Defining Crop Load Metrics for Quality Pinot Noir Production in Oregon

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Summary

A three year study began in 2013 to determine the impact of varying crop levels on vine growth and balance. The project involves two components: 1) a large grower collaborator crop load study and 2) a study that monitors vine growth, nutrition and physiology measures within four sites from the larger study. A total of 13 vineyard and winery collaborators have participated in the research by adjusting vines to two or more crop levels based on lag-phase cluster thinning, and they have completed two full growing seasons of data collection and wine production for the study (2013 and 2014). The 2013 season results from the large grower collaborative study indicates no differences in vine size (pruning weight), vine nutrient status, and only a few differences in fruit composition at harvest within 27% of the sites in 2013. Data from the 2014 season are currently being statistically analyzed in spring 2015. Data obtained from the four sites (study 2) during 2013 and 2014 show no differences in vine nutrient status at bloom or véraison, vine photoassimilation rates, nor differences in vine leaf area or dormant pruning weights when comparing full crop (non-thinned vines) with those cluster-thinned to one cluster/shoot. Despite very high yields in 2014, cluster thinning did not drastically change ripeness parameters measured. However, 3 of the 4 sites had greater polymeric anthocyanin in the lower crop level fruit during 2014. The differences in site vine vigor and productivity is valuable in understanding how crop load may be influencing fruit composition and quality in vineyards with different yield capacity. The data obtained from the first two years of this research suggests that the Pinot noir vines in the Willamette Valley of Oregon may reach vine balance on their own and may not require cluster thinning to adjust for fruit ripeness or to vine health. Further seasons of research are required to better understand the impacts of crop levels on long-term vine health and productivity.

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Cooperators: Project cooperators during 2014 included 13 commercial vineyards and/or winery businesses in Oregon: Adelshiem Vineyard, Airlie Winery, A to Z Wineworks, Bethel Heights Vineyard, Chehalem Winery, Domaine Drouhin, Domaine Serene, Ken Wright Cellars, Lemelson Vineyard, Van Duzer Vineyards, Willakenzie Estate, Winemakers Investment Properties, and Winter's Hill Winery.

Objectives and Experiments Conducted to Meet Stated Objectives

Objective 1: Develop the statewide research effort to implement and conduct research trials in commercial vineyards and wineries to address vine growth, fruit and wine quality as a result of yield management.

The statewide research program was initiated in 2012 with the recruitment of the first set of ten collaborators who successfully implemented the project. A recruitment call was released in April 2013 and 2014 to increase project participation. The application process requires the completion of an application form and review by the PI. Only businesses that meet the following criteria were approved to join the study: a healthy, uniform Pinot noir vineyard of >5 years of age and at least 1 to 1.5 acres in size to use for the trial, enough acreage to support involvement in a trial of this size without compromising their overall production, ability to conduct the research for at least three years in the same vineyard block, willingness to follow project protocols for experimental design and ability to collect data required according to project protocols. Since all new collaborators to date are from the Willamette Valley and in close proximity to OSU, they were trained through one-on-one meetings in the vineyard. The PI made initial site visits to each vineyard to check the suitability of the research block for use in the project and provided training on experimental design and layout for the project. Follow-up visits were conducted by the PI and faculty research assistant (FRA) as needed to ensure collaborator confidence in taking part in the study. Continued support to collaborators is provided by the PI and FRA on an on-going basis throughout the season.

Collaborators in the study continue to implement the same crop levels each year. Most have two to three crop levels but some have as many as five different crop levels implemented in their research vineyard block. The majority chose to implement 1 cluster/shoot, 2 clusters/shoot, or no crop thinning. Because Pinot noir fruitfulness rarely exceeds 2 clusters/shoot, crop thinning was easily managed on a larger scale by using these two thinning treatments. All collaborators developed their vineyard experiment using the same randomized complete block design with whole row plots and at least three field replicates.

Collaborators follow specific protocols developed by the PI for data collection. All data are collected from 10-vine reference plots within three replicates of each treatment. Data collection included fruitfulness counts in spring, shoot and cluster counts before thinning and post-thinning, yield weights at harvest and dormant pruning weights. All field data are collected by staff of the commercial vineyard following the project protocols. Data sheets are provided to the collaborators for all data collection protocols. A members-only website was developed in 2012 and continues to serve as a central hub for collaborators to locate protocols, data sheets, data entry files for the project. For weights, each collaborator was provided a calibrated hanging scale.

Vine nutrition samples (leaf blade and petiole) were collected from two treatments (1 cluster/shoot and either no-thinning or 2 clusters/shoot) per site at véraison in 2014. Grower collaborators collected the samples and submitted them to Precision Agri-Labs for analysis of macro- and micro-nutrients. Crop Production Services (CPS) volunteered to arrange for sample coordination and delivery from the collaborator to the commercial lab and coordinating data delivery to the PI.

Fruit samples were collected at least two time points prior to harvest to monitor ripening progression. These samples were gathered across the entire project (each treatment replicate, but avoiding the reference vines). At harvest, a 20-cluster fruit sample was collected from the reference vines in each plot, weighed and measured for cluster weight by the grower, and picked up by OSU for processing and shipping to ETS Labs. Fruit was analyzed using ETS Lab's basic ripening panel and rapid phenolic panel (total soluble solids, pH, TA, L-malic acid, tartaric acid, glucose + fructose, ammonia, alpha-amino acids, YAN, K, catechin, quercetin glycosides, tannins, polymeric anthocyanins, total anthocyanins, catechin/tannin index, and polymeric anthocyanin/tannin index). This service was donated by ETS Labs in 2014. Their donation of services was critical to obtaining more data than is possible through this funding.

At harvest, 11 of the 13 collaborators produced wines from the trial in 2014. All treatment plots were bulked for wine production in a minimum of 1.5 ton fermentations under each cropping level. Wines were produced to winery collaborator's commercial standard but using the same method for all of their treatment wines in the study. Wines will be evaluated in-house at each winery and by trained panels and consumer panels. Dr. Elizabeth Tomasino, OSU, developed in-house sensory methods for collaborators to begin using in 2014. All wines are to be bottle-aged two years before they will be entered into sensory evaluation by the trained panel at OSU.

A collaborator meeting is held each spring/summer to discuss protocols, project results and next steps in the research. Friendly reminders for data collection and coordination are sent out monthly per the next task to be implemented. The PI and FRA continuously communicate with the project collaborators to ensure project success.

Objective 2: Evaluate vine growth and nutrient status data with fruit/wine composition data to develop better vine balance metrics for Oregon Pinot noir.

Four sites were selected from the research sites involved in the project outlined in Objective 1. More detailed data collection has taken place in those sites during 2013 and 2014. Preference was given to sites that represent differing levels of vine vigor (based on vine growth observations and pruning weights). The four vineyards were monitored for shoot length and shoot leaf area at bloom and véraison. Leaf area and vine canopy measures were determined with various techniques, several of which are under development as potential new methods for field researchers to more efficiently measure leaf area. All measures were done in-field using non-destructive methods. Leaf assimilation and stomatal conductance was measured using a LICOR 6400 XT (LI-COR Biosciences, Lincoln, NE) during early ripening at all four sites. Leaf water potential measures were taken on the same leaves as the gas exchange measures to compare pressure chamber results to gas exchange measures. Leaf greenness (an estimate of chlorophyll) was measured with a SPAD-502 meter (Konica-Minolta, Ramsey, NJ) during bloom and véraison, and these measures were made on leaves selected for nutrient analysis at each time point. Vine nutrient status was monitored by collecting leaf blade and petiole samples at bloom and véraison. Samples were collected by the Skinkis and Schreiner labs, cleaned, dried, ground and analyzed for macro- and micronutrients at the USDA-ARS HCRL, Corvallis. Dormant pruning weights were measured during January 2015, and those data are being collated with other vine growth data, nutrient data, and pending carbohydrates for statistical analysis at the end of the field component of this trial. Vine nutrient and non-structural carbohydrate (sugars and starch) reserves will be measured in these dormant cane tissues. Currently, those tissues have been collected (2014) and stored at -80°C until analysis. Samples are being prepared from January 2015 during spring 2015.

The data collected in this Objective is currently being analyzed to determine vine productivity and how it relates canopy leaf area, yield, pruning weight and crop load (Ravaz; yield/pruning weight). The detailed measures obtained in this objective allows us to draw more conclusions in vine physiological response to crop level than is possible from the project in Objective 1. Additionally, the use of sites with varying vigor helps us evaluate crop load impacts and develop better guidelines for a broader range of vineyards.

Summary of Major Research Accomplishments and Results by Objective

Objective 1: Develop the statewide research effort to implement and conduct research trials in commercial vineyards and wineries to address vine growth and fruit and wine quality as a result of yield management.

As of this reporting, a total of 13 companies are collaborating in this research project. Ten companies joined in 2012, and an additional four companies joined the project since that time. As expected, a few collaborators had to leave the study within the first year or two, and this was mostly due to factors outside of our control. All collaborators are from the Willamette Valley, but they span across six AVAs (Chehalem Mountain, Dundee Hills, Eola-Amity Hills, Ribbon-Ridge, Willamette Valley, and Yamhill-Carlton). The composition of the collaborators

also spans across a diversity of site characteristics that allow for a greater ability to assess vine balance across the region. Collaborators also represent a diversity of different production goals and wine markets. During 2014, we recruited and trained one new collaborator, and we received nearly 100% of the data for all sites by March 1, 2015.

The 2013 season results showed that there were very few differences when comparing different crop levels within site or across sites. There were no differences found for dormant pruning weight or vine nutrient status measured at véraison in 2013. Also, there were few differences in fruit composition at harvest. Only 27% of the sites had any difference in fruit composition with different crop levels, and the factor influenced was not consistent across all sites. The lack of differences at harvest may have been due to dilution of the berries and possible degradation after a heavy rain event that occurred just prior to harvest in 2013. At this reporting, we have all of the 2014 season data in from collaborators and fruit composition data received from ETS Labs. Data analysis is currently underway, and results will be shared with the collaborators in the annual project conference scheduled for July 1, 2015.

Objective 2: Evaluate vine growth and nutrient status data with fruit/wine composition data to develop better vine balance metrics for Oregon Pinot noir.

The four sites selected from the larger "Statewide Crop Load Project" outlined in Objective 1 were monitored for vine physiological measurements during 2013 and 2014. Two of the sites (BH and RR) are located within the Eola-Amity Hills AVA, and the other two are located in Yamhill-Carlton AVA (MC and WKE). Focus of research was placed on only two treatments across all sites: a) 1 cluster/shoot and b) no thinning.

When statistically analyzed across all four sites, the vine growth data segregate into distinct vineyard groups based on the level of vine vigor. Leaf area measured at véraison in 2014 show that the four sites separate into two groups with BH and WKE having greater leaf area than MC and RR (Figure 1). Likewise, BH and WKE had greater yield per linear meter than MC and RR (Figure 2). Yield data matches that of fruitfulness data collected in spring 2014. The BH and WKE sites had greater fruitfulness in spring 2014 (1.6 clusters/shoot) compared to MC or RR with 1.3 and 1.0 clusters/shoot, respectively ($p<0.0001$). There was no relationship between fruitfulness in 2014 with véraison leaf blade or petiole N in 2013 or bloom 2014. However, there was a positive relationship with véraison leaf blade N in 2014 ($p=0.0001$, $r^2=0.4130$). This relationship between vine N status and fruitfulness warrants further investigation, particularly since N is a critical nutrient that drives vine growth and fruit development.

Three of the four sites (BH, MC, and WKE) had nearly 2-fold greater yields in 2014 compared to 2013. Yield at RR was similar to 2013. Cluster thinning reduced yields by 44% at RR, 47% at WKE, 58% at BH, and 68% at MC in 1 cluster/shoot treatments compared to No thin treatments in 2014. Nonetheless, crop level did not influence vine leaf area at bloom or véraison in 2014. Even after two consecutive years of full crop maintained on vines, there has been no decline in fruitfulness in spring 2014. Furthermore, the heavy yields due to good fruit set and large cluster size of 2014 did not suppress vine growth at any site, even those considered to be of lower vine vigor (RR and MC).

Vine nutrient samples were collected at bloom and véraison in 2013 and 2014 to monitor the impact that heavier yields may have on vine health long-term. Bloom and véraison data were

analyzed separately. For both years, crop level did not have an effect on any leaf blade or petiole nutrient concentrations measured at bloom or véraison ($p>0.05$). As expected, there were large differences in vine nutrient status among the sites. This likely explains the differences observed in canopy leaf area per meter of row, yield per meter of row, canopy density, fruitfulness, and pruning weights. With the larger crop levels in 2014, differences in vine nutrient concentrations were anticipated; however, no differences were found. This suggests that the vines have sufficient resources from reserves and/or the vineyard environment to maintain a healthy canopy and significant fruit yields. One site in particular had very low K levels in 2014, but it did not differ by crop level. The lower vigor sites (MC and RR) were anticipated to have declines in vine nutrient status with the No thin treatment; however, the vines were also lower-yielding than BH and WKE. This suggest that vines at RR and MC are already self-adjusted crop level (through lower fruitfulness) to match the canopy size.

Single leaf gas exchange was measured during ripening in all four sites in September 2013 and 2014. We anticipated greater differences in 2014 due to the higher crop level and warmer season. However, there were no differences found by crop level for photosynthetic assimilation or stomatal conductance at any of locations in either year.

Dormant pruning weights are typically one of the first vine growth parameters that change when conducting research to adjust vine vigor, whether it is with vineyard floor management, irrigation, or nutrition. After the 2013 and 2014 seasons, dormant pruning weights did not differ by crop level at any of the four vineyards, suggesting that the crop levels have not created vine stress, whether it is for water, mineral nutrients, or carbohydrates. Differences exist between sites, with BH and WKE having greater pruning weights (0.72 kg/m) compared to MC and RR (0.32 kg/m) following the 2014 season (Table 1). The BH and WKE sites are considered higher vigor than the MC and RR sites; however, all sites had similar vine balance (Ravaz Index; yield/pruning weight). Regardless of whether the site was higher or lower with respect to leaf area and pruning weight, there were similar Ravaz Indices for No Thin compared to 1 cluster per shoot with an average of 3.61 and 2.14, respectively ($p<0.0001$). Similarly, there were no differences in leaf area:yield ratios between sites, but there were differences by crop level with a mean of 2.33 m^2/kg for 1 cluster/shoot compared to 1.39 m^2/kg in the No Thin treatments. These data suggests that the vines have begun to reach their own balance with vineyards of higher vigor having similar Ravaz as those with lower vigor.

Tissues collected at dormancy (canes) are stored at -80°F and awaiting carbohydrate analysis. During 2014, carbohydrate analyses were conducted to fine-tune the methodology. Once the method is finalized, carbohydrate analyses will ensue.

There were very few differences in fruit composition at harvest in 2014. Crop level did not influence total soluble solids, pH, titratable acidity, or malic and tartaric acid, despite high yields (Table 1). The one exception was a higher TA in the No thin compared to 1 cluster/shoot at BH. Similar results were found in 2013 with no differences in basic fruit ripeness at harvest. Of the fruit parameters quantified at harvest, the most common difference in fruit composition was polymeric anthocyanins and total anthocyanins (Table 2). Cluster thinning increased polymeric anthocyanins in three of the four sites and total anthocyanins in two of four sites. Other crop load studies conducted by the PI show a similar affect on anthocyanins with cluster thinning. Only two of the four sites had greater concentrations of quercetin in 1 cluster/shoot which is often related to higher sunlight exposure. This may be related to cultural practices of

those vineyards rather than crop level. By cluster thinning, we effectively increase leaf area relative to the amount of fruit on the vine. However, there was no relationship between leaf area:yield or Ravaz Index when compared within or across sites for 2013 or 2014. Only 1 site (BH) had a statistically significant relationship between soluble solids (Brix) and leaf area:yield or Ravaz while the rest had no difference. The lack of differences with cluster thinning may be attributed to the fact that all vines had sufficient leaf area relative to the yield levels and a small difference in the Ravaz Indices (Table 1).

The differences in vine productivity among sites will be valuable in understanding how crop load may be influencing fruit composition and quality in vineyards with different yield capacity. The data obtained from the first two years of this research suggests that the Pinot noir vines in this study may reach vine balance on their own and do not require cluster thinning practices to adjust for fruit ripeness or to maintain vine growth. Further seasons of research will help evaluate this hypothesis.

Outside Presentations of Research

The results from the project outlined in Objective 1 have been presented by the PI to peers and industry at various events/venues during 2014. Results were shared at the annual collaborator meeting on 1 July 2014. Presentations on the first few years of research results have been shared with the Oregon industry through 4 seminars and 2 field days during 2014. Canopy quantification work from Objective 2 was presented in a poster at the OWRI Grape Day meeting in April 2014. Information from the large collaborative study was presented as an oral talk at the 2015 OWRI Grape Day at OSU in March. The PI plans to present this work at the American Society for Enology and Viticulture National Conference in Portland, during June 2015.

Research Success Statements

There has been strong grower collaboration in this study because they are seeking to understand how yield relates to wine quality. Currently the majority of industry uses a yield standard for Pinot noir, and this comes at a significant cost. The goal to develop vine balance metrics for vineyard production is important to Oregon's wine industry as they begin to apply the best management practices to different sites with different yield capacity, rather than subscribing to target yields that have become the status quo. Collaborators and the broader industry have reaffirmed that reducing canopy management (crop thinning) costs and increasing yields without compromising fruit quality is of paramount importance to the Oregon winegrape industry. This larger research project will help expand crop load research to different areas of Oregon's production regions and help develop better metrics that allow a flexible approach to managing vine balance and fruit quality rather than applying a standard target yield without regard to vine vigor, growing region, and season.

With labor becoming scarce for practices as labor-intensive as crop thinning, and the increasing costs of production, growers are more inclined to experiment with new ideas directly to help make future management decisions for their companies. Conducting this research by engaging grape growers and winemakers is beneficial for their understanding of the effects of yield management on their own vineyards and the resulting wine characteristics. As active

participants in the research, they also learn how to design on-farm studies to help address questions in a systematic way and think differently about their management decisions.

Fund Status

The project outlined in Objective 1 was initiated in 2012 and funded by the Oregon Wine Research Institute through a pilot project program. The funding provided in 2013/14 and 2014/15 through the Oregon Wine Board allowed for expansion of Objective 1 to new data collection and to begin investigating physiological responses of higher crop levels on vine health and productivity through Objective 2. Funds were used to support half of a full time faculty research assistant (Michael Kennedy) who works in the Skinkis Lab and assists in the communication and coordination of information between the PI, co-PI and industry collaborators. Funding for Objective 2 was used to travel to four research sites and collect data, including vine nutrient sampling, leaf area quantification, canopy metrics, shoot lengths, leaf gas exchange, etc. We will continue to use funds through August 2015 to finalize data analysis from Year 2 of the project.

The research team thanks the Oregon Wine Board for the financial support of this research project and for their continued support of other research within the program of the PI.

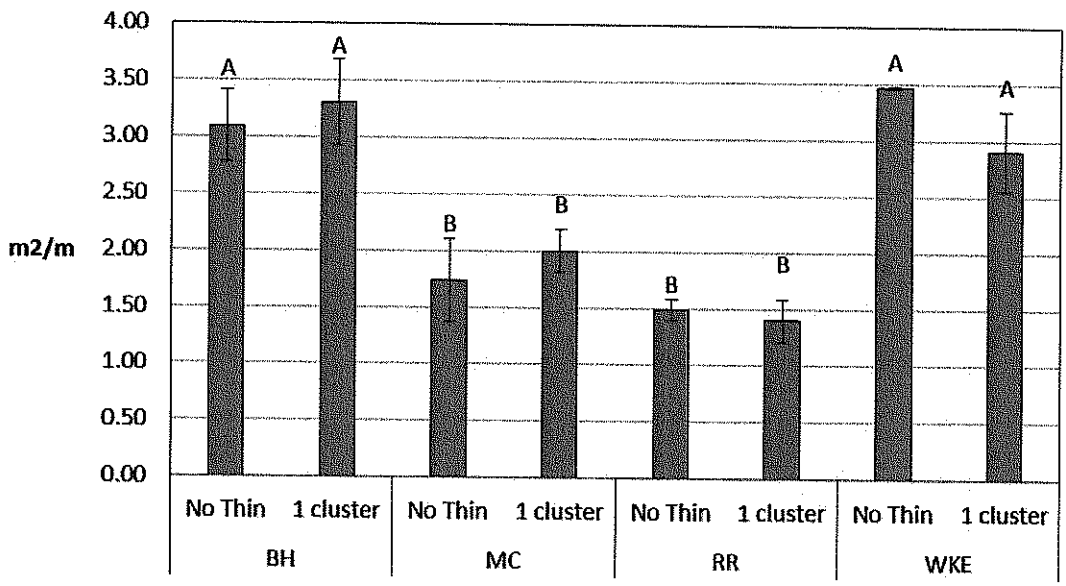

Figure 1. Mean (±SE) canopy leaf area at véraison presented as m^2 of leaf area per meter of row length. BH and RR are sites located in the Eola-Amity Hills AVA, and MC and WKE are sites located in the Yamhill-Carlton AVA. Treatments include 1 cluster (thinned to 1 cluster/shoot) and No Thin (no cluster removal occurred). Different letters indicate a difference in means by Tukey HSD mean separation ($p<0.05$).

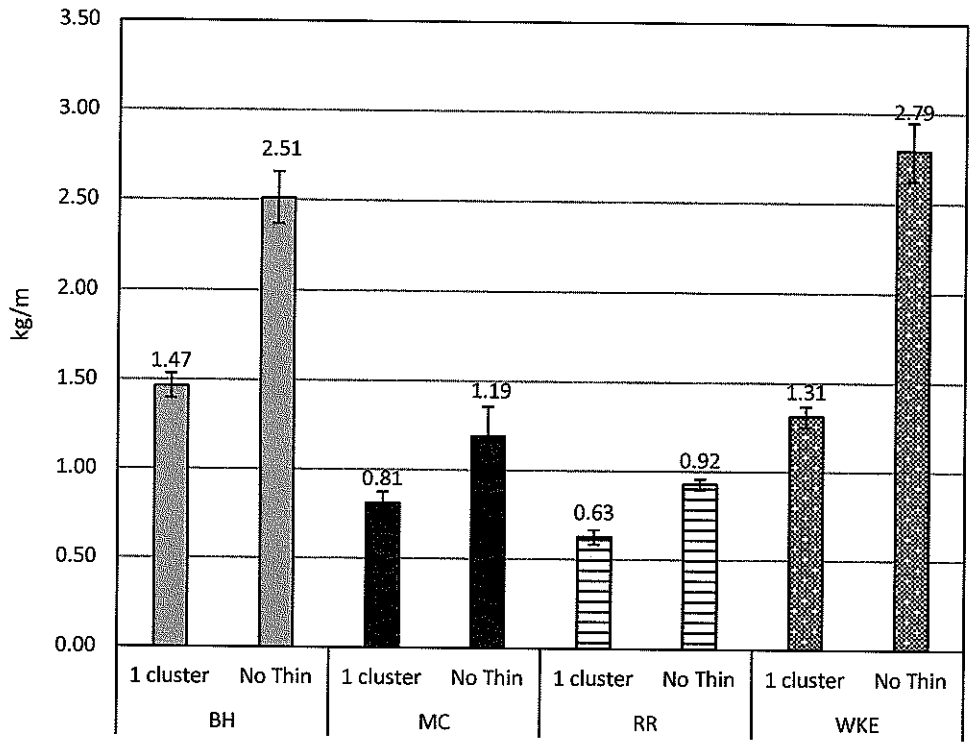

Figure 2. Mean (±SE) yield at harvest in 2014 from the detailed data collection sites (Objective 2). Yield is presented as the amount of fruit (kg) per linear row length (m). BH and RR are sites located in the Eola-Amity Hills AVA, and MC and WKE are sites located in the Yamhill-Carlton AVA. Treatments include 1 cluster (thinned to 1 cluster/shoot) and No Thin (no cluster removal occurred).

Table 1. Vine yield, balance metrics, and fruit ripeness at harvest from four vineyard sites, 2014. Means are presented and p-values for parameters where differences were found by treatment within site. No differences between treatments are denoted as n.s. (not significant, $p>0.05$). BH and RR are sites located in the Eola-Amity Hills AVA, and MC and WKE are sites located in the Yamhill-Carlton AVA. Treatments include 1 cluster (thinned to 1 cluster/shoot) and No Thin (no cluster removal occurred).

Site	Treatment	Yield (kg/vine)	Pruning wt (kg/m)	Ravaz Index	TSS (°Brix)	pH	TA (g/L)	L-malic (g/L)	tartaric (g/L)
BH	1 cluster	1.34	0.67	2.3	23.6	3.53	4.6	2.0	5.1
	No Thin	2.30	0.70	3.7	23.0	3.46	5.2	2.4	5.2
	p	**0.0006**	n.s.	**0.0185**	n.s.	n.s.	**0.0430**	n.s.	n.s.
MC	1 cluster	0.81	0.33	2.6	25.6	3.77	4.0	2.3	5.1
	No Thin	1.19	0.31	4.0	25.5	3.71	4.1	2.0	5.4
	p	0.0706	n.s.	**0.0305**	n.s.	n.s.	n.s.	n.s.	n.s.
RR	1 cluster	0.63	0.34	1.9	24.3	3.41	5.5	2.2	6.1
	No Thin	0.92	0.30	3.2	24.3	3.33	5.9	2.2	6.3
	p	**0.0011**	n.s.	**0.0179**	n.s.	n.s.	n.s.	n.s.	n.s.
WKE	1 cluster	2.00	0.73	1.8	24.6	3.54	5.9	3.3	5.5
	No Thin	4.25	0.78	3.6	24.4	3.55	6.3	3.7	5.5
	p	**0.0001**	n.s.	**<0.0001**	n.s.	n.s.	n.s.	n.s.	n.s.

Table 2. Fruit composition from four vineyard sites at harvest, 2014. Means are presented and p-values for parameters where differences were found by treatment within site. No differences between treatments are denoted as n.s. (not significant, $p>0.05$). BH and RR are sites located in the Eola-Amity Hills AVA, and MC and WKE are sites located in the Yamhill-Carlton AVA. Treatments include 1 cluster (thinned to 1 cluster/shoot) and No Thin (no cluster removal occurred). *Analysis was conducted through Kruskal-Wallis due to non-normal data. All others were analyzed through ANOVA.

Site	Treatment	ammonia N (mg/L)	alpha-amino N (mg/L)	YAN (mg/L)	K (mg/L)	tannin (mg/L)	polymeric anthocyanin (mg/L)	total anthocyanin (mg/L)	quercetin (mg/L)
BH	1 cluster	37.4	70.9	108.3	1405	390	14	730	75
	No Thin	36.9	54.1	91.1	1378	351	11	619	62
	p	n.s.	n.s.	n.s.	n.s.	n.s.	**0.0105**	n.s.	n.s.
MC	1 cluster	27.7	73.3	101.0	1790	408	19	717	80
	No Thin	33.4	65.8	99.2	1690	364	15	508	62
	p	n.s.	n.s.	n.s.	n.s.	n.s.	**0.0284***	**0.0209***	n.s.
RR	1 cluster	57.5	66.0	123.4	1370	401	16	1027	82
	No Thin	58.8	63.8	122.6	1235	375	14	939	61
	p	n.s.	n.s.	n.s.	**0.0477**	n.s.	n.s.	n.s.	**0.0040**
WKE	1 cluster	38.6	73.1	111.7	1975	327	12	567	44
	No Thin	51.9	90.4	142.3	2030	259	10	486	29
	p	n.s.	n.s.	n.s.	n.s.	**0.0168**	**0.0027**	**0.0142**	**0.0135**