of Riesling wines made in 2009 from low (A), medium (B), high (C), and control (D) crop vines averaged over responses of 40 panelists.

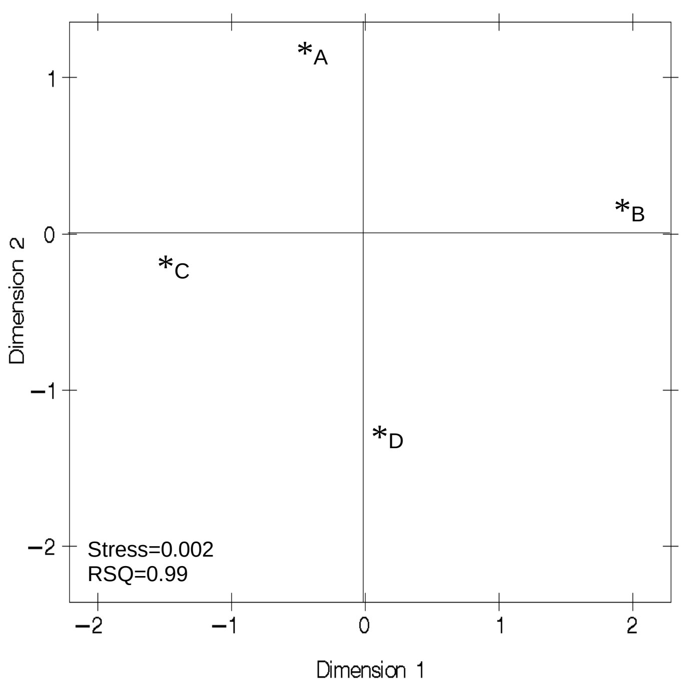

Figure 2.3 Two-dimensional consensus plot output from multidimensional scaling analysis of aroma similarity of Riesling wines made in 2010 from low (A), medium (B), high (C), and control (D) crop vines averaged over responses of 48 panelists.

Economic analysis

Yield and price parameters were obtained from data collected in the field trial or derived from published sources and entered in the CT economic model (Table 2.4). Yield of control vines was 12.4 t/ha in 2008, 9.3 t/ha in 2009 and 6.5 t/ha in 2010. Average market price for Finger Lakes Riesling was $1,773/t in 2008, $1,562/t in 2009 and $1,565/t in 2010. Because yield and price decreased each year of the field trial concomitantly potential revenue before CT (based on yield per hectare of the control plots) also decreased from $21,985/ha in 2008 to $14,527/ha in 2009 and $10,173/ha in 2010.

Variable and fixed production costs for managing one hectare of Riesling in the Finger Lakes, including additional labor costs of implementing CT, were derived from a published survey of vineyard management costs (White 2008) and entered into the model. Lost revenue from thinned fruit was calculated according to actual yields and market prices. Total costs were subtracted from potential revenue before CT to calculate grower net return, which in 2008 ranged from $2,832/ha in low crop to $16,055/ha in control, in 2009 ranged from -$115/ha in low crop to $8,596 in control, and in 2010 ranged from $1,938/ha in low crop to $4,242 in control. Compared to the base market price of $1,773/t the derived minimum price for a grower to recoup costs of implementing CT for low crop grapes in 2008 was $4,316/t, a 143% price increase. Compared to the base market price of $1,562/t in 2009 the minimum price for low crop grapes was $3,740/t, a 139% price increase. And compared to the base market price of $1,565/t in 2010 the minimum price for low crop grapes was $2,000/t, a 28% price increase.

Discussion

Reproductive growth and fruit composition

Cluster thinning had consistent advantageous effects on juice soluble solids accumulation consistent with other observations for *V. vinifera* (Bowen 2011; Nuzzo and Matthew 2006; Reynolds 1989; Reynolds et al. 1994a, 1994b), although the difference varied by year and was less pronounced in 2010. There seems to be little dispute that CT advances ripening in white

Table 2.4 Production costs and pricing parameters for Riesling in the Finger Lakes, NY, from 2008 to 2010. Grower net return analysis expressed by metrics of previously published CT economic sustainability model.[a] Cropping treatments were imposed by CT to varying crop levels at E-L stage 31.[b] Yield data are shown at harvest. Fixed and variable costs are based on maintaining one hectare of *V. vinifera* in the Finger Lakes for one year.[c]

	Potential yield before CT[e] (t/ha)			Expected market price before CT[f] ($/t)			Potential revenue before CT[g] ($/ha)		
Crop Level[d]	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Low	12.4	9.3	6.5	1773	1562	1565	21,985	14,527	10,173
Medium	12.4	9.3	6.5	1773	1562	1565	21,985	14,527	10,173
High	12.4	9.3	6.5	1773	1562	1565	21,985	14,527	10,173
Control	12.4	9.3	6.5	1773	1562	1565	21,985	14,527	10,173
	Actual yield after CT (t/ha)[h]			**Actual revenue after CT[i] ($/ha)**			**Production cost before CT[j] ($/ha)**		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Low	5.2	4.0	5.3	9,220	6,248	8,295	5,930	5,930	5,930
Medium	7.5	5.5	6.7	13,298	8,591	10,486	5,930	5,930	5,930
High	9.8	7.8	6.0	17,375	12,184	9,390	5,930	5,930	5,930
Control	12.4	9.3	6.5	21,985	14,527	10,173	5,930	5,930	5,930
	Production cost before CT[k] ($/t)			**Additional production cost after CT[l] ($/ha)**			**Additional production cost after CT ($/t)**		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Low	478	638	912	457	432	426	88	108	80
Medium	478	638	912	420	402	389	56	73	58
High	478	638	912	395	371	0	40	48	0
Control	478	638	912	0	0	0	0	0	0
	Total production cost after CT[m] ($/ha)			**Total production cost after CT ($/t)**			**Change in revenue after CT[n] ($/ha)**		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Low	6,388	6,363	6,357	566	746	993	-12,766	-8,279	-1,878
Medium	6,350	6,332	6,320	534	711	970	-8,688	-5,936	313
High	6,326	6,301	5,930	519	685	912	-4,610	-2,343	-783
Control	5,930	5,930	5,930	478	638	912	0	0	0
	Change in revenue after CT ($/t)			**Grower net return[o] ($/ha)**			**Grower minimum price[p] ($/t)**		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Low	-2,455	-2,070	-354	2,832	-115	1,938	4,316	3,740	2,000
Medium	-1,158	-1,079	47	6,947	2,259	4,166	2,987	2,714	1,576
High	-470	-300	-130	11,050	5,883	3,460	2,284	1,910	1,695
Control	0	0	0	16,055	8,596	4,242	1,773	1,562	1,565

[a]Preszler et al. 2010
[b]Eichorn-Lorenz stage 31 of shoot development, when at least two-thirds of berries reached pea-size, about six mm diameter
[c]White 2008
[d]Low: 1 cluster/shoot remains; Medium: 1.5 clusters/shoot remain; High: 2 clusters/shoot remain; Control: non-thinned
[e]Yield of Control field replicates (non-thinned) from Table 2.1
[f]Average market price of Riesling as surveyed annually by Cornell Cooperative Extension Finger Lakes Grape Program
[g]Potential yield before CT multiplied by expected market price before CT
[h]From Table 1
[i]Expected market price before CT multiplied by actual yield after CT
[j]Based on published cost of all viticultural practices on one hectare of *V. vinifera* in the Finger Lakes for one year (White 2008)
[k]Fixed production cost before CT divided by potential yield before CT
[l]Based on published costs of CT practices for one hectare of *V. vinifera* in the Finger Lakes (White 2008).
[m]Fixed production costs before CT plus variable production costs after CT
[n]Actual revenue after CT minus potential revenue before CT
[o]Actual revenue after CT minus total production cost after CT
[p]Market price a commercial grape grower would need to charge in order to maintain constant net return. Calculated as net returns for the control minus net returns for the CT treatment group ($/ha) all divided by reported yield ($/tonne) and added to the base minimum market price.

cultivars and cool climate regions. There were little or no CT effects on juice pH and TA at harvest which is reflected in the literature (Reynolds et al. 1994a). We cannot exclude the possibility that CT might have had different effects on compensating ripening parameters had it been implemented earlier in the season around bloom or later in the season approaching veraison. Additionally, another approach would be to study targeted thinning of green clusters that develop more slowly than others, but this practice also carries high labor cost.

The effects of CT on yield components were mostly predictable with cluster number per shoot and per vine reduced according to severity of CT treatment. There were no direct effects on berry weight from within-year CT treatments which is consistent with previous observations of CT in *V. vinifera* (Keller et al. 2005). In 2008 and 2009 differences in yield among CT treatments were primarily due to reduced cluster count but in 2010 cluster weight and berries per cluster were highest at the lower crop levels, which is consistent with other reports for white *V. vinifera* (Reynolds and Wardle 1989; Reynolds 1989; Reynolds et al. 1994a). The high crop and control exhibited suppressed vigor in 2010 such that yield was equivalent among all treatments (ranging from 5.3 to 6.5 t/ha), which may have been an indicator of vine carbohydrate reserves declining following the two previous years of very high crop level (between 7.8 and 12.4 t/ha).

Vegetative growth and canopy characterization

Control vines had reduced pruning weights in 2009 which is consistent with the literature for white *V. vinifera* (Reynolds and Wardle 1989; Reynolds et al. 1994a), however, in 2008 and 2010 pruning weights were not affected by CT likely as a result of individual vine variation. Wintertime cold acclimation as measured through DTA was not significantly affected by CT in any year, an observation supported by previous studies reporting no direct CT effect on bud cold hardiness (Bravdo et al. 1985; Keller et al. 2008). When compared to the control, CEL was higher in low crop in 2008, indicating more shading layers between clusters and their nearest canopy boundary, likely a result of increased growth of lateral and non-count shoots as a result of CT. However there was no indication that higher CEL also caused any decrease in cluster sunlight exposure or bud fruitfulness.

While we did not note significant differences in pruning weight and CEFA in the lower cropped vines these parameters were reported to be impacted in another recent CT study (Sun et al. 2012) and could have other effects on the economic sustainability and health of the vineyard. Particularly in regions with high rainfall, vigorous early season shoot growth and a shaded fruiting zone could increase pressure from powdery mildew. Denser canopies with less cluster sunlight exposure are more susceptible to powdery mildew growth and also experience reduced coverage of fruiting zone fungicide spray materials, and disease severity has been shown to be inversely proportional (and strongly linear) to the degree of sunlight exposure as defined by CEFA (Austin et al. 2011). When compared to linear response curves between CEFA and cluster disease severity in a previous study of Chardonnay in the Finger Lakes (Austin et al. 2011), the actual CEFA decrease in this study in 2008 would have increased disease severity from ~40% in control to ~50% in low crop. In 2009 the CEFA decrease as a result of CT would likely have increased disease severity from ~35% in control to ~55% in low crop. And in 2010 CEFA values would likely have increased disease severity from ~40% in control to ~60% in low crop. As such, lower cropped vines may require additional management tools in a commercial situation which were not applied under these research conditions. Tools such as shoot positioning and leaf pulling to expose the fruiting zone, and more frequent fungicide spray application, would all be available for the grower, and would increase the economic production costs beyond those modeled in this study.

Wine aroma sorting

Aroma sorting trial panelists were able to discern differences between at least two crop levels all three years as illustrated in the MDS configuration consensus plots with significant RSQ and stress values. In 2008 the low crop wine (crop load 2.9) sorted separately on its own dimension, distinctly different from all other wines (crop load 4.9 to 8.7). In 2009 low and medium wines (crop load 2.9 and 4.7 respectively) clustered together distinctly separate from high and control wines (crop load 7.1 and 9.9 respectively). For 2010 wines there were perceived differences among all four crop levels with no grouping of wines together in the same quadrant of the MDS map, indicating four stimulus sub-groups, even though the wines were made from a relatively small range of crop load (between 3.4 and 5.8) and yield per hectare among crop levels in 2010 did not differ. One possible hypothesis for this could be compositional differences in fruit and/or wine due to a carryover effect of crop load impacts, as well as N limitation and reduced carbohydrate storage in this vineyard during the 2009 growing season, which was relatively cool and had the lowest accumulation of growing degree days out of the previous 10 years (NOAA benchmark weather station #3031840, and FLGP 2010). Other studies have shown that fruit quality in current and subsequent growing seasons can suffer from limited N availability and assimilate supply (Keller 2005), and Riesling wines made from grapes with variable N availability differed in sensory qualities and concentration of aromatic monoterpenes (Webster et al. 1993). Although aroma chemistry was not examined in this study, various terpene concentrations have been reported in other thinning studies to increase at lower crop levels in Gewürztraminer (Reynolds and Wardle 1989), Müller-Thurgau (Eschenbruch et al. 1987), and Riesling (McCarthy 1986). In a study of Chardonnay Musqué thinned to one cluster per shoot wines exhibited increased herbaceousness and less tropical fruit (Reynolds et al. 2007), and CT has also been reported to decrease wine quality in Sauvignon Blanc (Gal et al. 1996; Naor et al. 2002). Additionally, yield control by pruning to lower bud numbers has been reported to reduce the intensity of fruity aromas and increase veggie aromas in Cabernet Sauvignon (Chapman et al. 2004).

The outlying wines were the low crop in 2008, and low and medium crop in 2009, all of which were made from vines yielding less than 2.5 kg/vine, less than 5.5 t/ha, less than 4.7 crop load, and greatly reduced financial net returns compared to the control. The goal of the sorting trial was to reveal any apparent similarities or differences between the wines without imposing questions of likeability, specific sensory properties or a quality construct such as fruitiness. It cannot be inferred from this data whether consumers preferred or disliked any specific wines as that data was not collected and no quality construct was asked of the panelists. The projective mapping technique does not provide any descriptive data so the MDS output dimensions require additional sensory or chemical data to assist with interpreting the underlying attributes (Kennedy and Heymann 2009; Nestrud and Lawless 2010). However, the meaningful aspect of the MDS configuration is the proximity of points to each other, and the larger relative distances between points indicate more dissimilar wines among varying crop levels. The MDS method is a practical and reliable tool for assessing overall aromatic similarities of white wine (Lee and Noble 2006), and panelists in this study were able to discern differences in aroma of wines made from varying crop levels.

Economic analysis

Commercial growers are motivated to recoup costs incurred from CT and maintain consistent net returns by charging above-market prices for grapes, which is only possible if buyers can discern sensory differences in wines and are willing to pay a premium for them. Without such a break-even point there will be a financial disincentive to employ CT as a viticultural practice. In 2008 the control vines exhibited positive financial net returns but the control juice only reached 18 Brix; the high crop had a positive net return and fruit reached 20 Brix at harvest, a more plausible threshold for winemaking. Both low and medium crop exhibited lower financial net returns and would require 143% and 68% price increases respectively over the control to recoup costs of CT. In 2008 the high crop was the most economically sustainable. In 2009 the control did not reach 19 Brix and the low crop had negative net returns, and the low and medium crop wines were undistinguishable by a sensory panel, so the high crop level, with positive net return and Brix greater than 20, was most economically sustainable. In 2010 all crop levels had positive net returns, all were deemed to be different from one another by a sensory panel, and all reached over 20 Brix at harvest, so the most sustainable crop level was medium since that maximized yield, Brix, and net returns.

The lowest crop level was most financially perilous, showing greatly reduced financial net returns than all other levels, and sub-zero returns in 2009, with severe differences in grower minimum price compared to the control that required 143%, 139%, and 28% grape price increases in each respective year. The significant enhancement to fruit ripening caused by CT, though not specifically valued financially in this study, may not be enough to outweigh the financial costs of implementing the practice, or the specter of selling grapes at grossly inflated prices. Future studies could include an examination of how sustainable yields vary between sites, cultivars, and years, or using viticultural management practices with different cost structures, or examining the flavor chemistry of wines made from varying crop load.

Conclusion

This study examined the effects of CT on various fruit, wine, sensory, and economic parameters of a commercial Riesling vineyard in the Finger Lakes, NY, to understand how CT is justified as part of a sustainable viticulture program. In 2008 a consumer aroma sorting panel cited differences between wines made from low crop (5.2 t/ha) and wines made from 1.5 or more clusters per shoot (7.5 to 12.4 t/ha), but the low crop grapes required a 143% price increase to compensate for lost yields and increased production costs. In 2009 aroma sorting panelists found differences among wines at the higher crop levels, but were not able to discern differences between wines made from grapes at 1.0 and 1.5 clusters per shoot (4.0 and 5.5 t/ha respectively), and the lowest crop level required 139% price increase for bulk grapes to maintain net returns. In 2010 sensory results showed differences for all CT treatment wines despite the fact that yields did not differ, a likely result of carryover effects of vineyard N limitation in the previous year. Since likability was not specifically rated in any year sensory differences between wines could reflect a negative or positive quality premium. There were no detrimental viticultural or cold hardiness effects of CT and despite higher soluble solids at harvest vines with crop load below 5 led to large financial losses for the grower at constant market prices. It is not clear whether the substantial price increases necessary to offset losses from CT would be merited based on wine quality or feasible based on bulk grape market conditions. Cluster thinning practices designed to reduce yields for fruit or wine quality purposes also reduce grower net returns, and more market price data is needed to determine if the financial losses from CT are too great to overcome.

REFERENCES

Arfelli, G., R. Zironi, B. Marangoni, A. Amati, and M. Castellari. 1996. The effects of cluster thinning on some ripening parameters and wine quality. Acta Hortic. 427:379-385.

Austin, C.N., G.G. Grove, J.M. Meyers, and W.F. Wilcox. 2011. Powdery mildew severity as a function of canopy density: associated impacts on sunlight penetration and spray coverage. Am. J. Enol. Vitic. 62:23-31.

Bowen, P., C. Bogdanoff, K. Usher, B. Estergaard, and M. Watson. 2011. Effects of irrigation and crop load on leaf gas exchange and fruit composition in red winegrapes grown on a loamy sand. Am. J. Enol. Vitic. 62:9-22.

Bravdo, B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. 1984. Effect of crop level on growth, yield and wine quality of a high yielding Carignane vineyard. Am. J. Enol. Vitic. 35:247-252.

Bravdo, B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. 1985. Effect of crop level and crop load on growth, yield, must and wine composition, and quality of Cabernet Sauvignon. Am. J. Enol. Vitic. 36:125-131.

Chapman, D.M., M.A. Matthews, and J.X. Guinard. 2004. Sensory attributes of Cabernet Sauvignon wines made from vines with different crop yields. Am. J. Enol. Vitic. 55:325-334.

Eschenbruch, R., R.E. Smart, B.M. Fisher, and J.G. Whittles. 1987. Influence of yield manipulations on the terpene content of juices and wines of Müller-Thurgau. *In* Proceedings of the 6th Australian Wine Industry Technical Conference. T. Lee (ed.), pp. 89-93. Australian Industrial Publishers, Adelaide.

Filippetti, I., S. Ramazzotti, M. Centinari, B. Bucchetti, and C. Intrieri. 2007. Effects of cluster thinning on grape composition: preliminary experiences on Sangiovese grapevines. Acta Hortic. 754:227-234.

FLGP (Finger Lakes Grape Program). 2010. Veraison to harvest newsletter. Cornell University Cooperative Extension, Penn Yan, New York.

Gal, Y., A. Naor, and B. Bravdo. 1996. Effect of shoot density, crop level and crop load on fruit and wine quality of Sauvignon Blanc grapes. Acta Hortic. 427:151-159.

Giguère, G. 2007. Collecting and analyzing data in multidimensional scaling experiments: a guide for psychologists using SPSS. Tutorials Quant. Meth. Psych. 2:26-37.

Howe, J., J. Cortell, S. Price, E. Brasher, and A. Connelly. 2002. Managing crop. In Oregon State University Viticulture Extension Newsletter, August. J. Howe et al. (eds.). Oregon State University, Corvallis.

Jackson, D.I., and P.B. Lombard. 1993. Environmental and management practices affecting grape composition and wine quality – a review. Am. J. Enol. Vitic. 44:409-430.

Johnson, H., and J. Robinson. 2001. World atlas of wine, 5th edition. Mitchell Beazley, London.

Keller, M. 2005. Deficit irrigation and vine mineral nutrition. Am. J. Enol. Vitic. 56:267-283.

Keller, M., L.J. Mills, R.L. Wample, and S.E. Spayd. 2005. Cluster thinning effects on three deficit-irrigated Vitis vinifera cultivars. Am. J. Enol. Vitic. 56:91-103.

Keller, M., R.P. Smithyman, and L.J. Mills. 2008. Interactive effects of deficit irrigation and crop load on Cabernet Sauvignon in an arid climate. Am. J. Enol. Vitic. 59:221-234.

Kruskal, J.B. 1964. Nonmetric multidimensional scaling: a numerical method. Psychometrika 29:115-120.

Lakso, A.N., and D.M. Eissenstat. 2005. Crop load – physiology, modelling and relationships to root growth in grapevines. In Proceedings of the Twelfth Australian Wine Industry Technical Conference, pp. 38-44. Australian Society of Viticulture and Oenology, Melbourne.

Lawless, H.T., and H. Heymann. 1998. Sensory evaluation of food: principles and practices. Chapman & Hall, New York.

Lawless, H.T. and S. Glatter. 1990. Consistency of multidimensional scaling models derived from odor sorting. J. Sens. Stud. 5:217-230.

Lee, S.J., and A.C. Noble. 2006. Use of partial least squares regression and multidimensional scaling on aroma models of California Chardonnay wines. Am. J. Enol. Vitic. 57: 363-370.

McCarthy, M.G. 1986. Influence of irrigation, crop thinning, and canopy manipulation on composition and aroma of Riesling grapes. M.Sc. Thesis, University of Adelaide, Australia.

Meyers, J.M., and J.E. Vanden Heuvel. 2008. Enhancing the precision and spatial acuity of point quadrat analyses via calibrated exposure mapping. Am. J. Enol. Vitic. 59:425-431.

Murisier, F. and R. Ziegler. 1991. Effets de la charge en bourgeons et de la densité de plantation sur la potentiel de production, sur la qualité du raisin et sur le developpement vegetatif. Essais sur Chasselas. Rev. Suisse Vitic. Arboric. Hortic. 23:277-282.

Naor, A., Y. Gal, and B. Bravdo. 2002. Shoot and cluster thinning influence vegetative growth, fruit yield, and wine quality of Sauvignon Blanc grapevines. J. Am. Soc. Hortic. Sci. 127:628-634.

Nestrud, M.A., and H.T. Lawless. 2010. Perceptual mapping of apples and cheeses using projective mapping and sorting. J. Sens. Stud. 25:390-405.

Nuzzo, V., and M.A. Matthews. 2006. Response of fruit growth and ripening to crop level in dry-farmed Cabernet Sauvignon on four rootstocks. Am. J. Enol. Vitic. 57:314-324.

Ough, C.S., and R. Nagaoka. 1984. Effect of cluster thinning and vineyard yields on grape and wine composition and wine quality of Cabernet Sauvignon. Am. J. Enol. Vitic. 35:30-34.

Preston, L.D., D.E. Block, H. Heymann, G. Soleas, A.C. Noble, and S.E. Ebeler. 2008. Defining vegetal aromas in Cabernet Sauvignon using sensory and chemical evaluations. Am. J. Enol. Vitic. 59:137-145.

Preszler, T., T.M. Schmit, and J.E. Vanden Heuvel. 2010. A model to establish economically sustainable cluster-thinning practices. Am. J. Enol. Vitic. 61:140-146.

Ravaz, M.L. 1911. L’effeuillage de la vigne. Ann. l’École Nat. Agric. Montpellier 11:216-244.

Reynolds, A.G. 1989. Riesling grapes respond to cluster thinning and shoot density manipulation. J. Am. Soc. Hortic. Sci. 114:364-368.

Reynolds, A.G. and D.A. Wardle. 1989. Impact of various canopy manipulation techniques on growth, yield, fruit composition, and wine quality of Gewürztraminer. Am. J. Enol. Vitic. 40:121-129.

Reynolds, A.G., C.G. Edwards, D.A. Wardle, D.R. Webster, and M. Dever. 1994a. Shoot density affects Riesling grapevines I: vine performance. J. Am. Soc. Hortic. Sci. 119:874-880.

Reynolds, A.G., S.F. Price, D.A. Wardle, and B.T. Watson. 1994b. Fruit environment and crop level effects on Pinot Noir I: vine performance and fruit composition in British Columbia. Am. J. Enol. Vitic. 45:452-459.

Reynolds, A.G., J. Schlosser, D. Sorokowsky, R. Roberts, J. Willwerth, and C. De Savigny. 2007. Magnitude of viticultural and enological effects II: relative impacts of cluster thinning and yeast strain on composition and sensory attributes of Chardonnay Musqué. Am. J. Enol. Vitic. 58:25-41.

Schiffman, S.S., and T.W. Knecht. 1993. Basic concepts and programs for multidimensional scaling. *In* Flavor measurement. C.T. Ho and C.H. Manley (Eds.), pp. 133-158. Marcel Dekker, New York.

Schiffman, S.S., M.L. Reynolds and F.W. Young. 1981. Introduction to multidimensional scaling: theory, methods, applications. Academic Press, New York.

Sun, Q., G.L. Sacks, S.D. Lerch, and J.E. Vanden Heuvel. 2012. Impact of shoot and cluster thinning on yield, fruit composition, and wine quality of Corot noir. Am. J. Enol. Vitic. 63:49-56.

Tang, C., and H. Heymann. 2002. Multidimensional sorting, similarity scaling and free-choice profiling of grape jellies. J. Sens. Stud. 17:493-509.

Tardaguila, J., P.R. Petrie, S. Poni, M.P. Diago, and F. Martinez de Toda. 2008. Effects of mechanical thinning on yield and fruit composition of Tempranillo and Grenache grapes trained to a vertical shoot-positioned canopy. Am. J. Enol. Vitic. 59:412-417.

Webster, D.R., C.G. Edwards, S.E. Spayd, J.C. Peterson, and B.J. Seymour. 1993. Influence of vineyard nitrogen fertilization on the concentrations of monoterpenes, higher alcohols, and esters in aged Riesling wines. Am. J. Enol. Vitic. 44:275-284.

Wilkinson, L. 1990. SYSTAT: the systems for statistics. SYSTAT, Evanston, IL.

Wolf, T.K. and M.K. Cook. 1992. Seasonal deacclimation patterns of three grape cultivars at constant, warm temperature. Am. J. Enol. Vitic. 43:171-179.

Wolf, T.K., and R.M. Pool. 1986. Microcomputer-based differential thermal analysis of grapevine dormant buds. HortScience 21:1447-1448.

Wolf, T.K., and R.M. Pool. 1987. Factors affecting exotherm detection in differential thermal analysis of grapevine dormant buds. J. Am. Soc. Hortic. Sci. 112:520-525.

CHAPTER 3

EFFECTS OF CLUSTER THINNING IN LATE HARVEST RIESLING ON ECONOMIC SUSTAINABILITY, YIELD COMPONENTS, FRUIT COMPOSITION, WINE QUALITY AND WILLINGNESS TO PAY OF NEW YORK CITY WINE PROFESSIONALS

Abstract

Crop levels of 1 (low), 1.5 (medium), and 2 (high) clusters per shoot established by cluster thinning (CT) were compared to non-thinned (control) "late harvest" Riesling vines over a three year period. In 2008, yields ranged from 5.5 t/ha in low crop to 8.4 t/ha in control and in 2009 from 4.7 to 7.8 t/ha respectively, and in both years yield reflected cluster number. By 2010, yield per vine and hectare did not differ among treatments. Cluster weight was unaffected by CT in 2009 but in 2008 and 2010 the control clusters weighed 19% and 23% less, respectively, than low crop. There was little or no significant CT effect on berries per cluster, pH, or TA. Pruning weight was unaffected in 2008 and 2009 but low crop vines had higher pruning weights than the control in 2010 which corresponded to higher OLN. Cluster light environment as measured by CEFA was unaffected in 2008 and 2010 but low crop vines were lower than the control in 2009. Soluble solids at harvest (Brix) ranged from 17.1 in control to 19.6 in low crop in 2008, from 17.8 to 19.9 Brix respectively in 2009, and from 19.1 to 21.4 Brix in 2010. In 2009 New York City wine industry professionals reported reduced fruitiness in medium crop late harvest wines and reduced mouthfeel in low crop wines, but no differences persisted in likability ratings or willingness to pay (WTP) for any crop levels. The same panel reported no differences in any sensory or preference attributes or WTP between any crop levels in 2010. Grower financial net return per hectare ranged from $8,261 in low crop to $16,414 in control in 2008, from $4,688 to $12,029 respectively in 2009 and from $4,936 to $7,613 respectively in 2010. Applying elicited consumer WTP in the model with these financial net returns illustrated the grower would have no optimal level of CT that would allow increasing net returns. Thus WTP trends inversely with

grower net returns and would not justify any increase in per-bottle prices to offset the financial losses associated with CT.

Introduction

The production of "late harvest" (LH) wines provides an avenue for wineries to reach a market segment of consumers who may prefer medium-dry or sweet wines. In cool climate regions, LH wines are typically made from aromatic white *Vitis vinifera* cultivars such as Riesling or Gewürztraminer that are harvested later in the growing season when soluble solids accumulation or infection by *Botrytis cinerea* allow an end product containing natural residual sugar and lower alcohol by volume (Clary et al. 2006). While fermentation and aromatic properties of LH wines have been reported on extensively (Cliff et al. 2002; Kontkanen et al. 2004; Skurray and Lawson 2001), their relation to viticultural practices and economics has not been studied.

The widespread popular belief that low yielding grapevines produce higher quality wines is also entrenched in the LH wine segment because LH wine is often marketed to consumers using scarcity as one of its quality signals. It is unclear how that ideology translates into the vineyard for LH wines in part because most viticultural studies about crop levels in cool climate premium winegrapes are conducted under the assumption that the grapes will be used for dry table wine. However, yield restrictions in commercial vineyards, imposed either voluntarily or as mandated by a quality appellation, may not be the most sustainable practice for LH wines because LH vines generally experience reduced yields due to water loss, disease and pest pressure. In many regions wine producers struggle to maximize both grapevine yields and wine quality simultaneously (Keller et al. 2008), and balancing these two objectives requires a quantitative and holistic approach to all aspects of yield management including financial returns, consumer preference and vine balance.

Vine balance is most often measured by use of the Ravaz Index (Ravaz 1911), or crop load (yield/pruning weight), which has particular usefulness when measurements are calibrated with fruit and/or wine quality. Crop load between 5 and 10 is thought to be ideal for quality winemaking (Bravdo et al. 1984, 1985), a principle subject to numerous investigations on various cultivars in warm (Chapman et al. 2004; Keller et al. 2005) and cool (Reynolds et al. 2007) climates. Anecdotal observations among commercial growers in the Finger Lakes region of New York indicate that the standard crop load range of 5 to 10 for quality dry table winemaking is assumed to hold true for LH wines as well. But the crop load metric does not encompass the full spectrum of decision making among grape growers, especially in regions where grape prices are pegged to other parameters besides soluble solids at harvest, and when the end product such as LH wines may reach a different market segment.

Commercial growers of aromatic white cultivars generally manage crop load by cluster thinning (CT) assuming it will result in quality improvements desired by the buyer so lost revenues can be recouped through higher prices. The primary quality improvement usually demonstrated with CT is increased soluble solids accumulation, which has been reported in white *V. vinifera* such as Riesling (McCarthy 1986; Reynolds 1989; Reynolds et al. 1994a), Chasselas (Murisier and Ziegler 1991), and Trebbiano (Arfelli et al. 1996). The effect of CT on LH wine quality has not been examined, but for dry wines it was reported to have no effect on quality in Gewürztraminer at one cluster per shoot (Reynolds and Wardle 1989), and CT reduced the perceived quality of Sauvignon Blanc (Gal et al. 1996; Naor et al. 2002) and Chardonnay Musqué (Reynolds et al. 2007). None of the aforementioned studies targeted or studied CT effects in LH vineyards specifically, which may be particularly important because of the additional carbon demands placed on vines to ripen fruit later in the season. Prolonged ripening time before harvest shortens vine post-harvest photoassimilation capacity and limits the restoration of carbohydrate reserves, which can decrease winter hardiness, yields, soluble solids accumulation and cluster weight in subsequent growing seasons (Smith and Holzapfel 2009).

The need for balancing fruit production and economic returns has been identified repeatedly (Jackson and Lombard 1993; Keller et al. 2008; Lakso and Eissenstat 2005; Reynolds et al. 1994b, 2007), but few quantitative tools exist to help growers calculate costs and benefits of CT. There are two primary costs associated with CT: skilled human labor and lost revenue from reduced yield. The cost of CT in Spain was determined to be $520 to $650/ha by hand and $220/ha by machine, but the impact of lower yields on net returns was not examined (Tardaguila et al. 2008). Other reports have stated CT is economically feasible only as a “band-aid” solution when vines are over-cropped or when environmental conditions impede ripening (Keller et al. 2005; Nuzzo and Matthews 2006), but no economic analyses were presented to support these statements. There is little data in viticulture literature relating to production costs and financial returns, and certainly none providing unique consideration for LH wines, making it difficult to evaluate economic sustainability of varying crop levels imposed in commercial vineyards.

To understand the value of a viticultural practice such as CT requires assessing whether consumers will take notice of the practice and have a greater or lesser willingness to pay (WTP), which can be revealed through a simple elicitation technique by asking consumers’ true preference for the goods in question (Lusk and Hudson 2004). New product attributes in food science and applied economics are typically studied by presenting taste panels with a series of flavor-differentiated samples and asking panelists if they perceive any sensory differences, if they have a preference, passion or intolerance for any of those sensory differences, and what they would pay for the products as a result (Umberger and Feuz 2004). This method does not assume a direct causal relationship between how much a consumer likes the taste of a product and how compelled they will be to purchase it (Jaeger and Harker 2005).

The New York City (NYC) metropolitan area is the largest wine market in the U.S. and consumes approximately 30% of America’s total imported wines (Wine Market Council 2009) making it a highly contested market for many quality wine districts. General consumers’ wine drinking habits in NYC are influenced heavily by a specialized niche of restaurant sommeliers, wine writers and wine shop owners who act as market gatekeepers and have specific awareness of NY wines (Preszler and Schmit 2009). Such industry professionals would make desirable sensory panelists because they have a robust vocabulary, expert understanding of important wine attributes and more finely honed sensory acumen than general consumers (Hughson and Boakes

2002; Lawless 1984; Lesschaeve 2007; Nestrud and Lawless 2008). Despite these advantages, culinary industry professionals are very rarely studied by the sensory science community (Nestrud and Lawless 2008) and to-date no published sensory study specifically targets NYC wine industry professionals. Further, sensory attributes such as aroma and flavor are seldom used in wine market research because most emphasis is placed on extrinsic attributes such as brand or label design, appellation, price and grape variety (Yang et al. 2009).

To best advise grape growers on optimal CT and yield management decisions it is important to quantify the additional value relationship assumed by buyers conditional on the level of CT. If a buyer's WTP for wines is differentiated for quality and parallels a grower's CT practices, then the grower's minimum price requirements for grapes can be expressed as a function of crop level. A model published by this research group (Preszler et al. 2010) was the first to position grapevine yield within a quantitative economic decision-making framework. In this study, the model was applied to viticultural and sensory data from a field trial of varying crop levels in a mature commercial Riesling vineyard, and the resulting LH wines were panel tested for sensory qualities and WTP among NYC wine professionals. The goal was to elucidate the effects of CT on yield components, fruit composition, LH wine quality, financial net returns, and WTP among NYC wine professionals, and by doing so, to enhance decision making acuity among winegrape growers using or considering CT.

Materials and Methods

Vineyard site and experimental design

This field experiment was conducted in 2008, 2009, and 2010 at a commercial vineyard on the east side of Cayuga Lake in King Ferry, NY, in the Finger Lakes AVA (42.38°N, 76.38°W, 224 m elevation), on a soil type classified as Cazenovia series with a silt loam structure (USDA-NRCS soil maps). Vines were *Vitis vinifera* L. cv. Riesling cl. 239, grafted on 3309C rootstock, planted in 1984 in a north-south row orientation on a westward facing slope, with 1.5 m spacing between vines and 3.0 m between rows. Vines were cane pruned and trained to the Pendelbogen vertically shoot-positioned system. The vineyard was managed by the cooperating commercial grower according to the standard viticultural and disease control practices for *V. vinifera* in the Finger Lakes region.

The research plot spanned three adjoining vineyard rows and the experiment was designed with a non-thinned control plus three CT treatments: 1.0 (low crop), 1.5 (medium crop), and 2.0 (high crop) clusters retained per shoot. Treatments were arranged in a randomized complete block with four replicates. Each CT treatment was nine contiguous vines, the outer two serving as guard vines and the inner seven used for data collection, for a total of 112 experimental units. When at least two-thirds of the vines reached or exceeded Eichorn-Lorenz (E-L) stage 9 of shoot development (two or three leaves unfolded), all secondary shoots were removed by hand and, in 2008, primary shoots were thinned to 27 per vine, which was the lowest density counted before thinning. In 2009 and 2010, primary shoots were thinned to 36 per vine to control excessive vigor. Cluster thinning treatments were applied when at least two-thirds of the vines had reached or exceeded E-L stage 31 of shoot development (pea-sized berries). Clusters located distally nearest the shoot apex were removed first, and the basal clusters were left intact.

Canopy characterization

Grapevine canopy characteristics relating to light environment and vegetative growth were recorded on a per vine basis when at least two-thirds of the vines had reached or exceeded E-L stage 35 of shoot development (early berry ripening, veraison). Enhanced Point Quadrat Analysis (EPQA) was used to quantify the light environment according to a previously specified methodology (Meyers and Vanden Heuvel 2008). A thin rod was inserted through the fruiting zone perpendicular to the row direction, at 20 cm intervals, and the rod’s sequential contact with leaves, clusters, and wires were recorded. Photon flux measurement was performed using a ceptometer (Decagon, model AccuPAR LP-80, Pullman, WA) for each vine between 11:00 and 14:00 hr on the same day as insertion data was collected. The ceptometer measurements were obtained by holding the probe (90 cm long with 80 photosensors) within the vine fruit zone and parallel to the row while simultaneously holding a photosynthetically active radiation sensor above the canopy, which was connected to the integrated controller. For each vine, 10 measurements were made over a period of 10 seconds, and the mean value for above- and within-canopy photon flux was recorded. The resulting data was analyzed by EPQA and CEM Tools, version 1.7 (available free of charge from Jim Meyers, jmm533@cornell.edu) to calculate occlusion layer number (OLN), the number of shade-producing contacts; cluster exposure layer (CEL), the number of shading layers between clusters and the nearest canopy boundary; and cluster exposure flux availability (CEFA), the percentage of above-canopy light that reaches clusters.

Harvest and yield components

Vegetative and yield component data were collected on a per vine basis. Experimental vines were harvested by hand in consort with the harvest schedule of the cooperating commercial grower three weeks after the typical Riesling harvest for this vineyard: 29 Oct 2008, 28 Oct 2009, and 3 Nov 2010. Clusters were snipped, counted, and weighed with a hanging scale accurate to 0.01 kg (Salter Brecknell, model SA3N340, Fairmont, MN) to determine yield per vine, total yield, and average cluster weight. A subsample of 100 berries was collected randomly in duplicate from each treatment replicate and weighed to determine average berry weight. During the week around 15 March in each year vines were pruned to three remaining canes with 40 nodes per vine and the prunings were weighed on a per vine basis with a hanging scale accurate to 0.01 kg (Salter Brecknell, model SA3N340, Fairmont, MN) and crop load (yield/pruning weight) was calculated for each vine.

Winemaking and basic juice chemistry

In 2009 and 2010 grapes from all field replicates were combined with like CT treatments and brought to the Cornell Orchards Teaching Winery for processing on the day of harvest. Wines were not made in 2008. All fruit underwent identical processing. Grapes from each treatment were whole-cluster pressed in a 40 L stainless steel hydraulic bladder press (Gino Pinto, model Zambelli Hydro 40 Inox, Hammonton, NJ), and duplicate 200 mL juice samples were collected from each treatment and frozen at -20°C for later analysis. Juice was treated with

50 mg/L sulfur dioxide added as potassium metabisulfite and allowed to settle for 12 hr. at 4°C. After pressing and settling, the juice was racked according to treatment into duplicate 19 L glass carboys for a total of eight fermentation lots. Carboys were chaptalized to the same level of soluble solids, 22 Brix, if necessary, and juice was inoculated with 0.25 g/L *Saccharomyces cerevisiae* strain R-HST yeast (Lallemand Inc., Toulouse, France) previously rehydrated in GoFerm (Lallemand) according to manufacturer's instructions. Carboys were fitted with airlocks, moved to a 16°C room and stirred daily. FermAid K (Lallemand) was added (0.15 g/L) at inoculation and again when wines reached 10 Brix. Wines fermented until residual sugar was measured in the medium-sweet category between 6.0% and 10.0% using Clinitest tablets (Bayer, West Haven, CT) and then fermentation was stopped by adding 40 mg/L free sulfur dioxide and moving carboys into a 2°C storage room. Wines did not undergo any acid adjustments or malolactic fermentation and were screened for faults by an expert panel prior to being bottled manually using standard 750 mL green glass bottles and natural corks, and then stored at 16°C.

Fruit composition data were collected as composite samples on a per replicate basis with duplicate analytical replicates. Juice soluble solids content was analyzed from previously frozen samples with a temperature compensating Brix scale (0-30) refractometer (Leica Inc., Buffalo, NY). Juice pH was measured with a benchtop pH meter (VWR SympHony, model SB80P1, Radnor, PA), TA was measured by titrating a 50 mL aliquot of juice against 0.10 M NaOH to pH 8.2 using an automatic titrator (Mettler Toledo, model DL22, Columbus, OH), and wine alcohol content was measured by ebulliometer (DuJardin-Salleron, Arcueil, France).

Wine sensory WTP panel

Approximately two years after bottling 2009 wines and one year after bottling 2010 wines, sensory attribute preference information was collected through controlled tastings with a judgment sample of 27 highly skilled sommeliers and professionals in the NYC wine, restaurant and hospitality industries. Panelists were recruited and assembled at the International Wine Center in NYC, the American headquarters of the Wine & Spirit Education Trust U.K. (WSET) which administers the Master of Wine (MW) certification program. At the time of the tasting, 14 of the panelists worked in wine sales at a business-to-business wine distributor or at a direct-to-consumer retail shop, hotel or restaurant, and the other 13 were writers, bloggers, critics, educators or media relations specialists. All panelists completed some stages of wine training through WSET and 21 of them graduated at the highest levels with the WSET Level 4 Diploma or MW. Nineteen panelists were female and all were between 25 and 55 years old, with 14 panelists between the ages of 31 and 40. No predetermination of attributes was made to discriminate among wines, no advance training of panelists was conducted, and no specific information was provided about the wines or viticultural practices used to make them.

Panelists were seated in a room illuminated with fluorescent lighting and served wines in 30 mL aliquots at room temperature in clear tulip-shaped (ISO) 220 mL wine glasses. Wines made in 2009 from all three CT treatments and non-thinned control were poured and presented simultaneously to panelists. Each glass was coded with a random identification number and the order of wines presented was randomized among panelists. Panelists were asked to smell and taste each wine, expectorate between samples, and use their own experience to record their impressions of three important sensory attributes that have been previously identified (Cliff et al. 2002) for evaluating LH Riesling wines: the fruity or floral intensity of the aroma, the petrol or fusel intensity of the flavor, and the structure or mouthfeel. In addition, panelists were asked to rate the overall likability and their likelihood of purchase for each wine. The intensity of each attribute was measured on a 10 cm line scale with anchors at 0 for “not at all” and 10 for “extremely,” and panelists were asked to mark a dot along the scale to indicate their response, which was later measured and converted to a numerical rating. After completing the attribute response exercise panelists were asked to record their typical WTP for an average 750 mL bottle of LH Riesling in a NYC retail store. Then they were asked to record their maximum WTP for each of the experimental wines presented in the tasting panel, assuming a hypothetical situation where they were buying a 750 mL bottle of the wine at a NYC retail store. After completing the entire tasting exercise for 2009 wines, the same protocol was repeated for 2010 wines. This method of collecting hedonic and descriptive data concurrently has been questioned by the sensory science community (Lawless and Heymann 1998), but intrinsic sensory qualities are major factors affecting consumers' purchasing decisions (Brennan and Kuri 2002) and it is potentially instructive to observe if sensory attributes influence WTP (Yang et al. 2009).

Economic analysis

Fixed and variable production costs for managing one hectare of Riesling in the Finger Lakes, including additional labor costs of implementing CT, were derived from a published survey of vineyard management costs (White 2008) and entered into a previously described CT economic model (Preszler et al. 2010). Specific input parameter data were yield (t/ha) before and after CT, fixed and variable production costs ($/t) before and after CT, and the market price for LH Riesling grapes ($/t). Lost revenue from thinned fruit was calculated according to actual yields and market prices. Total costs were subtracted from potential revenue before CT to calculate grower net returns ($/t), and minimum grape prices ($/t) that must be received in order to adopt CT practices at varying levels while maintaining net returns were calculated. The model assumes net returns per tonne increase with higher per tonne price requirements, but are offset due to lower yields and higher production costs. The minimum grape price ($/t) to keep net returns constant was also converted into the additional cost per 750mL bottle of wine a producer would need to receive in order to adopt CT at varying levels. The additional cost per bottle was determined by subtracting the expected market price before CT ($/t) from the minimum grape price for constant net returns ($/t) for each CT treatment, and then dividing by 488, which is the approximate number of 750mL bottles that were produced from one tonne of grapes in this experiment. The WTP values from the sensory panel were entered into the previously published economic model to determine the difference between break-even price and WTP and plot the computed response function for net returns based on actual WTP, which indicated whether market conditions would be favorable for wineries to command a per-bottle price sufficient to recoup the costs of CT, and whether there was an optimal level of CT based on WTP.

Statistical analysis

The SAS software version 8.0 (SAS, Cary, NC) was used to analyze viticulture and juice data for statistically significant differences using the General Linear Model procedure (GLM Proc) and separating means by the Fisher's Least Significant Difference (LSD) test at the 5% significance level. SAS was used to analyze wine sensory and WTP data by two-way ANOVA with panelist ID and CT treatment set as independent variables, and significant treatment effects were separated by multiple comparisons test with Tukey adjustment. A *p*-value equal to or less than 0.05 was necessary for results to be reported as significant. Canopy light environment data were analyzed using EPQA and Canopy Exposure Mapping (CEM) Tools, version 1.7 (Cornell University, Ithaca, NY). Microsoft Excel was used for basic descriptive statistics and economic data were analyzed using a previously published model (Preszler et al. 2010).

Results

Reproductive growth and fruit composition

When compared to the control, CT reduced clusters per vine at the low crop level by 53% in 2008, 45% in 2009 and 33% in 2010 (Table 3.1). Yield per vine in 2008 ranged from 3.9 kg in the control to 2.5 kg in low crop, corresponding to 8.4 and 5.5 t/ha respectively, or a 35% decrease in yield from CT. In 2009, yield per vine ranged from 3.6 kg in control to 2.2 kg in low crop, corresponding to 7.8 and 4.7 t/ha respectively, or a 40% decrease in yield. In 2010 CT predictably reduced yield per hectare in low and medium crop vines, however high crop and control yield was lower than in previous years and thus yield was equal among treatments.

In 2008 berry weight in low and medium crop (average 1.78 g) differed from high crop and control (average 1.45 g), and cluster weight was highest in low crop but equivalent at the other levels. In 2009 berry weight was highest at the low crop level and there was no significant CT effect on cluster weight; yield differences were due to number of clusters remaining after thinning. In 2010 berry weight in low and medium crop (average 1.51 g) differed from the

control, and cluster weight of low and medium crop (average 52.3 g) differed from high crop and control (average 39.5 g). There were no CT effects on berries per cluster in any year.
In 2008 soluble solids differed between low and medium crop (average 19.5 Brix) and high crop and control (average 17.3 Brix), and likewise in 2009 soluble solids differed between low and medium crop (average 19.7 Brix) and high crop and control (average 18 Brix). In 2010 Brix of low crop was highest but all other treatments were equivalent. Juice acid levels at harvest were highest in 2009 but CT had little or no significant effect on pH and TA in any year. There was no CT effect on wine pH, wine TA or percent alcohol by volume in any year.

Vegetative growth and canopy characterization

Low crop vines had significantly higher pruning weights compared to the control in 2010 only. Crop load in 2008 ranged from 3.3 in low crop to 6.3 in control, and in 2009 ranged from 3.2 to 7.0 respectively. In 2010 low crop vines had significantly reduced crop load compared to medium crop only. Crop load of low and medium crop vines remained consistent all three years, but high crop vines crop load fell to 4.2 in 2010 after reaching 6.6 in 2009 and 5.7 in 2008. Crop load of control vines fell to 4.6 in 2010 after reaching 7.0 in 2009 and 6.3 in 2008. Low crop vines had significantly higher OLN compared to other treatments in 2010 only (Table 3.2). Control vines had significantly higher CEFA compared to other treatments in 2009 only. There were no CT effects on CEL in any year.

Economic analysis and wine sensory WTP trial

Cost, price, yield and revenue parameters obtained from data collected in the field trial or derived from published sources were entered in the CT economic model (Table 3.3). Yield of control vines was 8.4 t/ha in 2008, 7.8 t/ha in 2009 and 5.8 t/ha in 2010. Average market price for Finger Lakes LH Riesling was $2,660/t in 2008, $2,350/t in 2009 and $2,400/t in 2010. Since yield and price decreased over the course of the study so did potential revenue before CT (based on yield per hectare of the control plots) from $22,344/ha in 2008 to $18,330/ha in 2009 and$13,920/ha in 2010. Taking into account the costs of implementing CT the change in revenue from thinned fruit was -$7,714/ha in 2008, -$7,285/ha in 2009 and -$2,640/ha in 2010.

Table 3.1 Yield components, fruit and wine composition of late harvest Riesling in the Finger Lakes, NY, from 2008 to 2010. Treatments were imposed by cluster thinning to varying crop levels at E-L stage 31.[a] Yield data are shown at harvest and each value is an average of four field replicates ± standard error. All musts were chaptalized to 22°Brix before fermentation and each value is an average of two fermentation replicates.

	Clusters/shoot			Clusters/vine		
Crop Level[b]	2008[c]	2009	2010	2008	2009	2010
Low	1.0 ± 0.04 c	1.0 ± 0.05 c	1.1 ± 0.04 c	27.9 ± 1.14 c	37.0 ± 1.90 c	41.3 ± 1.60 c
Medium	1.5 ± 0.03 b	1.6 ± 0.05 b	1.4 ± 0.06 b	39.3 ± 0.71 b	56.5 ± 1.93 b	49.8 ± 2.10 b
High	2.1 ± 0.07 a	2.0 ± 0.07 a	1.9 ± 0.08 a	57.8 ± 1.79 a	72.3 ± 2.51 a	69.7 ± 2.72 a
Control	2.2 ± 0.33 a	1.9 ± 0.16 a	1.7 ± 0.28 a	59.0 ± 8.94 a	67.6 ± 5.94 a	62.0 ± 10.02 a
	Cluster weight (g)			**Berries/cluster**		
Crop Level	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Low	91.4 ± 3.41 a	59.6 ± 5.49 a	53.4 ± 6.60 a	49.9 ± 1.13 a	46.4 ± 3.28 a	34.9 ± 2.75 a
Medium	75.7 ± 4.73 b	51.6 ± 4.14 a	51.1 ± 3.83 a	43.7 ± 1.76 a	43.8 ± 2.80 a	34.3 ± 2.93 a
High	63.7 ± 7.11 b	47.3 ± 3.28 a	36.0 ± 3.95 b	45.4 ± 5.15 a	44.9 ± 4.70 a	28.8 ± 3.29 a
Control	67.7 ± 3.52 b	54.3 ± 5.41 a	43.0 ± 3.01 b	48.0 ± 7.31 a	52.2 ± 3.34 a	35.4 ± 2.72 a
	Berry weight (g)			**Yield/hectare (t)**		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**
Low	1.83 ± 0.04 a	1.28 ± 0.04 a	1.52 ± 0.07 a	5.5 ± 0.03 b	4.7 ± 0.44 b	4.7 ± 0.53 a
Medium	1.73 ± 0.05 a	1.17 ± 0.02 b	1.50 ± 0.06 a	6.4 ± 0.35 a	6.3 ± 0.61 ab	5.5 ± 0.44 a
High	1.41 ± 0.08 b	1.07 ± 0.06 b	1.34 ± 0.04 ab	7.9 ± 0.65 a	7.3 ± 0.36 a	5.4 ± 0.55 a
Control	1.48 ± 0.16 ab	1.04 ± 0.08 b	1.22 ± 0.04 b	8.4 ± 0.84 a	7.8 ± 0.72 a	5.8 ± 1.22 a
	Yield/vine (kg)			**Pruning weight/vine (kg)**		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**
Low	2.5 ± 0.02 b	2.2 ± 0.21 b	2.2 ± 0.25 a	0.78 ± 0.04 a	0.69 ± 0.06 a	0.75 ± 0.05 a
Medium	3.0 ± 0.16 a	2.9 ± 0.29 ab	2.5 ± 0.21 a	0.73 ± 0.05 a	0.61 ± 0.05 a	0.62 ± 0.05 ab
High	3.7 ± 0.30 a	3.4 ± 0.17 a	2.5 ± 0.26 a	0.66 ± 0.10 a	0.54 ± 0.06 a	0.63 ± 0.09 ab
Control	3.9 ± 0.39 a	3.6 ± 0.33 a	2.7 ± 0.57 a	0.63 ± 0.05 a	0.52 ± 0.06 a	0.59 ± 0.05 b
	Crop load (yield/pruning weight)			**Pressed juice soluble solids (Brix)**		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**
Low	3.3 ± 0.15 c	3.2 ± 0.12 c	2.9 ± 0.30 b	19.6 ± 0.52 a	19.9 ± 0.19 a	21.4 ± 0.24 a
Medium	4.1 ± 0.11 b	4.8 ± 0.26 b	4.1 ± 0.20 a	19.4 ± 0.42 a	19.5 ± 0.31 a	20.3 ± 0.22 b
High	5.7 ± 0.49 a	6.6 ± 0.88 ab	4.2 ± 0.53 ab	17.5 ± 0.61 b	18.2 ± 0.37 b	19.5 ± 0.48 b
Control	6.3 ± 0.68 a	7.0 ± 0.46 a	4.6 ± 0.86 ab	17.1 ± 0.48 b	17.8 ± 0.44 b	19.1 ± 0.32 b
	Pressed juice pH			**Pressed juice titratable acidity (TA, g/L)**		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**
Low	3.43 ± 0.04 a	2.98 ± 0.01 a	2.81 ± 0.01 b	8.6 ± 0.63 a	12.0 ± 0.08 a	8.2 ± 0.02 a
Medium	3.46 ± 0.02 a	2.99 ± 0.01 a	2.86 ± 0.01 a	7.6 ± 0.15 a	12.0 ± 0.08 a	8.3 ± 0.03 a
High	3.48 ± 0.10 a	3.01 ± 0.00 a	2.85 ± 0.00 a	7.4 ± 0.19 a	11.7 ± 0.31 a	8.3 ± 0.06 a
Control	3.45 ± 0.01 a	2.99 ± 0.00 a	2.85 ± 0.01 a	7.5 ± 0.03 a	12.0 ± 0.06 a	8.3 ± 0.05 a
	Wine pH		**Wine TA (g/L)**		**Wine alcohol (% v/v)**	
	2009	**2010**	**2009**	**2010**	**2009**	**2010**
Low	2.87 a	3.07 a	11.1 a	9.8 a	9.3 a	10.0 a
Medium	2.86 a	3.09 a	11.0 a	10.0 a	9.8 a	10.2 a
High	2.85 a	3.09 a	11.2 a	10.0 a	9.6 a	10.3 a
Control	2.86 a	3.07 a	11.3 a	9.9 a	9.5 a	10.1 a

[a]Eichorn-Lorenz stage 31 of shoot development, when at least two-thirds of berries reached pea-size, about six mm diameter
[b]Low: 1 cluster/shoot remains; Medium: 1.5 clusters/shoot remain; High: 2 clusters/shoot remain; Control: non-thinned
[c]Analysis of variance was conducted through the General Linear Model (GLM) Procedure in SAS. Within year columns, means followed by different letters are significantly different at $p \leq 0.05$ by Fisher's least significant difference (LSD) test.

Table 3.2 Canopy characterization of Riesling in the Finger Lakes, NY, from 2008 to 2010, by Enhanced Point Quadrat Analysis (EPQA) metrics.[a] Cropping treatments were imposed by cluster thinning to varying crop levels at E-L stage 31.[b] Data shown were collected at E-L stage 35.[c] Each value is an average of four field replicates ± standard error.

	OLN[f]			CEL[g]			CEFA[h]		
Crop Level[d]	**2008[e]**	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Low	3.28±0.24a	2.93±0.10a	2.95±0.15a	1.07±0.05a	0.85±0.08a	0.70±0.09a	0.18±0.04a	0.28±0.03b	0.21±0.01a
Medium	3.06±0.21a	2.87±0.16a	2.61±0.16b	0.99±0.09a	0.82±0.06a	0.64±0.11a	0.23±0.03a	0.29±0.01b	0.25±0.04a
High	2.73±0.15a	2.84±0.13a	2.49±0.08b	0.95±0.08a	0.81±0.05a	0.66±0.07a	0.23±0.02a	0.32±0.03b	0.24±0.02a
Control	2.71±0.17a	2.74±0.29a	2.52±0.01b	0.98±0.09a	0.70±0.08a	0.58±0.17a	0.26±0.04a	0.39±0.03a	0.32±0.10a

[a]Meyers and Vanden Heuvel 2008
[b]Eichorn-Lorenz stage 31 of shoot development, when at least two-thirds of berries reached pea-size, about six mm diameter
[c]Eichorn-Lorenz stage 35 of shoot development, when at least two-thirds of berries reached early ripening phase, or veraison
[d]Low: 1 cluster/shoot remains; Medium: 1.5 clusters/shoot remain; High: 2 clusters/shoot remain; Control: non-thinned
[e]Analysis of variance was conducted through SAS GLM Proc and within year columns means followed by different letters are significantly different at $p \leq 0.05$ by Fisher's LSD.
[f]Occlusion Layer Number: a measure of the overall shade-producing biomass (clusters and leaves) density of a canopy
[g]Cluster Exposure Layer: the number of occlusion (shading) layers between clusters and their nearest canopy boundary
[h]Cluster Exposure Flux Availability: percentage of the available above-canopy photon flux that reaches clusters

Grower net returns in 2008 ranged from \$8,261/ha to \$16,414/ha at low crop and control respectively, from \$4,688/ha to \$12,029 respectively in 2009, and from \$4,936/ha to \$7,613 respectively in 2010 (Table 3.4). Compared to the base market price of \$2,660/t (or \$5.45 cost per bottle) the minimum price required to recoup costs for low crop grapes in 2008 was \$4,142/t (\$8.49/bottle), a 56% price increase. Compared to the base market price of \$2,350/t (\$4.82/bottle) in 2009 the minimum price for low crop grapes was \$3,991/t (\$8.18/bottle), a 70% price increase. And compared to the base market price of \$2,400/t (\$4.92/bottle) in 2010 the minimum price required for low crop grapes was \$3,050/t (\$6.25/bottle), a 27% price increase. If grapes were retained for winemaking by the grower rather than sold, based on the yields of these experimental conditions the additional cost per bottle of finished wine required to recoup costs of CT at the low crop level was \$3.03/bottle in 2008, \$3.36 in 2009 and \$1.33 in 2010. The elicited average WTP by NYC wine professionals was \$13.40 per bottle in 2009 and \$14.99 per bottle in 2010 however there were no differences in WTP among crop levels in either year.

Sensory panel ratings for 2009 wines revealed reduced fruitiness in medium crop wines and reduced structure or mouthfeel in low crop wines but no differences in likability ratings or any other attributes (Figure 3.2). The same panel reported no differences among crop levels for any sensory or preference attributes in 2010 wines (Figure 3.3). Grower net returns plotted as a function of CT and elicited NYC WTP in 2009 and 2010 were computed and response curves illustrated strongly negative and diminishing grower net returns based on actual WTP, thus no optimal level of CT could be derived based on the CT economic model in either year respectively (Figures 3.4 and 3.5).

Table 3.3 Production costs, price, yield and revenue parameters for late harvest Riesling in the Finger Lakes, NY, from 2008 to 2010, as expressed by metrics of previously published CT economic model.[a] Cropping treatments were imposed by CT to varying crop levels at E-L stage 31.[b] Yield data are shown at harvest. Fixed and variable costs are based on maintaining one hectare of *V. vinifera* in the Finger Lakes for one year.[c]

	Potential yield before CT[e] (t/ha)			Expected market price before CT[f] ($/t)			Potential revenue before CT[g] ($/ha)		
Crop Level[d]	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Low	8.4	7.8	5.8	2660	2350	2400	22,344	18,330	13,920
Medium	8.4	7.8	5.8	2660	2350	2400	22,344	18,330	13,920
High	8.4	7.8	5.8	2660	2350	2400	22,344	18,330	13,920
Control	8.4	7.8	5.8	2660	2350	2400	22,344	18,330	13,920
	Actual yield after CT (t/ha)[h]			**Actual revenue after CT[i] ($/ha)**			**Production cost before CT[j] ($/ha)**		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Low	5.5	4.7	4.7	14,630	11,045	11,280	5,930	5,930	5,930
Medium	6.4	6.3	5.5	17,024	14,805	13,200	5,930	5,930	5,930
High	7.9	7.3	5.4	21,014	17,155	12,960	5,930	5,930	5,930
Control	8.4	7.8	5.8	22,344	18,330	13,920	5,930	5,930	5,930
	Production cost before CT[k] ($/t)			**Additional production cost with CT[l] ($/ha)**			**Total production cost with CT[m] ($/ha)**		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Low	706	760	1,022	439	426	414	6,369	6,357	6,344
Medium	706	760	1,022	408	389	395	6,338	6,320	6,326
High	706	760	1,022	371	371	377	6,301	6,301	6,307
Control	706	760	1,022	0	0	0	5,930	5,930	5,930
	Total production cost with CT ($/t)			**Change in revenue, thinned fruit[n] ($/ha)**			**Change in revenue, thinned fruit ($/t)**		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Low	786	851	1,111	-7,714	-7,285	-2,640	-1,403	-1,550	-562
Medium	770	822	1,094	-5,320	-3,525	-720	-831	-560	-131
High	753	811	1,092	-1,330	-1,175	-960	-168	-161	-178
Control	706	760	1,022	0	0	0	0	0	0

[a]Preszler et al. 2010
[b]Eichorn-Lorenz stage 31 of shoot development, when at least two-thirds of berries reached pea-size, about six mm diameter
[c]White 2008
[d]Low: 1 cluster/shoot remains; Medium: 1.5 clusters/shoot remain; High: 2 clusters/shoot remain; Control: non-thinned
[e]Yield of Control field replicates (non-thinned) from Table 3.1
[f]Estimated market price of late harvest Riesling, personal communication, Hans Walter-Peterson, Cornell Cooperative Extension
[g]Potential yield before CT multiplied by expected market price before CT
[h]From Table 3.1
[i]Expected market price before CT multiplied by actual yield after CT
[j]Based on published cost of all viticultural practices on one hectare of *V. vinifera* in the Finger Lakes for one year (White 2008)
[k]Production cost before CT divided by potential yield before CT
[l]Based on published costs of CT practices for one hectare of *V. vinifera* in the Finger Lakes (White 2008).
[m]Fixed production costs before CT plus additional production costs with CT
[n]Actual revenue after CT minus potential revenue before CT

Table 3.4 Grower net return analysis for late harvest Riesling in the Finger Lakes, NY, from 2008 to 2010, as expressed by metrics of previously published CT economic model.[a] Four crop level field replicates were imposed by CT to varying levels at E-L stage 31.[b] Costs are based on the average wine volume after pressing fruit and maintaining one hectare of *V. vinifera* in the Finger Lakes for one year.[c]

	Grower net returns[e] ($/ha)			**Net returns constant[f] ($/t)**			**Net returns constant[g] ($/bottle)**		
Crop Level[d]	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Low	8,261	4,688	4,936	4,142	3,991	3,050	8.49	8.18	6.25
Medium	10,686	8,485	6,874	3,555	2,971	2,603	7.28	6.09	5.33
High	14,713	11,225	7,030	2,875	2,562	2,648	5.89	5.25	5.43
Control	16,414	12,029	7,613	2,660	2,350	2,400	5.45	4.82	4.92

	Price differential after CT[h] ($/bottle)			**Maximum NYC WTP[i] ($/bottle)**		
Crop Level	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Low	3.03	3.36	1.33	n/a	11.70 a	14.70 a
Medium	1.83	1.27	0.42	n/a	13.37 a	14.11 a
High	0.44	0.43	0.51	n/a	13.78 a	15.63 a
Control	0	0	0	n/a	14.74 a	15.52 a

[a]Preszler et al. 2010. Production costs, price, yield and revenue data parameters are outlined in Table 3.3
[b]Eichorn-Lorenz stage 31 of shoot development, when at least two-thirds of berries reached pea-size, about six mm diameter
[c]White 2008
[d]Low: 1 cluster/shoot remains; Medium: 1.5 clusters/shoot remain; High: 2 clusters/shoot remain; Control: non-thinned
[e]Actual revenue after CT minus total production cost after CT (Table 3.3)
[f]Market price a commercial grape grower would need to charge in order to maintain constant net returns. Calculated as expected price before CT plus additional production cost with CT plus change in revenue from thinned fruit ($/t).
[g]Base minimum market price a winery would need to charge per bottle of wine to maintain constant net returns. Calculated as net returns constant per tonne of grapes divided by the actual average wine volume after pressing fruit from this experiment (366.3 L wine or 488 bottles or 40 cases).
[h]Price differential per 750 mL bottle of wine produced after CT if grower does not sell grapes but rather retains them for winemaking.
[i]Maximum willingness to pay for one 750 mL bottle as elicited in a blind tasting of CT experiment wines by 27 New York City wine industry professionals. Wines were not made in 2008. Mean responses for each year were separately analyzed by two-way ANOVA with panelist ID and CT treatment set as independent variables. Subsequently, significant treatment effects were analyzed by multiple comparisons test with Tukey adjustment. Within each year, means followed by different letters are significantly different at $p \leq 0.05$.

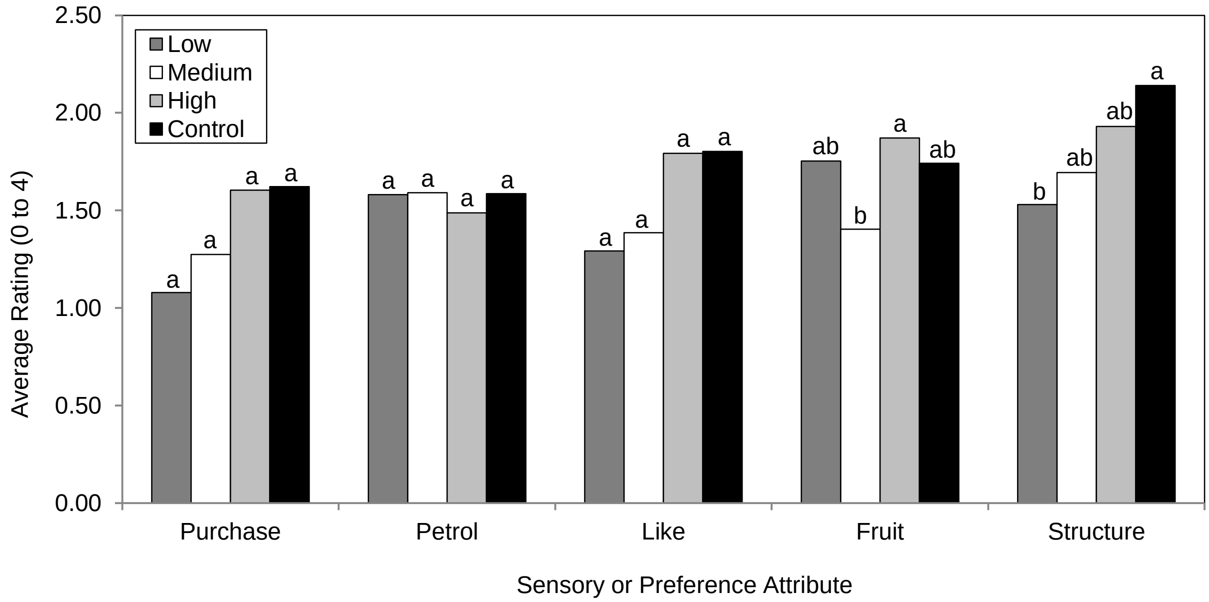

Figure 3.2 Sensory evaluation and preference rating by New York City wine industry professionals of late harvest Finger Lakes Riesling wines made in 2009 from vines cropped to varying levels by cluster thinning at E-L stage 31. Measurements are the mean of responses by 27 sensory panelists and wines are composites of four crop level field replicates. Data were analyzed by two-way ANOVA with panelist ID and CT treatment set as independent variables, and significant treatment effects were analyzed by multiple comparisons test with Tukey adjustment. Within each attribute, means followed by different letters are significantly different at $p \leq 0.05$.

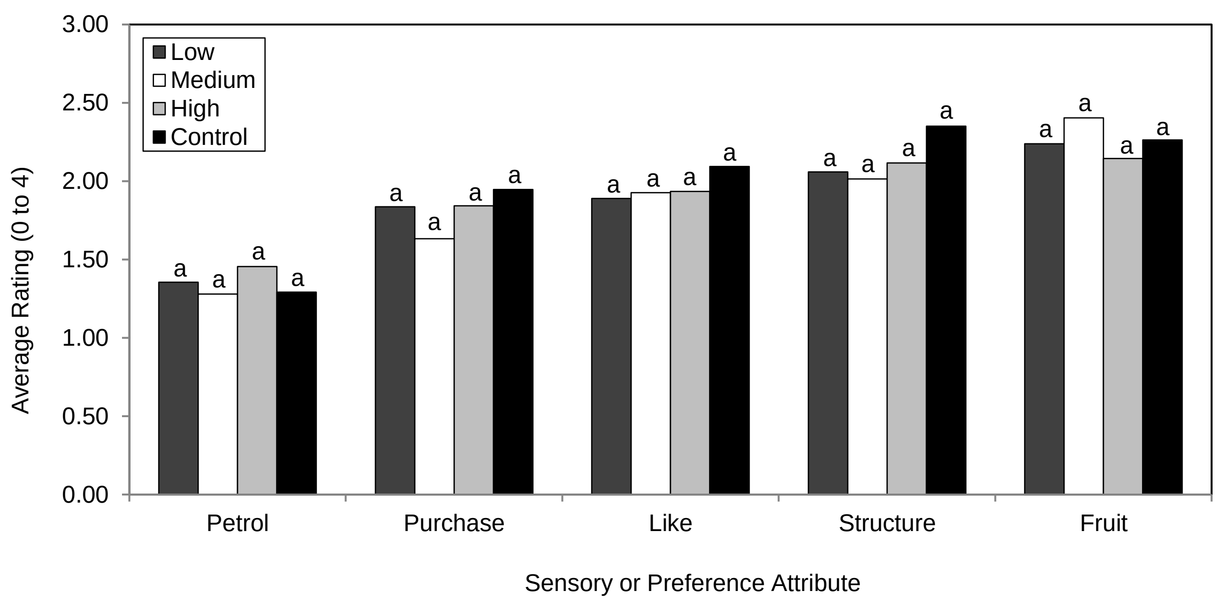

Figure 3.3 Sensory evaluation and preference rating by New York City wine industry professionals of late harvest Finger Lakes Riesling wines made in 2010 from vines cropped to varying levels by cluster thinning at E-L stage 31. Measurements are the mean of responses by 27 sensory panelists and wines are composites of four crop level field replicates. Data were analyzed by two-way ANOVA with panelist ID and CT treatment set as independent variables, and significant treatment effects were analyzed by multiple comparisons test with Tukey adjustment. Within each attribute, means followed by different letters are significantly different at $p \leq 0.05$.

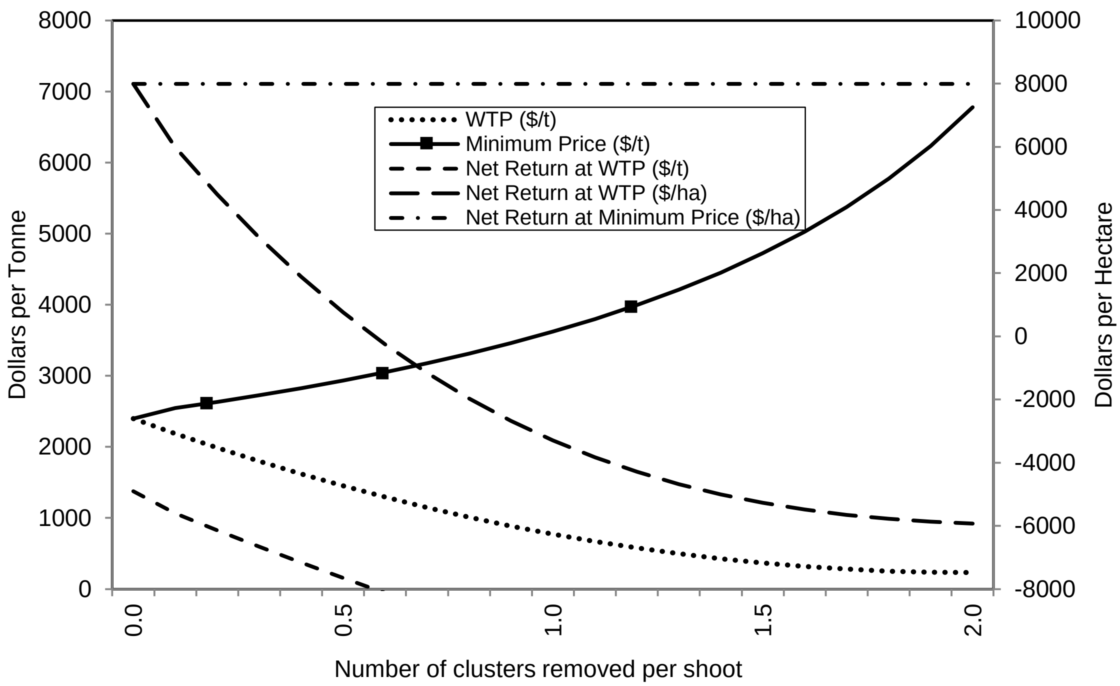

Figure 3.4 Grower net returns in 2009, computed by a previously published CT economic model, as a function of the level of CT and its effects on actual willingness to pay for 2009 late harvest Riesling wines, as elicited from NYC wine industry professionals in a WTP sensory trial. Data points on minimum price response curve represent low, medium and high crop levels based on the control yields of 7.8 t/ha harvested in 2009.

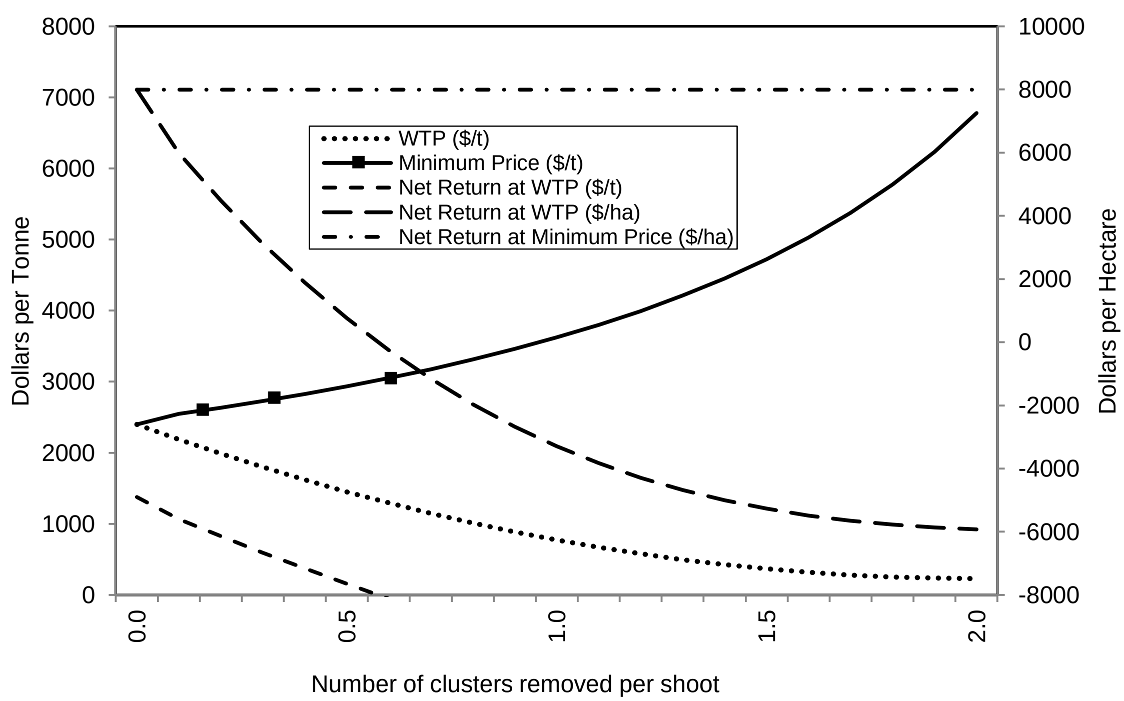

Figure 3.5 Grower net returns in 2010, computed by a previously published CT economic model, as a function of the level of CT and its effects on actual willingness to pay for 2010 late harvest Riesling wines, as elicited from NYC wine industry professionals in a WTP sensory trial. Data points on minimum price response curve represent low, medium and high crop levels based on the control yields of 5.8 t/ha harvested in 2010.

Discussion

Reproductive growth and fruit composition

The principle reason grape growers apply CT is to manage crop load for advanced ripening or increased soluble solids accumulation, which has benefits for regions with shortened growing seasons. In this experiment CT predictably increased juice soluble solids accumulation in the low and medium crop levels which was consistent with other observations for *V. vinifera* (Arfelli et al. 1996; Bowen 2011; Murisier and Ziegler 1991; Nuzzo and Matthew 2006; Reynolds 1989; Reynolds et al. 1994a, 1994b). Pressed juice soluble solids at the low crop level all three years did not reach the 22 Brix threshold as expected based on observations of other comparably cropped vines in the same commercial vineyard. This could be the result of pests consuming the ripest berries late in the season, as the cooperating grower did not install bird netting and pressure in the remaining LH vines intensified as the rest of the surrounding vineyards had been harvested, or soluble solids may have been underestimated as a function of raisined fruit which may have inhibited full sugar extraction from whole clusters in a small-scale (40 L) bladder press (Zoecklein et al. 1990). In order to maintain consistency in experimental protocol the grapes were not allowed skin contact to further enhance sugar extraction (Jones and Ough 1985). Nevertheless, in this experiment as in many others there seems to be little disputing that CT advances ripening. In some regions outside NY such as Ontario, Canada, growers are paid for bulk Riesling grapes based on a mandatory price schedule of soluble solids, and if such a regulated price structure were used in NY for this study it would have resulted in a $244, $273 and $286 per tonne price premium in each respective year (Gedeon 2012), not enough to offset the change in grower net returns.

The effects of CT on yield components were mostly predictable with cluster number per shoot and per vine reduced according to severity of CT treatment. There were positive effects on berry weight and cluster weight from within-year CT treatments in 2008 and 2010 which is consistent with previous observations of CT in Riesling (Reynolds 1989; Reynolds et al. 1994a) but inconsistent with observations in an arid climate (Keller et al. 2005). In 2009, a relatively cool and wet year, differences in yield among CT treatments were due to reduced cluster number per vine, but in 2008 and 2010 cluster weight and berry weight were highest at the low and medium crop levels, which is consistent with other reports for white *V. vinifera* (Reynolds and Wardle 1989; Reynolds 1989; Reynolds et al. 1994a). In 2010 yield was equivalent among all treatments, ranging from 4.7 to 5.8 t/ha, which may have been an indicator of vine carbohydrate reserves declining following two previous years of relatively high crop level between 7.3 and 8.4 t/ha. The crop load of control vines in this vineyard over all three years was generally quite low (ranging from 4.6 to 7.0) even though corresponding pruning weights were relatively large (ranging from 0.52 to 0.63 kg).

Vegetative growth and canopy characterization

Low crop vines exhibited more vigorous canopy growth and higher pruning weight in 2010 which is consistent with the literature for white *V. vinifera* (Reynolds and Wardle 1989; Reynolds et al. 1994a), however in 2008 and 2009 pruning weights were not affected by CT. Low crop vines in 2010 exhibited significantly higher OLN indicating more total biomass density (leaves, shoots, clusters) in the fruiting zone likely due to excessive growth of laterals and non-count shoots. Control vines in 2009 exhibited higher CEFA which is consistent with other observations for CT effects on CEFA (Sun et al. 2012) and indicates that control vines had less vigorous canopies and more cluster sunlight exposure than lower crop levels. Reduced CEFA in lower cropped vines could affect the health of the vineyard as well, particularly in regions with high rainfall, as a shaded fruiting zone could increase pressure from powdery mildew (Austin et al. 2011). As such, lower cropped vines may require other management tools such as shoot positioning and leaf-pulling in the fruiting zone, which were not applied under these research conditions but would increase production costs beyond those modeled here.

Economic analysis and wine sensory WTP panel

Commercial growers are motivated to recoup costs incurred from CT and maintain consistent net returns, and the only way to do this is to charge above-market prices for grapes if buyers are willing to pay a premium. Without such a break-even point there will be a financial disincentive to employ CT as a viticultural practice. In 2008 grower net returns were positive at the control crop level but fruit from those vines only reached 17.1 Brix, and the low crop level (19.6 Brix) would have required a 56% price increase to recoup costs of CT. In 2009 the control did not reach 18 Brix and the low crop had reduced net returns compared to the control, so the sustainable level of crop would need to balance considerations of ripeness and financial returns. In 2010 all crop levels had positive net returns and all reached over 19 Brix at harvest so the most sustainable crop level was the one that maximized yields. The lowest crop level was most financially perilous, showing negative financial net returns that required 56%, 70%, and 27% grape price increases compared to the control each respective year, not including any possible increased risks associated with late harvest, such as grapevine pest and disease management. It is unlikely that such large price increases would be tolerated by the market or justified by improved grape quality enough to outweigh the financial costs of implementing the practice. If the profit-motivated grower had kept the grapes for winemaking instead of selling them at inflated market prices, there would need to be assurances of higher consumer WTP for LH wines to justify the financial losses caused by CT. Nonetheless, a panel of NYC wine professionals reported no difference in WTP or likability for any crop levels in 2009 and 2010, and the only perceived differences among wines either year were the 2009 low crop with reduced structure and 2009 medium crop with reduced fruitiness. Although wine aroma chemistry was not measured in this study, it does not seem that these results lend support to other CT studies generally citing yield as a predictor of aromatic intensity (Eschenbruch et al. 1987; McCarthy 1986; Reynolds et al. 2007; Reynolds and Wardle 1989).

Low and medium cropped vines led to substantially smaller grower financial net returns. Under these experimentally imposed yield and cost conditions in order for the grape grower to break even financially there would need to be an impetus to charge more for each bottle of wine to recoup the costs of CT. Such a price increase could only be warranted by higher consumer WTP for wines made from lower cropped vines. The consumer preference elicitation technique applied here has been reported previously as a reliable tool for assessing WTP in wine (Yang et al. 2009). Panelists were asked to cite the retail price they would normally pay for a 750 mL bottle of LH Riesling and answers ranged from $15 to $30/bottle with an average of $22.41/ bottle, well above the average WTP for LH wines grown in this study. Perhaps the lower WTP for these experimental wines was due to the fact that they did not undergo typical commercial finishing techniques such as enzyme additions, acid and sugar adjustments, or filtering. When actual NYC WTP results were entered into the previously published CT economic model (Figure 3.4 and 3.5), conditional on a relatively small sample size (27), the resulting response curves for grower net returns based on WTP were strongly negative, and as such no optimal level of CT beyond zero (non-thinned) existed and the model demonstrated grower financial net returns based on WTP decreased from the first unit of CT.

Conclusion

This three year study examined the effects of cluster thinning on various fruit, wine, sensory, and economic parameters of a commercial Riesling vineyard in the Finger Lakes, NY, to understand how CT can be justified as part of a sustainable viticulture program for late harvest winemaking. Despite having higher soluble solids at harvest, which are not valued economically in the Finger Lakes as they are in other regions, vines with crop load below 5 led to large financial losses for the grower due to the substantially lower yields harvested. According to surveyed NYC wine industry professionals, wines made from vines at varying crop levels were neither preferred nor likely to garner any price increase per bottle. Thus the results presented herein, conditional upon research parameters cited relating to sample size, vineyard site and cultivar, demonstrated that CT practices designed to reduce yields for fruit or wine quality purposes also reduce grower financial net return, and since CT did not result in enhanced quality ratings or higher WTP, the costs of implementing CT were not financially justifiable.

REFERENCES

Arfelli, G., R. Zironi, B. Marangoni, A. Amati, and M. Castellari. 1996. The effects of cluster thinning on some ripening parameters and wine quality. Acta Hortic. 427:379-385.

Austin, C.N., G.G. Grove, J.M. Meyers, and W.F. Wilcox. 2011. Powdery mildew severity as a function of canopy density: associated impacts on sunlight penetration and spray coverage. Am. J. Enol. Vitic. 62:23-31.

Bowen, P., C. Bogdanoff, K. Usher, B. Estergaard, and M. Watson. 2011. Effects of irrigation and crop load on leaf gas exchange and fruit composition in red winegrapes grown on a loamy sand. Am. J. Enol. Vitic. 62:9-22.

Brennan, C.S., and V. Kuri. 2002. Relationship between sensory attributes, hidden attributes and price in influencing consumer perceptions of organic foods. *In* UK organic research: Proceedings of the COR Conferences. J. Powell et al. (eds.), pp. 65-68. Aberystwyth, UK.

Bravdo, B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. 1984. Effect of crop level on growth, yield and wine quality of a high yielding Carignane vineyard. Am. J. Enol. Vitic. 35:247-252.

Bravdo, B., Y. Hepner, C. Loinger, S. Cohen, and H. Tabacman. 1985. Effect of crop level and crop load on growth, yield, must and wine composition, and quality of Cabernet Sauvignon. Am. J. Enol. Vitic. 36:125-131.

Chapman, D.M., M.A. Matthews, and J.X. Guinard. 2004. Sensory attributes of Cabernet Sauvignon wines made from vines with different crop yields. Am. J. Enol. Vitic. 55:325-334.

Clary, C., A. Gamache, M. Cliff, J. Fellman, and C. Edwards. 2006. Flavor and aroma attributes of Riesling wines produced by freeze concentration and microwave vacuum dehydration. J. Food Proc. Preserv. 30:393-406.

Cliff, M.A., D. Yuksel, B. Girard, and M.A. King. 2002. Characterization of Canadian ice wines by sensory and compositional analyses. Am. J. Enol. Vitic. 53:46-53.

Eschenbruch, R., R.E. Smart, B.M. Fisher, and J.G. Whittles. 1987. Influence of yield manipulations on the terpene content of juices and wines of Müller-Thurgau. *In*

Proceedings of the 6th Australian Wine Industry Technical Conference. T. Lee (ed.), pp. 89-93. Australian Industrial Publishers, Adelaide.

Gal, Y., A. Naor, and B. Bravdo. 1996. Effect of shoot density, crop level and crop load on fruit and wine quality of Sauvignon Blanc grapes. Acta Hortic. 427:151-159.

Gedeon, J. 2012. Two-year deal sets bulk prices for most popular varietals in Ontario. Wine Business Monthly, April 11.

Hughson, A.L., and R.A. Boakes. 2002. The knowing nose: The role of knowledge in wine expertise. Food Qual. Pref. 13:463-472.

International Riesling Foundation. 2012. Riesling taste profile. http://drinkriesling.com/. Accessed March 25, 2012.

Jackson, D.I., and P.B. Lombard. 1993. Environmental and management practices affecting grape composition and wine quality – a review. Am. J. Enol. Vitic. 44:409-430.

Jaeger, S.R., and F.R. Harker. 2005. Consumer evaluation of novel Kiwifruit: Willingness to pay. J. Sci. Food Agric. 85:2519-2526.

Jones, R.S., and C.S. Ough. 1985. Variations in the percent ethanol (v/v) per °Brix conversions of wines from different climatic regions. Am. J. Enol. Vitic. 36:268-270.

Keller, M., L.J. Mills, R.L. Wample, and S.E. Spayd. 2005. Cluster thinning effects on three deficit-irrigated Vitis vinifera cultivars. Am. J. Enol. Vitic. 56:91-103.

Keller, M., R.P. Smithyman, and L.J. Mills. 2008. Interactive effects of deficit irrigation and crop load on Cabernet Sauvignon in an arid climate. Am. J. Enol. Vitic. 59:221-234.

Kontkanen, D., D.L. Inglis, G.J. Pickering, and A. Reynolds. 2004. Effect of yeast inoculation rate, acclimatization, and nutrient addition on icewine fermentation. Am. J. Enol. Vitic. 55:363-370.

Lakso, A.N., and D.M. Eissenstat. 2005. Crop load – physiology, modelling and relationships to root growth in grapevines. In Proceedings of the Twelfth Australian Wine Industry Technical Conference, pp. 38-44. Australian Society of Viticulture and Oenology, Melbourne.

Lawless, H.T. 1984. Flavor description of white wine by "expert" and nonexpert wine consumers. J. Food Sci. 49:120-123.

Lawless, H.T. and H. Heymann. 1998. Sensory evaluation of foods, principles and practices. Springer, New York.

Lesschaeve, I. 2007. Sensory evaluation of wine and commercial realities: Review of current practices and perspectives. Am. J. Enol. Vitic. 58:252-258.

Lusk, J.L., and D. Hudson. 2004. Willingness-to-pay estimates and their relevance to agribusiness decision making. Rev. Agric. Econ. 26:152-169.

McCarthy, M.G. 1986. Influence of irrigation, crop thinning, and canopy manipulation on composition and aroma of Riesling grapes. M.Sc. Thesis, University of Adelaide, Australia.

Meyers, J.M., and J.E. Vanden Heuvel. 2008. Enhancing the precision and spatial acuity of point quadrat analyses via calibrated exposure mapping. Am. J. Enol. Vitic. 59:425-431.

Murisier, F. and R. Ziegler. 1991. Effets de la charge en bourgeons et de la densité de plantation sur la potentiel de production, sur la qualité du raisin et sur le developpement vegetatif. Essais sur Chasselas. Rev. Suisse Vitic. Arboric. Hortic. 23:277-282.

Naor, A., Y. Gal, and B. Bravdo. 2002. Shoot and cluster thinning influence vegetative growth, fruit yield, and wine quality of Sauvignon Blanc grapevines. J. Am. Soc. Hortic. Sci. 127:628-634.

Nestrud, M.A., and H.T. Lawless. 2008. Perceptual mapping of citrus juices using projective mapping and profiling data from culinary professionals and consumers. Food Qual. Pref. 19:431-438.

Nuzzo, V., and M.A. Matthews. 2006. Response of fruit growth and ripening to crop level in dry-farmed Cabernet Sauvignon on four rootstocks. Am. J. Enol. Vitic. 57:314-324.

Preszler, T., and T.M. Schmit. 2009. Factors affecting wine purchase decisions and presence of New York wines in upscale New York City restaurants. J. Food. Dist. Rsrch. 40:16-30.

Preszler, T., T.M. Schmit, and J.E. Vanden Heuvel. 2010. A model to establish economically sustainable cluster-thinning practices. Am. J. Enol. Vitic. 61:140-146.

Ravaz, M.L. 1911. L'effeuillage de la vigne. Ann. l'École Nat. Agric. Montpellier 11:216-244.

Reynolds, A.G. 1989. Riesling grapes respond to cluster thinning and shoot density manipulation. J. Am. Soc. Hortic. Sci. 114:364-368.

Reynolds, A.G. and D.A. Wardle. 1989. Impact of various canopy manipulation techniques on growth, yield, fruit composition, and wine quality of Gewürztraminer. Am. J. Enol. Vitic. 40:121-129.

Reynolds, A.G., C.G. Edwards, D.A. Wardle, D.R. Webster, and M. Dever. 1994a. Shoot density affects Riesling grapevines I: vine performance. J. Am. Soc. Hortic. Sci. 119:874-880.

Reynolds, A.G., S.F. Price, D.A. Wardle, and B.T. Watson. 1994b. Fruit environment and crop level effects on Pinot Noir I: vine performance and fruit composition in British Columbia. Am. J. Enol. Vitic. 45:452-459.

Reynolds, A.G., J. Schlosser, D. Sorokowsky, R. Roberts, J. Willwerth, and C. De Savigny. 2007. Magnitude of viticultural and enological effects II: relative impacts of cluster thinning and yeast strain on composition and sensory attributes of Chardonnay Musqué. Am. J. Enol. Vitic. 58:25-41.

Skurray, G., and J. Lawson. 2001. Eiswein without the frosts. Aust. Grape. Wine. 449:49-52.

Smith, J.P., and B.P. Holzapfel. 2009. Cumulative responses of Semillon grapevines to late season perturbation of carbohydrate reserve status. Am. J. Enol. Vitic. 60:461-470.

Sun, Q., G.L. Sacks, S.D. Lerch, and J.E. Vanden Heuvel. 2012. Impact of shoot and cluster thinning on yield, fruit composition, and wine quality of Corot noir. Am. J. Enol. Vitic. 63:49-56.

Tardaguila, J., P.R. Petrie, S. Poni, M.P. Diago, and F. Martinez de Toda. 2008. Effects of mechanical thinning on yield and fruit composition of Tempranillo and Grenache grapes trained to a vertical shoot-positioned canopy. Am. J. Enol. Vitic. 59:412-417.

Umberger, W.J., and D.M. Feuz. 2004. The usefulness of experimental auctions in determining consumers' willingness-to-pay for quality-differentiated products. Rev. Agric. Econ. 26:170-185.

Wine Market Council. 2009. The U.S. wine market: consumer trends and analysis. Wine Market Council, San Francisco.

White, G.B. 2008. Cost of establishment and production of vinifera grapes in the Finger Lakes region of New York – 2007. Cornell University Department of Applied Economics and Management Extension Bulletin 2008-05.

Yang, N., J.J. McCluskey, and C. Ross. 2009. Willingness to pay for sensory properties in Washington State red wines. J. Wine Econ. 4:81-93.

Zoecklein, B.W., K.C. Fugelsang, B.H. Gump, and F.S. Nury. 1990. Production wine analysis. Van Nostrand Reinhold, New York.