PALISSAGE: AN ALTERNATIVE TO MECHANICAL HEDGING IN VITIS VINIFERA VINEYARDS

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment of the Requirements for the Degree of

Master of Science

by

Justin Allen France

January 2017

ABSTRACT

Hedging grapevines is a common canopy management practice in Northeast vineyards. Hedging can manipulate vine vigor, yield, fruit composition, wine quality, winter hardiness, and canopy microclimate. Although mechanical hedging is common practice in many vineyards, it is criticized as being a “Band-Aid solution” to vine vigor because it may stimulate lateral growth, resulting in a cycle of hedging and leaf removal that costs growers time and money.

Palissage is an alternative canopy management tool where long shoot tips were tucked or wrapped horizontally along the top of the canopy. Anecdotally, growers report that palissage initiated earlier cessation of shoot growth during the growing season and the technique reduced or eliminated the need for leaf removal in the fruiting zone due to fewer laterals.

Palissage trials were conducted on “Riesling” and “Cabernet Franc” (*Vitis vinifera* L.) in commercial vineyards in King Ferry (Finger Lakes region, New York) and Cutchogue (North fork of Long Island, New York), respectively. The trials at the two sites were randomized complete block designs, each with four replications. Three canopy management treatments were applied at King Ferry when shoots tips were 1 meter over the top wire: shoot tuck (ST), shoot wrap (SW), and hedging (Control). Two canopy management treatments were applied at Long Island when shoots tips were 1 meter over the top wire: shoot tuck (ST) and hedging (Control).

In King Ferry, shoot tuck and shoot wrap treatments reduced the number of laterals per vine by 32% and 34%, respectively, when compared to the control ($P < .0001$). Shoot tuck increased yield per vine by 1.3 kg ($P = 0.0041$), rachis length by 1.4 cm ($P = 0.0002$), and TA by 0.7 g/L ($P = 0.0236$), when compared to the control. Shoot tuck and shoot wrap decreased disease incidence from 2.5% to 0.0% in 2016, when compared to the control. A sensory panel ($n = 100$) detected aroma differences between wines made from shoot wrap and control treatments.

Palissage did not impact shoot length, shoot diameter, lateral diameter, or yield ($P < 0.05$) in Cabernet Franc at the Cutchogue site. Shoot tuck increased TA by 1.2 g/L ($P = 0.0007$) and increased YAN by 121.5 mg/L ($P < 0.0001$), when compared to the control.

This study suggests that palissage may be a viable alternative to hedging however further research is needed to elucidate the long-term impact of palissage on vines and management systems.

BIOGRAPHICAL SKETCH

Justin France was born and raised in Cobleskill, New York. Justin earned an Associate degree in Landscape Design and Construction at SUNY Cobleskill. He then moved to Galway, Ireland, where he managed an Irish language café that focused on local and sustainably sourced food. This piqued Justin's interest in local foods, and he took up a sustainability internship at the Spannocchia Foundation in Tuscany, Italy. While at Spannocchia, he had the opportunity to work with grapevines and his love for viticulture was born. Justin met his future wife at Spannocchia and they traveled back to New Zealand, her home country. He earned a BSc (Hons) in Horticultural Science at New Zealand's Massey University, focusing on vineyard management. He then became an Assistant Viticulturalist at Stanmore Farms in Ohau, New Zealand, where he oversaw the establishment and day-to-day running of the vineyard. Justin and his wife moved their family back to upstate NY in 2010 to pursue postgraduate degrees. He joined the Cornell University Department of Horticulture for his Masters studies, working with Dr. Justine Vanden Heuvel. Justin and his family are now moving back to New Zealand, where he will work in the grape and wine industry in North Auckland.

I dedicate this thesis to all my friends and family in New York, New Zealand and everywhere in between.

I want to thank my father, mother, brother, sister, and their families. In your own unique ways, you have inspired me to be the person I am today, and I love you all.

And to my wife Alice, and my daughters Siena and Rosa. You truly are the loves of my life. Without your love and support, I'd be lost.

ACKNOWLEDGEMENTS

Firstly, I would like to express my deep gratitude to Dr. Justine Vanden Heuvel for the opportunity to undertake the Palissage project. Justine was my mentor and an amazing support during my time at Cornell University.

I would like to thank Dr. Wayne Wilcox for his advice and guidance on grapevine disease as a committee member and as a professor. I would also like to thank Dr. James Meyers for his help with the MDS analysis and interpretation.

David Thompson and Erin Troxell at Bedell Cellars, and Thomas Bechtold and Cryus Parseghian at King Ferry Vineyards were indispensable collaborators, whose hard work was essential to the success of the trials.

I would like to thank Luann Preston-Wilsey for making our wine and helping in the vineyard (and for keeping Steve in line).

The help offered by Taylor Mattus, Ming-Yi Chou, Raquel Kallas, Anne Kearney, Hans Walter-Peterson, Steve Lerch, Katey Larwood, and Matt Minarchek not only ensured my success at Cornell, but provided life-long friendships. Thank you.

Funding for this research and thesis came from the New York State Viability Institute, and the Cornell University Horticulture Section.

TABLE OF CONTENTS

INTRODUCTION

Excessive vigor is often an issue for vineyards in the Northeastern region of the USA. This is especially true when the site has adequate access to water and fertile soils. Vines grown in these conditions develop long internodes, large leaves, and strong lateral growth (Wolf 2008; Smart and Robinson 1991). Excessive vigor causes extra shading in the fruit zone, resulting in increased disease incidence and severity due to reduced airflow, light exposure and spray penetration into the canopy (Austin and Wilcox 2011). Shading in the fruit zone can negatively impact wine chemistry by increasing pH and methoxypyrazine concentration (Scheiner et al. 2012), while lowering sugar content (Bledsoe et al. 1988), and polyphenol and anthocyanin levels (Morrison and Noble 1990). Ultimately, good vineyard practice requires growers in cool climates to manage vine canopies to reduce fruit shading and disease incidence (Wolf 2008).

Hedging, the removal of shoot tips from vertically shoot positioned vines, is a common canopy management practice in cool climate vineyards. Hedging can reduce vine vigor, yield, fruit composition, wine quality, winter hardiness, and canopy microclimate (Reynolds and Wardle 1989a; A. G. Reynolds and Wardle 1989b). Hedging significantly reduced °Brix, titratable acidity, and anthocyanins, potentially reducing wine quality in deChaunac (Reynolds and Wardle 1989b). Although mechanical hedging is common practice in many vineyards, it is criticized as being a “Band-Aid solution” to vine vigor because it may stimulate lateral growth, resulting in a cycle of hedging, and lateral and leaf removal that costs growers time and money (Smart and Robinson 1991).

Canopy hedging promotes lateral growth and emergence (Reynolds and Wardle 1989a). The loss of apical dominance stimulates lateral emergence and increases fruit zone shading (Komm and Moyer 2015), decreasing solar radiation interception and air movement, resulting in poor fruit ripening and increased disease severity (Zoecklein et al. 1992). There is conflicting information about the role that laterals play in grape ripening. Lateral leaf area can contribute to carbohydrate production, compensating for leaf area lost from hedging in VSP systems (Candolfi-Vasconcelos et al. 1994). However, lateral production can also potentially act as a sink, diverting carbohydrate from ripening fruit in GDC trained vines (Reynolds and Wardle 1989a). There is a need to develop alternative canopy management strategies that reduce lateral emergence in the fruit zone, fruit shading, and increase air movement, all which impact fruit development and juice chemistry.

Palissage is a canopy management technique that aims to eradicate the need for mechanical hedging. The technique involves either wrapping the shoots tips around the top catch wire or bending shoot tips back downward into the canopy. Growers in the Alsace and Burgundy regions of France, and the New York Finger Lakes region reported reduced cluster density, lateral growth, and vigor with no detrimental impacts to yield or increased disease severity. Furthermore, decreased vine vigor was a commonly reported phenomenon after several years of practicing palissage. In the future, these finding will need to be substantiated with well-designed experimentation.

Shoot wrapping was used as the control treatment for a study evaluating the impacts of delaying first hedging in *V. vinifera* Pinot Gris and Riesling (Molitor et al. (2015). The rational for using palissage was to preserve shoot tips for accurately quantifying pruning weights. The authors found that the shoot wrap treatment had no impact on yield or yield components, and increased °Brix in both Pinot Gris and Riesling, potentially improving juice chemistry. A criticism about shoot wrapping is the potential to increase disease severity because increased leaf density in the fruit zone and upper canopy. However, shoot wrap treatment had a lower cluster density index and fewer berries per cluster length (a measure of cluster compactness) in Pinot Gris when compared to some hedging treatments (Molitor et al. 2015). Shoot wrap did not increase *Botrytis cinerea* disease severity when compared to several of the hedging timings, mostly likely a function of lower cluster density (Molitor et al. 2015).

The objective of this study was to determine the impact of shoot wrapping and shoot tucking canopy management techniques on vine growth, fruit composition, and wine characteristics in a cool climate Riesling vineyard and Cabernet Franc vineyard. This study is the first to evaluate palissage as an alternative to mechanical hedging.

MATERIALS AND METHODS

Experimental Site 1: King Ferry, NY

Vineyard Site and Experimental Design

The study was conducted in 2015 and 2016 in an ~0.40 ha commercial vineyard block located ~830 m from the eastern shore of Cayuga Lake, King Ferry, NY, in the Finger Lakes American Viticultural Area (lat. 42°38'17.7"N; long. 76°38'36.9"W; 208 m asl). The vineyard soils have been classified as Aurora silt loam (Soil Survey Staff) on a 2 to 6% west-facing slope. *Vitis vinifera* L. cv. Riesling, unknown clone and rootstock (but based on neighboring blocks likely cl. 239 on 3309C), was planted in 1997. Vines were planted 1.8 m apart with 2.8-m row spacing; rows were planted perpendicular to the slope of the hill, with an orientation of 347°NNW.

The vines were pruned to four canes and trained on a single-tier vertical shoot-positioned trellis. Vines were shoot thinned to 7 buds per linear foot of canopy. Disease was controlled using standard practices for *V. vinifera* in the northeastern United States (Wolf 2008). Powdery mildew (*Erysiphe necator*) and downy mildew (*Plasmopara viticola*) were not observed in the vineyard because of disease management practices. The block was dry-farmed. Native vegetation was established undervine to suppress weeds.

Three canopy management treatments were established 2015. The vineyard block consisted of 12 ten-panel rows, and each experimental unit was four panels with four

vines per panel. The interior two panels were designated as treatment data collection panels.

The three canopy management treatments were replicated four times in a randomized complete block design: hedging (C, the control), shoot tucking (ST, tucking the growing shoot tip back into the canopy), and shoot wrapping (SW, wrapping growing shoot tip around the top trellis wire) (Figure 1). The treatments were applied on 30 June 2015 and 7 July 2016 when actively growing shoots were approximately 50 cm above the top trellis wire.

Climate Data

Climate data for the site were recorded from the Cornell University Network for Environment and Weather Applications (NEWA) Lansing station (newa.cornell.edu), located ~5.3 km south of the vineyard and at a similar elevation. Precipitation and temperature data from 1 April through 31 Oct were used to calculate rainfall and growing degree days (base threshold of 10°C) for each growing season.

Vegetative Growth

In late February of 2016 and December 2016, dormant vines were pruned to four canes with 10 nodes per cane, leaving 40 nodes per vine. The pruning weight of wood from the previous year was weighed for each vine with a hanging scale accurate to 0.1

kg (Salter Brecknell, SA3N340). This value and yield from the previous year were then used to calculate the Ravaz index (yield/pruning weight).

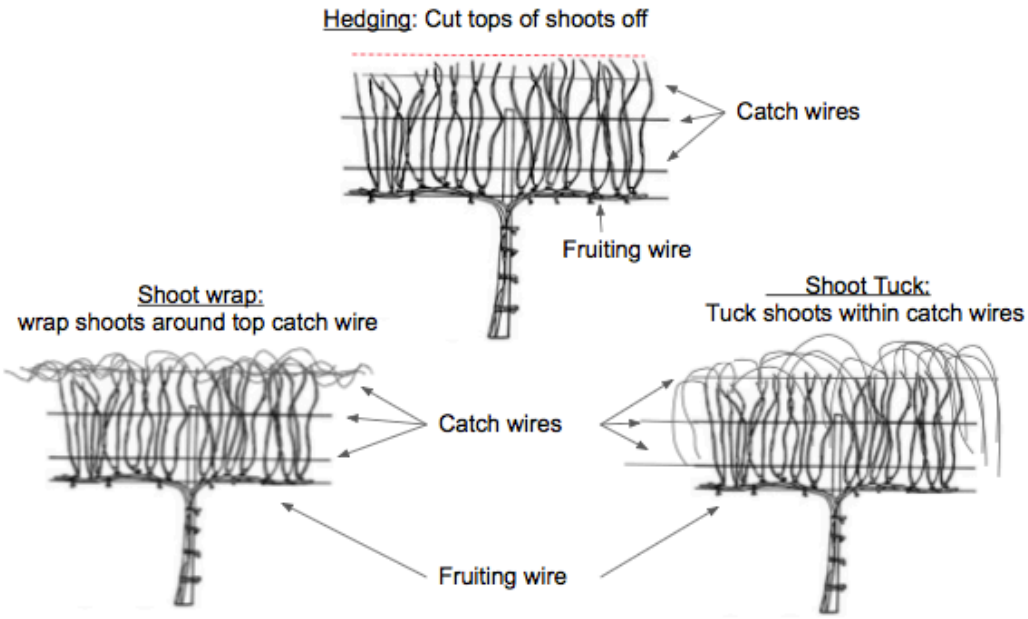

Figure 1 Diagram illustrating treatments: control (top), shoot wrap (bottom left), and shoot tuck (bottom right). Diagram by Anne Kearney

Shoot Length and Diameter

Shortly after bud-break, four randomly selected shoots per data vine (32 shoots per experimental unit), were tagged and labeled 1 to 4. From that time onward, shoot lengths were measured approximately every 10 days, from the base of the shoot to the shoot tip using a flexible measuring tape until early July, when treatments were applied.

Each randomly selected shoot described above was also measured for shoot diameter on the same day that shoot length measurements were taken. Using electronic calipers (Hangzhou Maxwell Tools, model ME1002) each shoot was measured at its greatest diameter and least diameter above their first fully developed nodes to account for oval internodes. These two measurements were then averaged for the actual shoot diameter.

Lateral Emergence

Laterals were counted on each data vine at veraison in 2015 and after harvest in 2016. The vine canopy was divided vertically into three sections: fruit zone (fruiting wire to 20 cm above fruiting wire), middle canopy (20 cm to 40 cm above the fruiting wire), and upper canopy (more than 40 cm above the fruiting wire).

Enhanced Point Quadrat Analysis

Vine canopy structure and light environment were characterized on a per-vine basis using enhanced point quadrat analysis (EPQA) at ~50% veraison on 29 August 2015 and 27 Aug 2016 (Meyers and Vanden Heuvel 2008). A thin rod was inserted through the fruiting zone perpendicular to the vine row at 20-cm intervals horizontally along the vine row, and the sequence of leaves and clusters contacted by the rod was recorded (Smart and Robinson 1991).These data were used to calculate leaf layer numbers, percent interior clusters, and percent interior leaves. The light environment in the canopy interior was recorded between 1200 and 1400 hr by recording photon ux

measurements using a 90-cm- long ceptometer that contained 80 photosensors (AccuPAR LP-80, Decagon). The ceptometer was inserted within the fruit zone parallel to the row with the sensors directed up- ward while a photosynthetically active radiation (PAR) point sensor was held above the canopy. The ratio of PAR intensity within and above the canopy was used to calculate an in-canopy ux value for each vine by averaging 10 in-canopy ux measurements over 10 sec. Canopy structure and photon in-canopy ux data were analyzed using Canopy Exposure Mapping Tools, version 1.7 (available free of charge from Jim Meyers, jmm533@cornell.edu). This software was developed to calculate occlusion layer number, cluster exposure layers, and cluster exposure flux availability (Meyers and Vanden Heuvel 2008).

Harvest and Yield Components

The grapes from each experimental unit were hand harvested one day before commercial harvest (10 October 2015 and 7 October 2016). Harvest data were taken across each panel due to overlapping canes and difficulty distinguishing separate vines). Clusters were counted and weighed with a hanging scale accurate to 0.1 kg (Salter Brecknell, SA3N340). Ten clusters from each panel were randomly collected and frozen to determine individual cluster weight, 100 berry weight, and cluster compactness (number of berries per centimeter of main rachis).

After weighing clusters from each panel at harvest, an additional 20 clusters were randomly collected from each experimental unit and evaluated for *Botrytis cinerea* bunch rot severity and incidence. Botrytis disease severity was assessed by visually rating

individual clusters on a 1 to 4 scale, based on the proportion of cluster tissue covered with the pathogen (1 = 0% - 25%; 2 = 26% - 50%; 3 = 51% - 75%; 4 = 76% - 100%); all ratings were made by a single individual (J. France).

After disease assessment, the 20 clusters were then frozen at -25 °C until processing. Samples were thawed, warmed in a water bath at 60 °C, and then pressed by hand and filtered through cheese cloth. Juice was brought to room temperature before analysis of soluble solids, TA, and pH. The soluble solids were measured using a digital refractometer with temperature compensation (Misco, model PA203X, Cleveland, OH), pH was measured using a calibrated pH meter (Fisher Scientific, Accument Basic AB15, Hampton, NH), and TA was measured by autotitrating 5 mL of juice with 0.10 M NaOH to a pH endpoint of 8.2 by a pH meter (Metrohm, 848 Titrino Plus, Switzerland). Juice samples were also tested for YAN by enzymatic analysis for Primary Amino Nitrogen and Ammonia (Randox Monaco RX, model RS-232, United Kingdom).

Winemaking

Immediately after harvest, fruit with more than 30% rot were removed and discarded. The fruit was transported to the New York State Wine Analytical Lab in Geneva, NY. The fruit from each treatment was combined and stored in a temperature-controlled cooler. The grapes were destemmed and crushed and pressed within 24 hrs of arrival and treated with 50 mg/L sulfur dioxide added as potassium metabisulfite, and allowed to settle for 12 hrs at 4°C. After settling, juice was racked per treatments and divided into duplicate lots for fermentation. The juice was brought to 16 °C and inoculated

with Saccharomyces cerevisae strain DV10 (Scott Laboratories) (0.25 g/L) rehydrated with Go-Ferm (Lallemand) (0.3 g/L). Fermaid K (Lallemand) was added at 0.25 g/L. Diammonium phosphate (DAP (Scott Laboratories, CA)) was added at rates calculated to bring the YAN to 200 mg N/L. Fermentation was performed in 114-L jacketed stainless steel fermenters with automated temperature control. Wines were fermented until dryness, less than 0.5% residual sugar measured with Clinitest tablets (Bayer, West Haven, CT). Finished wines were then racked into clean tanks SO2 was added to achieve 40 mg/L free SO2, and wines were cold-stabilized at 2°C for ~4 mos prior to bottling. Wines were not subjected to acid adjustments or malolactic fermentation and were screened for faults by experts, then bottled in 750-mL Stelvin finish screw cap glass bottles (dead leaf, Verallia), and stored at 16C

Wine Sensory Sorting Trial

Wine from the 2015 vintage was evaluated separately for sensory similarities in the fall of 2016. The 2015 vintage was sorted on 28 September 2016. The sensory panel consisted of 100 individuals between ages 21 and 70 who reportedly drank white wine at least once per month. Panelists seated at a table separated by white partitions in a room with fluorescent lighting. Wines were poured in 30 mL servings at room temperature in clear, tulip-shaped (ISO) 220-mL wine glasses covered with plastic lids. Two replicates of each canopy management treatment were served, a total of six glasses coded with a random 3-digit unique identification number were presented to panelists in a randomized order. Panelists were asked to sort wines, by aroma only without tasting, into one to three

groups, placing wines that were found to be similar by aroma together, using their own sorting criteria. To reduce imposed researcher bias, panelists did not receive sensory training and there was no rating of wine characteristics (Lawless et al. 1995; Preszler et al. 2013). Panelists were compensated $5 for participating in the sensory study.

The sensory data were analyzed by assigning a similarity score: wines that panelists grouped together received a similarity score of one; wines that were not grouped together received a score of zero. The sum of the similarity scores for each possible combination of wines was used to form a 6 × 6 similarity square matrix for each vintage. This matrix was analyzed using multidimensional scaling (MDS) (Kruskal 1964) in SAS (version 9.4). MDS analysis visually represents differences in sensory attributes even when underlying characteristics are not well defined (Lawless and Heymann 2010), and has been widely used in research on wine aroma (Lee and Noble 2006) and wine taste (Parr et al. 2007). The MDS analysis creates a two-dimensional perceptual map of the similarity among samples by placing more frequently paired samples closer together, and less frequently paired samples farther apart on a coordinate plane (Nestrud and Lawless 2010). A squared correlation value (R2) quantifies how well the two-dimensional mapping accounts for variance among samples.

Statistics

All vineyard and juice characteristic data were analyzed using JMP Pro 12 (SAS Institute, Cary, NC) using a mixed model ANOVA, with treatment as a fixed variable and

replicate number as random. Significance was determined using the Tukey HSD test at a 5% significance level.

To analyze sorting results, wines that were grouped together were given a similarity rating of one and wines not sorted into the same group scored a zero. The sum of the similarity scores for each pair of samples was calculated and similarity square matrix for each vintage created and analyzed using multidimensional scaling (MDS) statistical analysis (Kruskal 1964) using SAS (Version 8.0, Cary, NC). MDS generates a visual representation of the similarity square matrix, where samples that were paired together more often are closer spatially and those that were not grouped together were farther apart. The resulting graphical output of the MDS analysis can be used to interpret similarity among samples, even when the underlying attributes are not exactly known (Lawless and Heymann 2010). MDS has been previously used for food science studies (Lawless and Heymann 2010) and specifically white wine aroma evaluation (Lee and Noble 2006; Preszler et al. 2013).

.

Experimental Site 2: Cutchogue, NY

Vineyard Site and Experimental Design

The study was conducted in 2015 and 2016 in an ~0.10 ha commercial vineyard block located ~2 km from the northern shore of Long Island, Southhold, NY, in the Long Island American Viticultural Area (lat. 41°02'33.4"N long. 72°27'20.9"W; 5 m asl). The vineyard soils were classified as Haven loam (Soil Survey Staff) and a 0 to 2% north-

facing slope. Vitis vinifera L. cv. Cabernet Franc, unknown clone grafted on SO4 rootstock, was planted in 1997. Vines were planted 1.8 m apart with 2.8-m row spacing; rows were planted perpendicular to the slope of the hill, with an orientation of 318°NNW.

The vines were spur-pruned and trained on a single-tier vertical shoot-positioned trellis. Vines were shoot thinned to 28 buds per vine. Control vines were side-hedged and leaf-pulled at veraison. Disease was controlled using standard practices for *V. vinifera* in the northeastern United States (Wolf 2008). Powdery mildew (*Erysiphe necator*) and downy mildew (*Plasmopara viticola*) were not observed in the vineyard because of disease management practices. Glyphosate herbicide was applied undervine by the vineyard manager to control weeds.

Two canopy management treatments were established in 2015 in a randomized complete block with four replications: hedging (C, the control) and shoot tucking (ST, tucking the growing shoot tip down into the canopy). The vineyard block consisted of two 16 panel rows. Four panels comprised an experimental unit, data were collected from the two interior panels. Each panel contained four vines so that each experimental unit contained 16 vines. Each row contained two full replicates. Treatments were applied on 24 June 2015 and 27 June 2016 when actively growing shoots were approximately 50 cm above the top trellis wire.

In 2016 data collection was discontinued at 50% veraison because an erroneous herbicide application to portions of the block making canopy management treatment comparisons untenable.

Climate Data

Climate data for the site were recorded from the Cornell University Network for Environment and Weather Applications (NEWA) Southhold (Corey Creek) station (newa.cornell.edu), located ~ 860 m east of the vineyard and at a similar elevation. Precipitation and temperature data from 1 April through 31 Oct were used to estimate rainfall and growing degree days (base threshold of 10°C) for each growing season.

Pruning Weight

In mid-January of 2016, dormant vines were spur pruned to two nodes per spur, with 14 nodes per cordon, leaving 28 nodes per vine. The pruning weight of wood from the previous year was weighed for each vine with a hanging scale accurate to 0.1 kg (Salter Brecknell, SA3N340). This value and yield from the previous year were then used to calculate the Ravaz index (yield/pruning weight).

Shoot Length and Diameter

Shoot lengths were measured as described for site 1 throughout the growing season until early July, when hedging commenced. Shoot diameters were measured as describe for site 1.

Lateral Emergence

Laterals were counted on each data vine at veraison in 2015 as describe for site 1.

Enhanced point quadrat analysis

Vine canopy structure and light environment were characterized as described for site 1 at ~50% veraison on 18 August 2015.

Harvest and yield components

The grapes from each replicate treatment were hand harvested one day before commercial harvest (29 September 2015). On a per-vine basis, clusters were counted and weighed with a hanging scale accurate to 0.1 kg (Salter Brecknell, SA3N340). To determine average berry weight, 200 berries per treatment panel were collected and weighed at harvest.

Yield components and juice chemistry were determined as described for site 1.

Statistics

All vineyard and juice characteristic data were analyzed using JMP Pro 12 (SAS Institute, Cary, NC) using a mixed model ANOVA, with treatment as a fixed variable and replicate number as random. Significance was determined using the Student's t-test at a 5% significance level.

RESULTS

Climate Data

At the King Ferry site (KF), the growing season average temperature was the same for both years. However, June, July, and August average temperatures were 2°, 2° and 4°C higher in 2016 compared to 2015. The higher summer temperatures in 2016 resulted in 168 more GDD than 2015. The 2015 growing season had 131 mm more precipitation, with the largest difference occurring in June compared to 2016. The 2016 growing season was classified as a Class III drought (Drought Monitor).

At the Cutchogue site (CH), the growing season average temperatures were similar. The 2015 growing season had 15 more GDD than 2016 (Table 1). The 2015 growing season had 372 mm more precipitation, with the largest difference occurring in June compared to 2016.

Table 1 Average temperature**, a**ccumulation of growing degree days (GDD), and precipitation from April 1 through Oct 31, 2015 and 2016 in King Ferry, NY and Cutchogue, NY.

	King Ferry					
	Average temp (°C)		**GDD base °C**		**Precipitation (mm)**	
Month	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
April	8	7	27	29	54	46
May	18	15	245	161	37	45
June	18	20	249	299	141	21
July	21	23	340	421	122	41
August	20	24	325	428	39	93
September	20	19	304	287	131	43
October	11	12	77	111	64	169
Total	**17**	**17**	**1567**	**1735**	**588**	**457**

	Cutchogue					
	Average temp (°C)		**GDD base °C**		**Precipitation (mm)**	
Month	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
April	9	9	32	33	34	40
May	16	15	198	152	35	38
June	19	20	275	296	156	8
July	24	24	420	424	53	39
August	24	24	418	434	45	0
September	21	20	334	302	119	3
October	13	14	116	137	65	8
Total	**18**	**18**	**1793**	**1778**	**507**	**135**

Vegetative and Reproductive Growth

ST and SW did not affect pruning weight when compared to the control in both years at KF (Table 4), but ST increased pruning weight per vine by 0.8 kg when compared to the control in 2015 at CH. Treatment effects between the palissage treatments (SW and ST) and the control were expected at both sites due to the large amount of plant

material removed at hedging in the control plots. Pruning weight and Ravaz index should be interpreted cautiously for that reason.

ST and SW did not affect Ravaz indices in 2015 at KF, however ST and SW lowered Ravaz indices from 14.2 to 9.4 and 9.5, respectively, when compared to the control in 2016 at KF. ST lowered the Ravaz index from 2.6 to 1.6 when compared to the control in 2015 at CH. Ravaz index scores were not recorded in 2016 at CH.

Canopy treatments did not affect primary shoot length in 2015 at either site (Table 2, Table 3). SW treatment increased shoot length by 9% at phenological stage BBCH75 in 2016 at CH. However, there were no treatment differences in 2016 at KF.

SW decreased primary shoot diameter by 4% at BBCH75 when compared to the control in 2015 at CH; however, there were no treatment differences at KF that year. ST shoot diameters were 6% larger than SW diameters, but both ST and SW had similar diameter to the control at flowering in 2016 at KF. ST shoot diameters were 7% larger than the control and SW treatments at phenological stage BBCH 73 in 2016 at KF.

Table 2 Primary **s**hoot diameter and shoot lengths of Riesling grapevines with different canopy management treatments from 2015 and 2016 in King Ferry, NY. Values are means of four repetitions per treatment.

	2015 Shoot diameters (mm)			
Treatment[a]	**Jun 11, 2015**	**Jun 19, 2015**	**Jun 30, 2015**	**Jul 07, 2015**
C	6.9 ± 0.2	7.3 ± 0.2	7.6 ± 0.2	7.7 ± 0.3
ST	6.8 ± 0.2	7.4 ± 0.2	7.9 ± 0.2	7.9 ± 0.3
SW	7.0 ± 0.2	7.4 ± 0.2	7.9 ± 0.2	7.8 ± 0.3
p value[c]	0.6449	0.5602	0.1421	0.6169
	2016 Shoot diameters (mm)			
Treatment	**Jun 07, 2016**	**Jun 15, 2016**	**Jun 21, 2016**	**Jul 14, 2016**
C	6.1 ± 0.2	6.3 ± 0.1 ab[b]	6.6 ± 0.1 b	6.6 ± 0.2
ST	6.3 ± 0.2	6.6 ± 0.1 a	7.1 ± 0.1 a	7.1 ± 0.2
SW	6.1 ± 0.2	6.2 ± 0.1 b	6.6 ± 0.1 b	6.9 ± 0.2
p value	0.3296	0.0438	0.0021	0.0643

	Shoot length (cm)	
Treatment	**Jun 11, 2015**	**Jun 15, 2016**
C	66.9 ± 2.6	62.0 ± 2.3
ST	63.6 ± 2.6	66.6 ± 2.3
SW	67.3 ± 2.6	62.6 ± 2.3
p value	0.2588	0.1343

[a]Treatment: C = control, ST = shoot tuck, SW = shoot wrap.
[b]Lowercase letters indicate a separation of treatments by a Tukey HSD test at a 5% significance level.
[c]*P* value for the fixed variable “canopy treatment” in a mixed model ANOVA.

Table 3 Primary shoot diameter and shoot length of Cabernet Franc grapevines with different canopy management treatments from 2015 and 2016 in Cutchogue, NY. Values are means of four repetitions per treatment.

	2015 Shoot diameters (mm)				
Treatment[a]	**Jun 04, 2015**	**Jun 23, 2015**	**Jul 14, 2015**	**Aug 18, 2015**	**Sep 19, 2015**
C	7.5 ± 0.1	8.5 ± 0.1	9.5 ± 0.1 a[b]	9.2 ± 0.1	8.8 ± 0.1
ST	7.6 ± 0.1	8.5 ± 0.1	9.1 ± 0.1 b	9.2 ± 0.1	8.7 ± 0.1
p value[c]	0.5478	0.7932	0.0108	0.9712	0.7159

	2016 Shoot diameters (mm)	
Treatment	**Jun 01, 2016**	**Jun 27, 2016**
C	7.2 ± 0.1	8.4 ± 0.2
ST	7.3 ± 0.1	8.6 ± 0.2
p value	0.701	0.371

	Shoot length (cm)			
	2015		2016	
Treatment	**Jun 04, 2015**	**Jun 23, 2015**	**Jun 01, 2016**	**Jun 27, 2016**
C	57.2 ± 1.6	135.0 ± 4.2	42.5 ± 1.3	133.6 ± 4.2 b
ST	58.3 ± 1.6	138.3 ± 4.2	43.2 ± 1.3	145.8 ± 4.2 a
p value	0.5568	0.4478	0.5880	0.0197

[a]Treatment: C = control, ST = shoot tuck.

[b]Lowercase letters indicate a separation of treatments by a Student's t-test at a 5% significance level.

[c]*P* value for the fixed variable “canopy treatment” in a mixed model ANOVA.

Yield Components

Treatments did not affect yield per vine, cluster number per vine, or cluster weight in 2015 at KF (Table 4). SW increased berry weight by 0.02 g compared to the control, while ST reduced berry weight by 0.04 g when compared to the control in 2015 at KF. ST did not affect total yield and cluster per vine, but SW decreased cluster size by 28 g, increased berry weight by 0.05 g, and reduced number of berries per cluster from 98.9 to 81.1, when compared to the control in 2015 at CH (Table 5).

ST increased yield per vine by 1.3 kg (28%), but decreased cluster number per vine by 19% when compared to the control in 2016 at KF (Table 4). ST and SW increased cluster weight by 50.1 g and 22.7 g, respectively; berry weight by 0.35 g and 0.25 g, respectively; and berry number per cluster from 45.3 to 54.7 and 53.8, respectively, when compared to the control in 2016 at KF. Yield data were not collected in 2016 in CH.

ST and SW did not affect cluster compactness (Table 6), but ST increased rachis length by 1.4 cm when compared to C in 2016 at KF. Cluster compactness was not evaluated at CH.

Disease Severity and Incidence

Canopy treatments did not impact *Botrytis cinerea* severity at either site. ST and SW did not affect disease incidence in 2015 at KF (Table 4), but ST increased disease incidence by 22.6% when compared to the control in 2015 at CH (Table 5). Both ST and

SW decreased disease incidence to 2.5 when compared to the control treatment in 2016 at KF. Botrytis incidence was not evaluated in 2016 at CH. The incidence of other diseases appeared to be minimal and were not formally evaluated.

Juice Chemistry

ST reduced total soluble solids (TSS) by 1.3°Brix and increased TA by 11%, when compared to C, while SW did not impact juice chemistry when compared to C in 2015 at KF (Table 4). ST and SW had no impact on juice chemistry in 2016 at KF (Table 4). SW did not affect °Brix, but decreased pH by 5% to 3.9 and increased TA by 1.5 g/L to 7.1 g\L when compared to the control in 2015 at CH. SW also increased YAN by 121.5 mg/L, when compared to the control in 2015 at CH, moving YAN into the recommended range for winemaking (Bell and Henschke 2005). Juice chemistry data were not collect in 2016 at CH.

Table 4 Harvest data, disease severity and incidence, and fruit composition of Riesling grapevines with different canopy management treatments from 2015 and 2016 in King Ferry, NY. Values are means of four repetitions per treatment.

	Pruning weight (kg/vine)		Ravaz index (yield/pruning weight)	
Treatment[a]	**2015**	**2016**	**2015**	**2016**
C	0.9 ± 0.1	0.5 ± 0.1	7.0 ± 1.7	14.2 ± 1.5 a
ST	1.1 ± 0.1	0.7 ± 0.1	6.0 ± 1.8	9.4 ± 1.5 a
SW	1.1 ± 0.1	0.7 ± 0.1	5.6 ± 1.8	9.5 ± 1.5 a
p value[c]	0.1718	0.0519	0.6222	0.0326
	Yield (kg/vine)		**Cluster weight (g/cluster)**	
Treatment	**2015**	**2016**	**2015**	**2016**
C	5.3 ± 1.4	4.7 ± 0.3 b[b]	87.3 ± 27.1	53.8 ± 6.1 b
ST	4.5 ± 1.4	6.0 ± 0.3 a	92.8 ± 27.2	83.7 ± 6.1 a
SW	4.9 ± 1.4	5.1 ± 0.3 ab	106.4 ± 27.2	76.5 ± 6.1 a
p value	0.6962	0.0041	0.5656	<0.001
	Cluster number/vine		**Berry weight (g/berry)**	
Treatment	**2015**	**2016**	**2015**	**2016**
C	59.2 ± 4.9	88.9 ± 3.8 a	1.9 ± 0.03	1.2 ± 0.07 c
ST	52.2 ± 4.9	72.4 ± 3.9 b	1.9 ± 0.03	1.5 ± 0.07 a
SW	47.7 ± 4.9	70.1 ± 3.8 b	1.9 ± 0.03	1.4 ± 0.07 b
p value	0.0541	0.0003	0.1600	<0.0001
	Botrytis severity		**Botrytis Incidence (%)**	
Treatment	**2015**	**2016**	**2015**	**2016**
C	1.3 ± 0.1	1.1 ± 0.03	20.9 ± 4.4	2.5 ± 0.6 a
ST	1.2 ± 0.1	1.0 ± 0.03	19.6 ± 4.5	0.0 ± 0.6 b
SW	1.2 ± 0.1	1.0 ± 0.03	27.8 ± 4.5	0.0 ± 0.6 b
p value	0.1113	0.1367	0.3712	<0.001
	Soluble solids (°Brix)		**pH**	
Treatment	**2015**	**2016**	**2015**	**2016**
C	19.5 ± 0.4 a	19.6 ± 0.3	3.41 ± 0.02	3.38 ± 0.03
ST	18.2 ± 0.4 b	19.2 ± 0.3	3.44 ± 0.02	3.33 ± 0.03
SW	19.5 ± 0.4 a	19.4 ± 0.3	3.42 ± 0.02	3.35 ± 0.03
p value	0.0072	0.5205	0.6063	0.3708
	Titratable acidity (g/L)		**Yeast assimilable nitrogen (mg/L)**	
Treatment	**2015**	**2016**	**2015**	**2016**
C	6.4 ± 0.2 b	5.0 ± 0.2	84.6 ± 10.2	65.2 ± 7.8
ST	7.1 ± 0.2 a	5.5 ± 0.2	115.9 ± 10.2	66.0 ± 7.8
SW	6.7 ± 0.2 ab	5.2 ± 0.2	108.1 ± 10.2	69.4 ± 7.8
p value	0.0236	0.2589	0.0671	0.9249

[a]Treatment: C = control, ST = shoot tuck, SW = shoot wrap.

[b]Lowercase letters indicate a separation of treatments by a Tukey HSD test at a 5% significance level.

[c]*P* value for the fixed variable "canopy treatment" in a mixed model ANOVA.

Table 5 Harvest data, disease severity and incidence, and fruit composition of Cabernet Franc grapevines with different canopy management treatments from 2015 in Cutchogue, NY. Values are means of four repetitions per treatment.

Treatment[a]	Pruning weight (kg/vine)	Ravaz index (yield/pruning weight)
C	1.8 ± 0.3 b[b]	2.6 ± 0.5 a
ST	2.6 ± 0.3 a	1.6 ± 0.5 b
p value[c]	<0.0001	0.0001

Treatment	Yield (kg/vine)	Cluster weight (g/cluster)
C	4.1 ± 0.4	167.7 ± 9.1 a
ST	3.7 ± 0.4	139.7 ± 9.1 b
p value	0.2312	0.0004

Treatment	Cluster number/vine	Berry weight (g/berry)
C	24.5 ± 2.1	1.69 ± 0.02 b
ST	26.2 ± 2.1	1.74 ± 0.02 a
p value	0.3717	0.0382

Treatment	Botrytis severity	Botrytis Incidence (%)
C	1.2 ± 0.1	0.3 ± 2.6 b
ST	1.2 ± 0.1	22.9 ± 2.5 a
p value	0.8459	<0.0001

Treatment	Soluble solids (°Brix)	pH
C	20.9 ± 0.4	4.01 ± 0.04 a
ST	20.1 ± 0.4	3.90 ± 0.04 b
p value	0.0524	0.0034

Treatment	Titratable acidity (g/L)	Yeast assimilable nitrogen (mg/L)
C	4.0 ± 0.3 b	129.6 ± 12.0 b
ST	5.2 ± 0.4 a	251.1 ± 12.0 a
p value	0.0007	<0.0001

[a]Treatment: C = control, ST = shoot tuck.

[b]Lowercase letters indicate a separation of treatments by a Student's t-test at a 5% significance level.

[c]*P* value for the fixed variable “canopy treatment” in a mixed model ANOVA.

Table 6 Cluster compactness of Riesling grapevines with different canopy management treatments from 2016 in King Ferry, NY. Values are means of four repetitions per treatment.

Treatment[a]	Cluster compactness (berry/rachis length)	Rachis length (cm)	Berry number per rachis
C	7.1 ± 0.4	9.6 ± 0.4 b[b]	67.7 ± 4.0
ST	6.7 ± 0.4	11.0 ± 0.4 a	74.5 ± 4.1
SW	6.8 ± 0.4	9.4 ± 0.4 b	64.0 ± 4.0
p value[c]	0.7953	0.0002	0.1789

[a]Treatment: C = control, ST = shoot tuck, SW = shoot wrap.
[b]Lowercase letters indicate a separation of treatments by a Tukey HSD test at a 5% significance level.
[c]*P* value for the fixed variable "canopy treatment" in a mixed model ANOVA.

Lateral Emergence

Treatments reduced lateral emergence. SW reduced fruit zone, mid-canopy, upper canopy, and total lateral emergence by 35%, 16%, 34%, and 31%, respectively, and ST reduced upper and total canopy lateral emergence by 29% and 18%, respectively, when compared to the control in 2015 at KF (Table 7). ST reduced upper canopy and total lateral emergence by 18% and 13%, respectively, in 2015 at CH (Table 7). SW reduced upper and total lateral emergence by 77% and 76%, respectively, in 2016 at KF. Lateral emergence data were not collected in 2016 at CH.

Table 7 Impacts of canopy management treatments on lateral counts of Riesling grapevines at King Ferry, NY in 2015 and 2016, and Cabernet Franc grapevines in Cutchogue, NY in 2015. Values are means of four repetitions per treatment.

	2015 King Ferry, NY			
Treatment[a]	**Fruit Zone**	**Middle Canopy**	**Upper Canopy**	**Total**
C	15.5 ± 1.1 a	20.4 ± 0.9 a	38.6 ± 1.8 a	74.6 ± 3.2 a
ST	13.8 ± 1.1 a	19.3 ± 0.9 a	27.5 ± 2.1 b	61.1 ± 3.7 b
SW	10.3 ± 1.1 b	15.6 ± 0.9 b	25.4 ± 1.8 b	51.3 ± 3.2 b
p value[c]	<0.0001	0.0032	<0.0001	< 0.0001

	2016 King Ferry, NY			
Treatment	**Fruit Zone**	**Middle Canopy**	**Upper Canopy**	**Total**
C	0.4 ± 0.2	0.6 ± 0.2	4.0 ± 0.8 a	5.1 ± 0.9 a
ST	0.0 ± 0.2	0.2 ± 0.2	2.1 ± 0.8 ab	2.3 ± 1.0 ab
SW	0.3 ± 0.2	0.2 ± 0.2	0.9 ± 0.9 b	1.2 ± 1.0 b
p value	0.1507	0.0454	0.0378	0.0781

	2015 Cutchogue, NY			
Treatment	**Fruit Zone**	**Middle Canopy**	**Upper Canopy**	**Total**
C	8.3 ± 0.9	14.1 ± 0.9	31.6 ± 1.9 a[b]	54.1 ± 3.7 a
ST	10.0 ± 1.3	12.3 ± 1.0	26.0 ± 2.1 b	47.1 ± 4.0 b
p value	0.2501	0.1439	0.0047	0.0284

[a]Treatment: C = control, ST = shoot tuck, SW = shoot wrap.
[b]Lowercase letters indicate a separation of treatments by a Tukey HSD test at a 5% significance level.

[c]*P* value for the fixed variable "canopy treatment" in a mixed model ANOVA.

Enhanced Point Quadrat Analysis

EPQA analysis showed that canopy treatment had an impact on many characteristics of canopy structure and density. ST increased leaf layer number by 0.9 layers, occlusion layers by 1.0 layers, percent interior leaves by 21%, interior clusters by 7%, cluster exposure layer by 0.6, and leaf exposure layer by 0.26, when compared to the control, but SW did not impact canopy structure when compare to the C in 2015 at KF (Table 8). ST had no impact on canopy architecture when compared to the control in 2015 at CH (Table 9). ST and SW did not affect canopy architecture in 2016 at KF. EPQA was not performed at veraison in 2016 at CH.

Wine Sensory Sorting

Calculated R^2 (0.90) and stress values for the multi-dimensional sorting consensus (MDS) plots indicated an acceptable fit in the one-dimensional model (Fig. 2). Panelists detected sensory differences between SW and C because the treatments were separate from each other, yet the reps were close together on dimension 1. ST reps were not grouped together on dimension 1 and therefore not perceived different from SW and C.

Table 8 Enhanced point quadrat analysis (EPQA) characteristics of Riesling grapevines with different canopy treatments measured on 29 August 2015 and 27 Aug 2016 at veraison in King Ferry, NY. Values are means of four repetitions per treatment.

	Leaf layer number		Occlusion layer number	
Treatment[a]	2015	2016	2015	2016
C	3.7 ± 0.2 b[b]	3.0 ± 0.1	4.5 ± 0.3 ab	4.2 ± 0.2
ST	4.6 ± 0.2 a	2.9 ± 0.1	5.5 ± 0.3 a	4.2 ± 0.2
SW	3.4 ± 0.2 b	3.0 ± 0.1	4.3 ± 0.3 b	4.0 ± 0.2
p value[c]	0.0159	0.9574	0.0308	0.7908

	Interior leaves (%)		Interior clusters (%)	
Treatment	2015	2016	2015	2016
C	47.7 ± 2.2 b	37.7 ± 2.7	88.3 ± 2.9	85.7 ± 2.1
ST	57.6 ± 2.3 a	34.5 ± 2.7	94.8 ± 2.9	93.3 ± 2.1
SW	45.3 ± 2.3 b	37.8 ± 2.7	88.8 ± 2.9	88.8 ± 2.1
p value	0.0129	0.5189	0.2399	0.091

	Cluster exposure layer		Cluster exposure flux availability (%)	
Treatment	2015	2016	2015	2016
C	1.3 ± 0.1 b	1.2 ± 0.1	0.1 ± 0.02	0.1 ± 0.01
ST	1.9 ± 0.1 a	1.2 ± 0.1	0.1 ± 0.02	0.1 ± 0.01
SW	1.3 ± 0.1 b	1.2 ± 0.1	0.1 ± 0.02	0.1 ± 0.01
p value	0.0185	0.9009	0.286	0.1517

	Leaf exposure layer		leaf exposure flux availability (%)	
Treatment	2015	2016	2015	2016
C	0.6 ± 0.05 b	0.4 ± 0.04	0.27 ± 0.01 ab	0.32 ± 0.01
ST	0.8 ± 0.05 a	0.4 ± 0.04	0.25 ± 0.01 b	0.36 ± 0.01
SW	0.5 ± 0.05 b	0.4 ± 0.04	0.30 ± 0.01 a	0.35 ± 0.01
p value	0.0185	0.6393	0.0295	0.1270

[a]Treatment: C = control, ST = shoot tuck, SW = shoot wrap.

[b]Lowercase letters indicate a separation of treatments by a Tukey HSD test at a 5% significance level.

[c]*P* value for the fixed variable “canopy treatment” in a mixed model ANOVA.

Table 9 Enhanced point quadrat analysis (EPQA) characteristics of Cabernet Franc grapevines with different canopy treatments measured on 15 August 2015 at veraison in Cutchogue, NY. Values are means of four repetitions per treatment.

Treatment[a]	Leaf layer number	Occlusion layer number	Interior leaves (%)	Leaf exposure layer
C	3.1 ± 0.2	3.6 ± 0.2	36.7 ± 3.6	0.4 ± 0.06
ST	3.1 ± 0.2	3.6 ± 0.2	38.7 ± 3.6	0.5 ± 0.06
p value[c]	0.9407	0.9245	0.6781	0.3189

Treatment	Interior clusters (%)	Cluster exposure layer	Cluster exposure flux availability (%)	Leaf exposure flux availability (%)
C	85.8 ± 4.3	1.1 ± 0.1	17.3 ± 4.3	51.4 ± 16.6
ST	89.9 ± 4.3	1.2 ± 0.1	0.8 ± 4.3	0.9 ± 16.6
p value	0.5445	0.5457	0.0683	0.1190

[a]Treatment: C = control, ST = shoot tuck, SW = shoot wrap.
[b]Lowercase letters indicate a separation of treatments by a Student's t-test at a 5% significance level.
[c]*P* value for the fixed variable “canopy treatment” in a mixed model ANOVA.

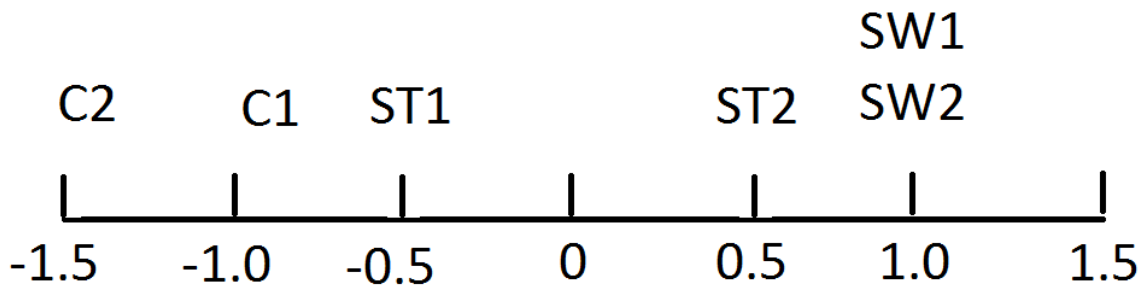

Figure 2. Single dimensional consensus plot of aroma similarity ratings of Riesling made in 2015 from C (control), ST (shoot tuck), and SW (shoot wrap) treated vines averaged from 100 panelists. King Ferry, NY.

DISCUSSION

Vines across all treatments were generally smaller in 2016 than 2015 at King Ferry, likely caused by the Class III drought. It is reasonable to assume the severe the drought caused water stress in 2016, affecting vine size and yield components, however there is no data to confirm this because plant water status was not measured.

Pruning weight and Ravaz index provide a mathematical basis for vine growth and balance but don't apply well to this study due to the large amount of plant material removed during hedging. More applicable parameters for assessing vine growth in this study include shoot length and diameter.

ST had consistently larger shoot diameters in the 2016 growing season compared to the control and SW, possibly a function of ethylene production in the shoot as a response to the downward tucking of the shoot tips. Ethylene production increases when shoots are bent downward when compared to horizontal shoots in apples (Sanyal and Bangerth 1998), and increased ethylene production has been connected to increased trunk diameter in woody plants (Telewski and Jaffe 1986). Diameter of shoots in the SW treatment was not impacted.

The reduced cluster numbers in ST and SW in 2016 was likely a function of denser canopies resulting in poor bud initiation in 2015. Buds that develop in dense canopies are less fruitful than buds that have greater access to solar radiation (Sánchez and

Dokoozlian 2005). Reduced cluster number per vine in ST and SW was compensated for by heavier clusters, more berries per cluster, and greater berry weight. Yield component compensation is common in *V. vinifera* (Keller 2015) a function of carbohydrate reallocation (Dokoozlian and Hirschfelt 1995). Total yield per vine was impacted significantly at KF in 2016 with ST producing more yield than the control. Reduced yield in the C is likely due to slightly reduced vegetative growth; however, we have no data to verify this because EPQA canopy characterizations were similar and pruning weights irrelevant.

The reduced Brix noted in the ST treatment may be a function of fewer laterals contributing to carbohydrate production. Increased TA was also noticed in ST vines in Pinot Gris growing in Maryland (Vanden Heuvel, unpublished data). Higher TA in palissage treated vines may be due to the preservation of malic acid, which is less likely to degrade in shaded fruit (Bledsoe et al. 1988). The higher leaf layers, occlusion layers, proportion of interior leaves, cluster exposure layers, and leaf exposure layers in the ST treatment suggests the fruit in that treatment was more shaded, although CEFA for all treatments was extremely low.

ST brought YAN into the optimal range for must fermentation, which should be more than 150 mg/L to prevent sluggish or stuck fermentations and to reduce the chance of producing hydrogen sulfide (Bell and Henschke 2005). The increased YAN in ST may be due to increased number of leaves per shoot which increased transpiration rate per

vine and nitrogen uptake. YAN was dramatically lower across treatments in 2016. A reduction in vine uptake of N from the soil was likely caused by the Class III drought experienced in 2016 at KF.

Canopy treatments had varying effect on *Botrytis cinerea* incidence. The increased botrytis incidence in ST at CH was likely a result of post-veraison canopy leaf removal and side hedging performed by the collaborating grower. There is an inverse relationship between CEFA and powdery mildew severity (Austin et al. 2011) and it is reasonable to assume a similar relationship between CEFA and Botrytis incidence (Zoecklein et al. 1992). Powdery mildew incidence can also be reduced by shoot defoliation (Chellemi and Marois 1992) and side hedging (Smart and Robinson 1991) . SW and ST had no impact on disease incidence in 2015 in KF because there were fewer laterals in the fruiting zone, reducing fruit shading and improving air movement which lowers Botrytis severity (Zoecklein et al. 1992).

The increase in rachis length in the ST treatment was likely a function of varying auxin availability from the shoot tip and/or cluster meristem among treatments (Keller 2015). Rachis internode length is a function of cell expansion, cell division, or a combination of the two (Shavrukov et al. 2004) and the rachises of looser-clustered cultivars (ex. Sultana) contain elongated cells compared to tighter clustered cultivars (ex. Riesling, Chardonnay). Gibberellins produced in the shoot tip (Keller 2015) may also play a role in cell elongation of the rachis.

One limitation of using multi-dimensional sorting is that sensory panelists do not describe the characteristics they are using to sort the wines. The differences detected between SW and C wines when subjected to multi-dimensional sorting based on aroma may have been due to differences in canopy density, since fruit shading can decrease C13 norisoprenoids, β-damascenone, TDN, and vitispriane (Meyers et al. 2013). Variable N, as reflected in differences in YAN, may also have impacted wine sensory qualities (Webster et al. 1993).

CONCLUSION AND FURTHER WORK

Canopy management practices that break the hedging-leaf removal cycle are vital. This study demonstrated that palissage was a viable canopy management technique in Riesling, reducing lateral emergence in the fruiting zone, increasing rachis length, lowering disease incidence, and maintaining or increasing yield. However, the potential long-term impacts palissage has on vine vigor, yield, and fruit quality need to be further explored. Studying the effect of palissage on root development and plant hormones will bring us closer to the underpinning physiological mechanisms of the technique. Evaluating palissage timing and its effects on vigor, yield, canopy architecture, and juice chemistry will help develop a framework for which we can use palissage as an effective canopy management strategy.

REFERENCES

Austin CN, Grove GG, Meyers JM, and Wilcox WF. 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.

Austin CN and Wilcox WF. 2011. Effects of Fruit-Zone Leaf Removal, Training Systems, and Irrigation on the Development of Grapevine Powdery Mildew. Am. J. Enol. Vitic. 62:193–198.

Bell S-J and Henschke PA. 2005. Implications of nitrogen nutrition for grapes, fermentation and wine. Aust. J. Grape Wine Res. 11:242–295.

Bledsoe AM, Kliewer WM, and Marois JJ. 1988. Effects of Timing and Severity of Leaf Removal on Yield and Fruit Composition of Sauvignon blanc Grapevines. Am. J. Enol. Vitic. 39:49–54.

Candolfi-Vasconcelos MC, Koblet W, Howell GS, and Zweifel W. 1994. Influence of Defoliation, Rootstock, Training System, and Leaf Position on Gas Exchange of Pinot noir Grapevines. Am. J. Enol. Vitic. 45:173–180.

Chellemi DO and Marois JJ. 1992. Influence of Leaf Removal, Fungicide Applications, and Fruit Maturity on Incidence and Severity of Grape Powdery Mildew. Am. J. Enol. Vitic. 43:53–57.

Dokoozlian NK and Hirschfelt DJ. 1995. The Influence of Cluster Thinning at Various Stages of Fruit Development on Flame Seedless Table Grapes. Am. J. Enol. Vitic. 46:429–436.

Drought Monitor. U.S. Drought Monitor Map Archive. Available from: http://droughtmonitor.unl.edu/MapsAndData/MapArchive.aspx

Keller M. 2015. The Science of Grapevines: Anatomy and Physiology. Second Edition. San Diego, CA: Elsevier Inc.

Komm BL and Moyer MM. 2015. Effect of Early Fruit-Zone Leaf Removal on Canopy Development and Fruit Quality in Riesling and Sauvignon blanc. Am. J. Enol. Vitic. 66:424–434.

Kruskal JB. 1964. Nonmetric multidimensional scaling: A numerical method. Psychometrika 29:115–129.

Lawless HT and Heymann HA-P-2010. 2010. Sensory evaluation of food : principles and practices. 2nd ed. New York: Springer Available from: http://proxy.library.cornell.edu/login?url=http://link.springer.com/openurl?genre=book&isbn=978-1-4419-6487-8

Lawless HT, Sheng N, and Knoops SSCP. 1995. Multidimensional scaling of sorting data applied to cheese perception. Food Qual. Prefer. 6:91–98.

Lee S-J and Noble AC. 2006. Use of Partial Least Squares Regression and Multidimensional Scaling on Aroma Models of California Chardonnay Wines. Am. J. Enol. Vitic. 57:363–370.

Meyers JM, Sacks GL, and Vanden Heuvel JE. 2013. Glycosylated Aroma Compound Responses in “Riesling” Wine Grapes to Cluster Exposure and Vine Yield. HortTechnology 23:581–588.

Meyers JM and Vanden Heuvel JE. 2008. Enhancing the Precision and Spatial Acuity of Point Quadrat Analyses via Calibrated Exposure Mapping. Am. J. Enol. Vitic. 59:425–431.

Molitor D, Baron N, Sauerwein T, André CM, Kicherer A, Döring J, et al. 2015. Postponing First Shoot Topping Reduces Grape Cluster Compactness and Delays Bunch Rot Epidemic. Am. J. Enol. Vitic. 66:164–176.

Morrison JC and Noble AC. 1990. The Effects of Leaf and Cluster Shading on the Composition of Cabernet Sauvignon Grapes and on Fruit and Wine Sensory Properties. Am. J. Enol. Vitic. 41:193–200.

Nestrud MA and Lawless HT. 2010. Perceptual Mapping of Apples and Cheeses Using Projective Mapping and Sorting. J. Sens. Stud. 25:390–405.

Parr WV, Green JA, White KG, and Sherlock RR. 2007. The distinctive flavour of New Zealand Sauvignon blanc: Sensory characterisation by wine professionals. Food Qual. Prefer. 18:849–861.

Preszler T, Schmit TM, and Vanden Heuvel JE. 2013. Cluster Thinning Reduces the Economic Sustainability of Riesling Production. Am. J. Enol. Vitic. 64:333–341.

Reynolds AG and Wardle DA. 1989a. Effects of Timing and Severity of Summer Hedging on Growth, Yield, Fruit Composition, and Canopy Characteristics of de Chaunac. I. Canopy Characteristics and Growth Parameters. Am. J. Enol. Vitic. 40:109–120.

Reynolds AG and Wardle DA. 1989b. Effects of Timing and Severity of Summer Hedging on Growth, Yield, Fruit Composition, and Canopy Characteristics of de Chaunac. II. Yield and Fruit Composition. Am. J. Enol. Vitic. 40:299–308.

Sánchez LA and Dokoozlian NK. 2005. Bud Microclimate and Fruitfulness in Vitis vinifera L. Am. J. Enol. Vitic. 56:319–329.

Scheiner JJ, Heuvel JEV, Pan B, and Sacks GL. 2012. Modeling Impacts of Viticultural and Environmental Factors on 3-Isobutyl-2-Methoxypyrazine in Cabernet franc Grapes. Am. J. Enol. Vitic. 63:94–105.

Shavrukov YN, Dry IB, and Thomas MR. 2004. Inflorescence and bunch architecture development in Vitis vinifera L. Aust. J. Grape Wine Res. 10:116–124.

Smart R and Robinson M. 1991. Sunlight into Wine: A Handbook for Winegrape Canopy Management. Adelaide, Australia: Winetitles

Soil Survey Staff. Web Soil Survey. Available from: http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx

Telewski FW and Jaffe MJ. 1986. Thigmomorphogenesis: the role of ethylene in the response of Pinus taeda and Abies fraseri to mechanical perturbation. Physiol. Plant. 66:227–233.

Webster DR, Edwards CG, Spayd SE, Peterson JC, and Seymour BJ. 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.

Wolf TK. 2008. Wine Grape Production Guide for Eastern North America. Ithaca, New York: Natural Resource, Agriculture, and Engineering Service

Zoecklein BW, Wolf TK, Duncan NW, Judge JM, and Cook MK. 1992. Effects of Fruit Zone Leaf Removal on Yield, Fruit Composition, and Fruit Rot Incidence of Chardonnay and White Riesling (Vitis vinifera L.) Grapes. Am. J. Enol. Vitic. 43:139–148.