PW PRACTICAL Winery & Vineyard JOURNAL

How Leaf Area: Fruit Weight Ratio Influences Date of Véraison and Synchrony of Primary and Secondary Metabolites

Mike Trought and Amber Parker

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Key Points

- Reducing the leaf area:fruit weight ratio via trimming delays *véraison and* directly slows the rate of sugar accumulation.
- In contrast, the rate of decrease in concentration of acidity and other secondary metabolites such as methoxypyrazines are less affected.
- As a result, when harvesting fruit at the same sugar concentrations, fruit will have a lower acidity or green character when the leaf area:fruit weight ratio is reduced.
- Delaying and slowing sugar accumulation by trimming shoots is a useful tool for growers to manipulate the synchrony of fruit metabolites and may be valuable in combating the consequences of climate change.

Leaves are the powerhouses of grapevines and the source of carbohydrates to the vine. In the simplest terms, the green chlorophyll of leaves takes up carbon dioxide from the atmosphere, which is converted into sugars to form the backbone of all organic compounds necessary for vine growth and development. The rate at which leaves photosynthesize depends on many factors including the degree of exposure to sunlight, which provides the energy for photosynthesis and the demand for photosynthates by the various sinks (fruit, shoot and root growth, carbohydrate reserves and demands for respiration).

However, all leaves within a vine are not equal in their capacity to photosynthesize. For example, the exposed leaves in the canopy absorb 85 percent of the photosynthetically active radiation (PAR), (that part of sunlight energy that can be used for photosynthesis by plants). Only a maximum of nine percent is transmitted through to underlying leaves.[10] Additional leaf layers will further reduce the sunlight energy reaching interior leaves, and as a consequence, interior leaves may be at light levels below the compensation point (that intensity at which respiration is equivalent to the rate of photosynthesis). Leaves in the interior of a dense canopy frequently senesce.

FIGURE 3 Trimming experiment. Pinot Noir shoots were trimmed to medium-trim of approximately 60 cm (LEFT), left untrimmed (MIDDLE), or short-trimmed to just above the fruiting zone (approximately 30 cm) (RIGHT), shortly after fruit set. Laterals were removed to maintain a constant leaf area. Vines were spaced 3 meters between vine rows and 1.8 meters apart within the vine row.

Similarly, the leaf area:fruit weight ratio (or source to sink ratio) will influence the rate of photosynthesis per unit leaf area. Measurements on exposed leaves or using whole vine photosynthesis chambers has demonstrated that defoliation either by leaf removal and/or trimming of shoots increased the rate of photosynthesis per unit leaf area.[7,8] However, the higher rate of photosynthesis did not compensate fully for the reduced leaf area, and net vine photosynthetic rate was still less than untrimmed vines.[7,8] A reduction in photosynthetic rate as leaves age can,[3] in part, be explained by the increase in overall leaf area as vines grow and the increase in the source to sink ratio.[7]

When considering the capacity of a vine to photosynthesize, one must differentiate between the total leaf area (leaf number multiplied by average leaf area), and the light-exposed leaf area (generally the canopy height multiplied by vine spacing) with respect to the light-exposed leaf area:fruit mass ratio. The ratio between total and exposed leaf area depends on the training system and canopy density. The greatest exposed leaf area is achieved using a pergola training system.

Understanding how the balance between the vine photosynthetic capacity (the source of photosynthates) and sinks for photosynthates (fruit, shoot and root growth) is important if optimum fruit composition is to be achieved at harvest.[11] In application, adjusting the leaf area:fruit weight ratio can be used to manipulate the date of véraison and harvest.

Desynchronising Soluble Solids and Acidity at Harvest

An experiment undertaken in Marlborough, New Zealand investigated the influence of crop thinning (fruit removal) and shoot trimming on both Pinot Noir and Sauvignon Blanc. In the first experiment, Sauvignon Blanc shoots were trimmed to retain either six or 12 leaves, with 0, 50 or 75 percent fruit removal (six treatments in total) **(TABLE 1).** A low leaf area to fruit weight ratio resulted in a longer time between flowering and véraison (8° Brix),[4] and slower soluble solids accumulation in the fruit from véraison to harvest **(FIGURE 1A)**.[5] However, other fruit metabolites, for example acidity, were less affected by leaf area reduction **(FIGURE 1B).** As a consequence, the greater effect of reducing the leaf area was on soluble solids accumulation which altered the sugar:acid synchrony in fruit **(FIGURE 2).**[5]

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How Leaf Area: Fruit Weight Ratio Influences Date of Véraison and Synchrony of Primary and Secondary Metabolites

	Leaf Treatment	
Thinning treatment	**Six leaves**	**12 leaves (normal canopy height)**
0% (unthinned control)	1	4
50 percent	2	5
75 percent	3	6

TABLE 1 Experimental Treatment Design. Numbers denote treatments. Note: treatment pairs of 2 and 4, and 3 and 5 have similar leaf area:fruit weight ratios.

Vines with similar leaf area:fruit weight ratio (12 leaves and full crop (trt-4) compared to six leaves, and 50 percent crop removal (trt-2) or 12 leaves and 50 percent crop removal (trt-5) compared to six leaves and 75 percent crop removal (trt-3) had similar sugar-acid balance **(FIGURE 2)**. This demonstrates that it is the ratio of effective leaf area to fruit weight (or carbohydrate source:sink ratio) that is critical to determine the timing of fruit development and synchrony of the fruit composition. Increasing the time taken to achieve a target soluble solids (or the hang time) resulted in a lower acidity concentration.

Sensory Properties of Pinot Noir Wines Made From Different Leaf Area:Fruit Weight Ratios

In a second experiment in Marlborough, New Zealand, Pinot Noir vines were trimmed after fruit set to 30 cm (short trim), 60 cm (medium trim) or 100 cm (tall trim) above the fruiting wire **(FIGURE 3)**. Reduced canopy height delayed the date of veraison (8° Brix) and slowed the rate of soluble solids accumulation to reach a target soluble solid concentration of 20.5° Brix by up to 15 days.[6] As a result, fruit from short-trimmed vines was 21.1° and 21.7° Brix at harvest in 2011 and 2012 respectively compared to 23.9° and 23.2° Brix for the tall-trimmed vines, with medium-trimmed vines intermediate in soluble solids accumulation in both years.

Wines made from fruit exhibited different sensory attributes, with short-trimmed vines scoring lower in most wine sensory attributes **(TABLE 2)**. Similar results have been observed when secondary metabolites rather than sensory attributes are measured in response to leaf area:fruit weight ratio manipulations. For example, D.M. Chapman et al. reported that high yielding Cabernet Sauvignon vines had lower methoxypyrazine concentrations and lower vegetal aromas when harvested at the same soluble solids as lower cropped vines.[1,2]

	2011 vintage			2012 vintage		
Canopy height	Short	Medium	Tall	Short	Medium	Tall
	Fruit composition					
Soluble solids (°Brix)	21.1°a	22.5°b	23.9°c	21.7°a	22.1°a	23.2°b
Titratable acidity (g/L tartaric acid equivalent)	6.63	6.34	6.14	6.71	6.91	6.66
pH	3.56	3.56	3.57	3.6	3.53	3.53
	Wine sensory					
Dark berry	48b	56ab	63b	47ab	52ab	57a
Spicy	46b	50ab	58a	32b	43a	41ab
Astringent	38b	45ab	50a	32ab	34ab	40a
Mid palate fruit weight	39b	50a	55a	36b	48a	46a
Body/viscosity	36b	49a	55a	34b	46a	45a

TABLE 2 Influence of Canopy Height on Fruit Composition and Wine Sensory Attributes of Pinot Noir.

Note: Vines were trimmed to retain a canopy height of 30 cm (short), 60 cm (medium) or 100 cm (tall) from the fruiting wire. The 2011 and 2012 data were analysed separately and values with different subtending letters were significantly different (P less than 0.05). Herbaceous/vegetal, red berry, candied cherries, woody/stalks, earth/fresh mushroom flavor attributes and acid, sweet and bitter texture attributes were non-significant (P > 0.1). Full experimental design and results can be found in Parker et al. (2016) and Pineau et al. (2017).

CHANGING BERRY COMPOSITION SYNCHRONY

- The potential photosynthetic capacity of a grapevine is largely determined by the exposed leaf area.
- An increase in photosynthetic rate, per unit leaf area, is observed as the leaf area:fruit weight ratio decreases, but this generally does not fully compensate for the reduced leaf area.
- A low leaf area:fruit weight ratio may extend the time from flowering to véraison and slow the rate of soluble solids accumulation by fruit to the extent that fruit may not reach an acceptable soluble solids by harvest. Other metabolites (such as titratable acidity) appear to be less affected.
- The balance of sugar to other metabolites (titratable acidity and methoxypyrazine) can be managed by altering the size of canopy height and/or fruit thinning. Low yields may result in greater acidity and methoxypyrazine concentrations (at a given soluble solids) and trimming less (to slow sugar accumulation) may be useful to increase the "hang time" enabling acidity and methoxypyrazine concentrations to decrease.
- Adjusting the leaf area:fruit weight ratio is an important viticultural management practice to ensure that the fruit reaches adequate maturity before the end of the growing season, while at the same time attaining an appropriate balance of primary and secondary metabolites.

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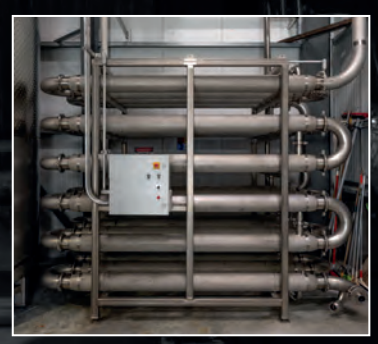

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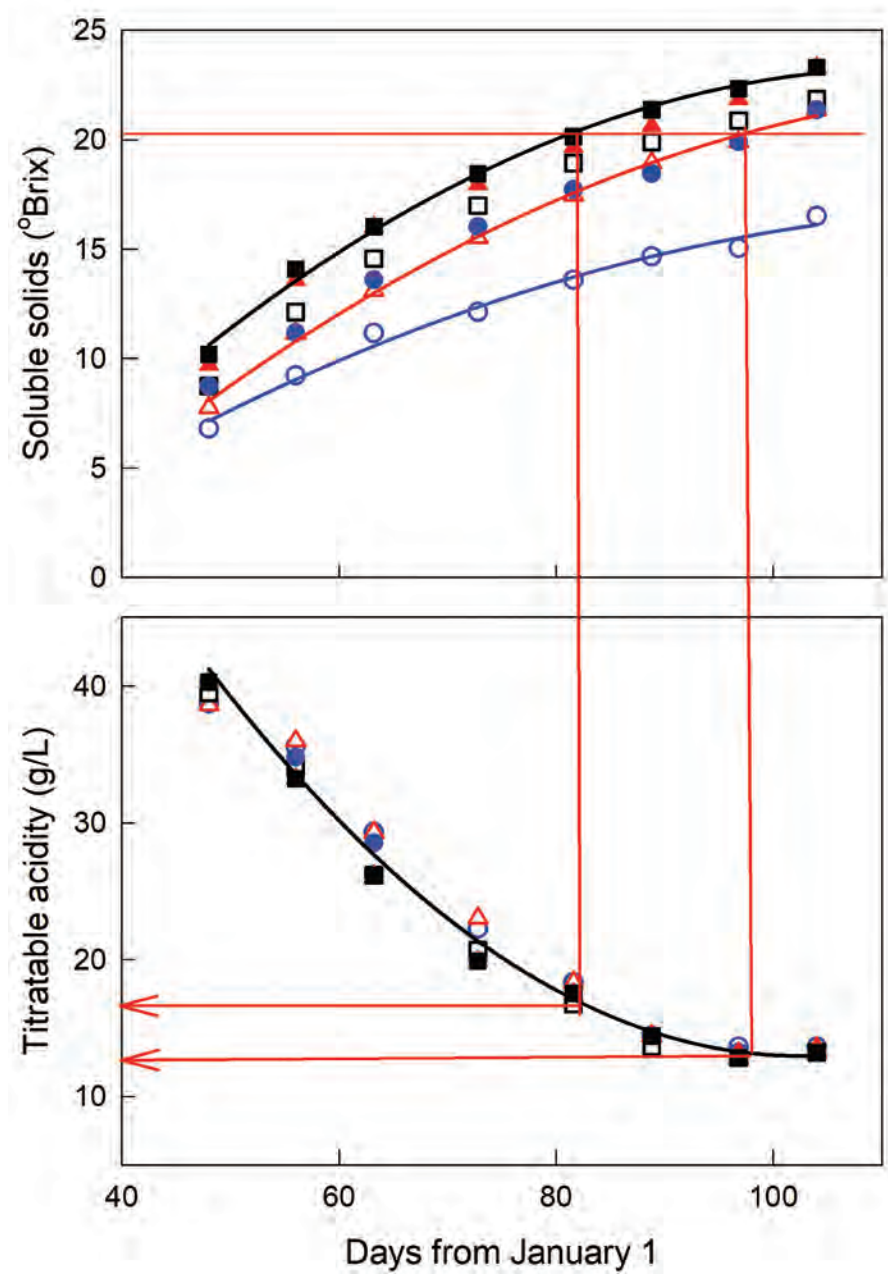

FIGURE 1 Influence of trimming and crop removal on changes in soluble solids (a) and titratable acidity (b) of Sauvignon Blanc**.** Vines were trimmed shortly after fruit set. Véraison coincides with fruit reaching 8° Brix. Open and closed symbols, six and 12 leaves per shoot respectively. ●○ full crop; ▲△ 50 percent crop reduction, ▪ □ 75 percent crop reduction.

Note: vines with a similar leaf area:fruit weight ratio have similar rates of soluble solids accumulation. i.e. six leaf/50 percent crop removal (▲) have a similar rate of soluble solids accumulation as 12 leaves/no crop removal (○).

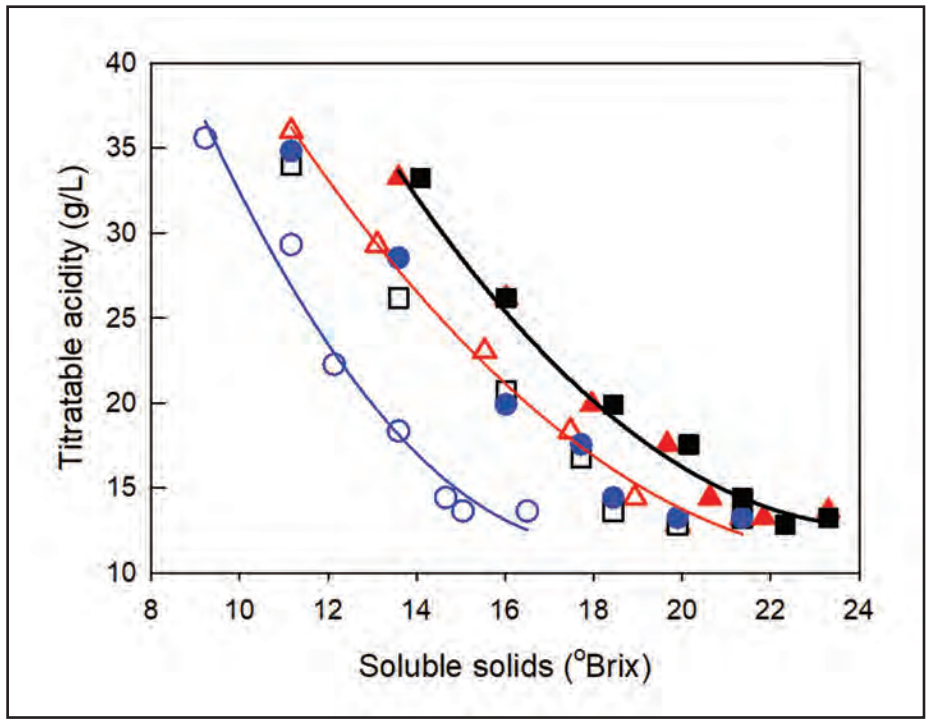

FIGURE 2 Influence of leaf area:fruit weight ratio on soluble solids to titratable acidity ratio in Sauvignon Blanc. For legend, see Figure 1.

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Viticulture Trial
Leaf Area vs. Crop Load

Understanding same-season and carryover effects of grapevine canopy size and crop load manipulations on yields, berry ripening and wine quality.

Bryan Avila

Bryan Avila is a formally trained enologist, seasoned commercial winemaker, ACUE-Credentialed Educator and co-founder of the Vintners Institute. The Vintners Institute is a grassroots, next-gen effort to bring wine industry producers and allies together, online and in-person, to innovate with nature, educate the workforce and inspire good leaders. A freelance writer for *WBM*'s Winemaker Trials, Bryan would love to hear what you are doing in your vineyard and winery to overcome challenges, grow better grapes and make better wine. Contact: *bryan@vintnersinstitute.com.*

Trial Lead: S. Kaan Kurtural, Ph.D., Extension Specialist for UC Davis, Oakville Station Vineyard

Dr. Kaan Kurtural joined the Department of Viticulture and Enology at UC Davis in November of 2015 as a new Cooperative Extension Specialist in Viticulture. Dr. Kurtural's research focuses on three main parts with short- and long-term outcomes: 1) improving production efficiency in vineyards by applying principles of canopy and crop load management using vineyard mechanization and applied water amounts, 2) identifying quality improvement traits in berry composition by translating fundamental research into applied production practices in vineyards and 3) adapting viticulture to climate change and drought tolerance through the use of mitigating methods. Dr. Kurtural has a statewide appointment and travels California's grape growing regions, providing extension and outreach to grape growers, working with county farm advisors and conducting research projects. He and his laboratory team are based at UC Davis' Oakville Station in Napa Valley.

Most wine growers have heard through the grapevine that the threshold for growing a high-quality crop load is somewhere between 1.5 to 3.5 tons per acre with the implication that lower tonnage means higher quality. Fixated on achieving these numbers, growers often try to achieve these lower yields by inhibiting plant growth through leaf removal or by simply dropping crop with the idea of concentrating flavor to the remaining clusters. The fact of the matter is: it's not that simple, and many growers are leaving money on the table. In the pursuit of vine balance, grape growers can prune stems, remove leaves and drop clusters. The perennial nature of the grapevine means that its floral development follows a two-year cycle, requiring a three-year study to adequately observe how the first year's canopy management practices manifest themselves over the following two years. Without the resources to deeply study vineyard trials, this long delay in feedback can feel like a black box experiment. This is what experimental vineyards are all about. This three-year trial was performed at UC Davis' Experimental Vineyard in Oakville, which was designed and managed by a cooperative extension specialist in viticulture and a post-doctoral researcher. In short, their primary mission is to deliver high-quality research that most farmers don't have the ability to do easily.

This viticulture trial is a factorial design which combines leaf thinning and cluster thinning practices and evaluates their performance through the measurement of grapevine sugars from their source, leaf area and its photosynthetic activity, its storage in the roots and its final destination into the fruit (aka source).

To evaluate this experiment, measurements were taken to characterize the plant's response to these practices by studying differences in photosynthesis, carbon storage throughout the vine and roots and their relationship to quality. The following methods of analysis were used to evaluate photosynthesis in each treatment: stomatal conductance and net carbon assimilation. Stomatal conductance (gs) estimates the rate of gas exchange, namely CO_2 uptake and water evaporation, through the physical resistance between the air and the leaf through the stomates. Net carbon assimilation (A_{net}) is an important indicator of physiological photosynthetic capacity.

These numbers may not mean much to day-to-day farming operations; however, when they are evaluated versus universally accepted success criteria for producing quality winegrapes, the results of these analyses provide the evidence and lead to new best practices. These new practices are needed to make the leap from conventional to a greater precision and confidence that producing more, higher quality grapes is possible. In other words, award-winning wines can be made from grapes cropped higher than 3.5 tons per acre when quality is viewed through the lens of leaf area.

Quality winegrape benchmarks:

1. the vineyard block ripens uniformly with good varietal expression,
2. the clusters are undamaged and clean, yielding a low microbial load at harvest,
3. avoiding excessive hangtime allows less risk of color loss from heat, inclement weather or fire.

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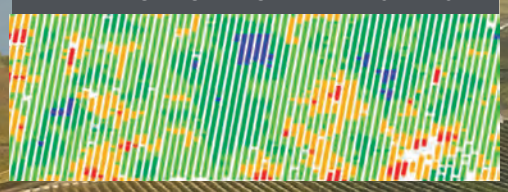

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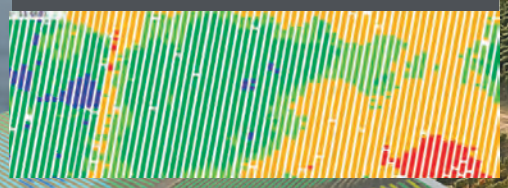

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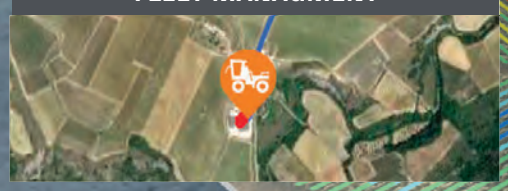

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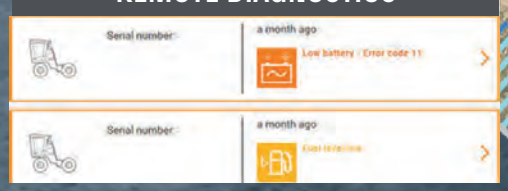

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Viticulture Trial: Leaf Area vs. Crop Load

TRIAL OBJECTIVE:

This peer-reviewed trial[1], written by Johann Martinez-Lüscher and Sahap Kaan Kurtural, describes the objective in its abstract: "The aim of this work was to study the same season and carry-over effects of manipulating source-to-sink ratios on grapevine phenology, leaf gas exchange, yield components, berry soluble solids accumulation, and reserve carbohydrate and soluble sugar concentration in roots."

In other words, the trial studies the impact of the ratios of leaf area to crop load. Performance indicators include measurements of plant fitness, nitrogen use efficiency, shifts in phenology, berry composition and wine composition. These results were used to determine the effects of plant reserves on next year's carry-over effects and kinetics of ripening and to provide science-based research to California winegrowers to get growers to work on leaf area versus dropping crop to obtain their quality requirements for winemaking.

TRIAL DESCRIPTION:

This trial used Cabernet Sauvignon grapevines (clone 7/110R) grown at the Oakville Station Experimental Vineyard. They were growing on UCD 60° trellis and drip-irrigated to 65 percent evapotranspiration replacement (ET_{crop}). All experimental vines, including neighboring vines, received the same nitrogen application, 15 kg/ha. These vines were arranged in a Randomized Complete Block Design, which is a standard design for ag experiments to minimize variation by accounting for spatial effects in field studies.

In mid-June, low, medium and high levels of leaf retention were matrixed in with low, medium and high levels of fruit retained in a factorial design, leading to the production of 36 research vines as shown in **FIGURE 1**.

Within this study, four major extremes provided the outer boundaries for the experiment. These extremes are shown in a more simplified table in

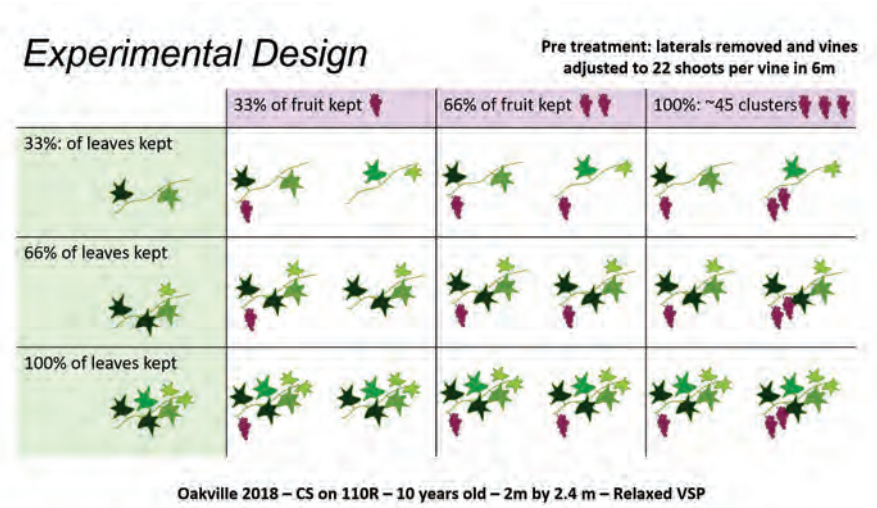

FIGURE 1 Factorial design of source (leaf area) versus sink (crop)

FIGURE 2 and used as data labels for this article. These boundary treatments signify the following:

- *No Thinning* – No clusters or leaves were removed from the primary shoot positions showing the effect of a relatively balanced high crop load, allowing for a plant-driven balance.
- *Under Cropped* – 100 percent of the leaves were removed, but only 33 percent of the crop was retained, showing the effect of too much leaf area per cluster.
- *Over Cropped* – 33 percent of the leaves were retained, but 100 percent of the crop was kept, showing how the vine compensates for too much crop per leaf area.
- *Extreme Thinning* – 33 percent of the leaves and crop were thinned, showing the effect of a relatively balanced low yield.

NO THINNING	100% Leaves and clusters retained	
UNDER CROPPED	100% leaves retained / 33% clusters retained	
OVER CROPPED	33% leaves retained / 100% clusters retained	
EXTREME THINNING	33% of leaves and clusters retained	

FIGURE 2 Major experimental treatments

FIGURE 3 shows the vines at the time of treatment application, and **FIGURE 4** shows the same vines prior to veraison. Please note that all lots had lateral growth removed, which is why there are leaves on the ground for the *No Thinning* treatments. For each vintage, treatments were harvested once they reached 25.5 °Brix (% sugar) and taken to Groth Winery in Oakville to perform small-lot fermentations so that chemical testing results could be evaluated for flavor in addition to performance.

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FIGURE 3 Comparative photo showing the difference in canopy shade from full leaf and crop retention (left) versus extreme leaf removal (right) at the time of treatment in mid-June.

FIGURE 4 Comparative photo showing the difference in canopy shade from extreme leaf removal (left) versus full leaf and crop retention (right) prior to veraison.

CONCLUSIONS:

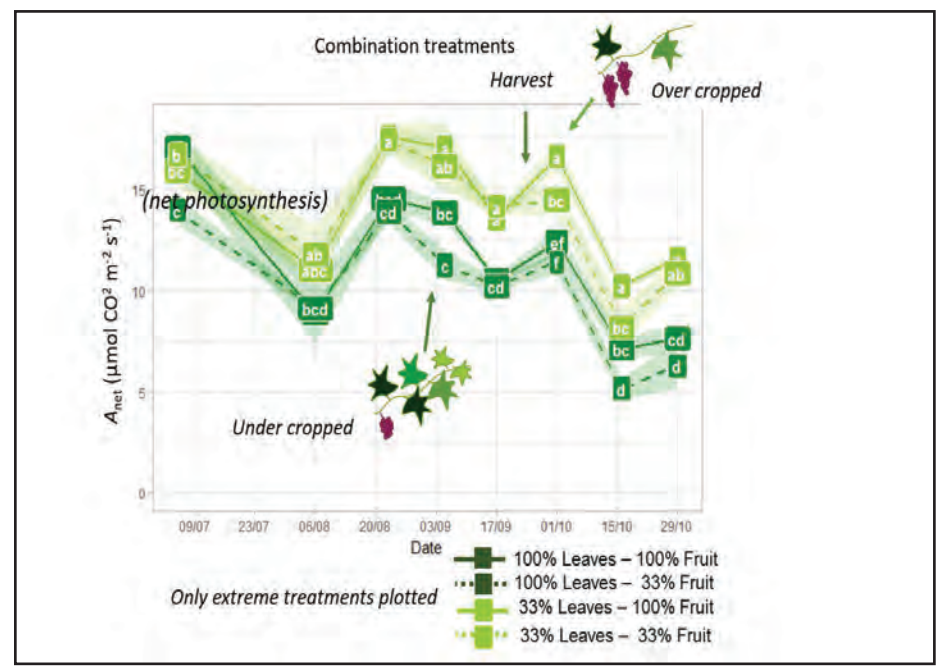
The trial data led to several takeaway messages as noted by Dr. Kurtural in his summary presentation for growers:

- Berry size (and thus yield) are more sensitive to canopy size than crop load or irrigation,
- Small canopies are more likely to reduce plant reserves (root starch) than over cropping,
- The challenge for increasing yields is controlling big canopies in EARLY SEASON.

Based on the information obtained from this experiment, his perspectives on what to do with this information are as follows:

Leaf area determines carbon fixation, not the fruit.

As stated in the paper's abstract, "After many efforts directed at balancing grapevine canopy by focusing on fruit removal, a renewed focus on maintaining an active leaf area with proper solar radiation exposure to clusters is needed." This diagram shows the impact of leaf area on the fruit. Most importantly, notice that the major responses in photosynthesis throughout the growing season tracked consistently with the percentage of leaves removed rather than the percentage of clusters removed, indicating that leaf removal is a more powerful tool for managing vine balance.



Cluster and berry thinning do not improve anthocyanin content in Cabernet Sauvignon.

Data sets showed that within each level of leaf retention, cluster removal actually had the effect of reducing the total anthocyanin content per berry.

Extreme crop thinning and leaf removal have strong negative effects on wine flavor.

Chemical and sensory analyses were run to characterize the aromatic profiles of these wines that would be consistent with other high-quality wines.

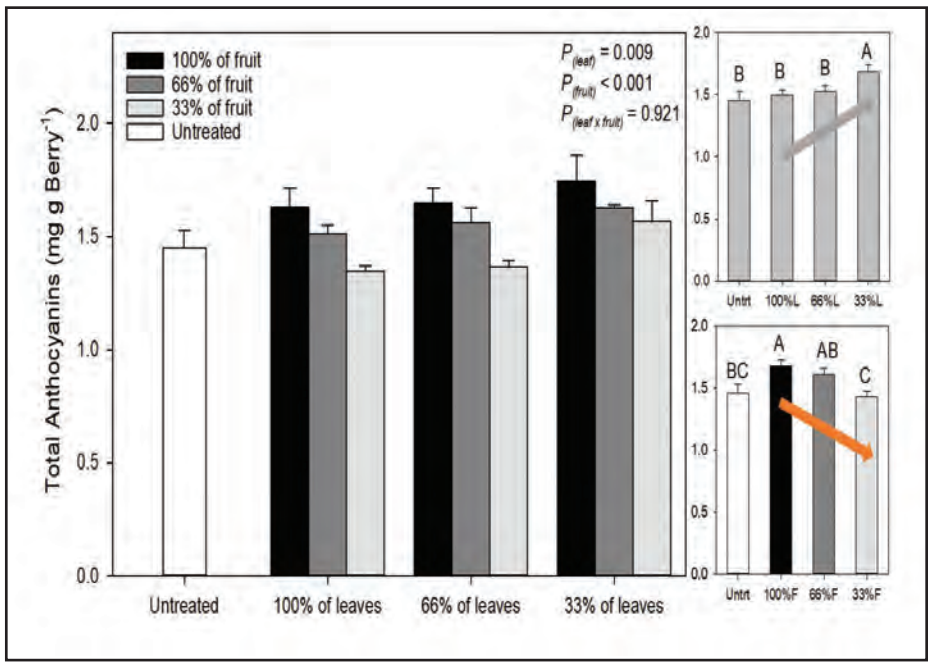


FIGURE 5 shows the effect of vegetal aroma (IBMP aka 2-methoxy-3-isobutylpyrazine). Notice that trying to control fruit quality, through leafing only, while bearing a full crop load, resulted in significantly higher perceived green character in blind tasting studies.

For a deeper look into the aromatic profile of each resulting treatment type between the highlighted extremes, refer to the chart below. This chart shows the treatment types of positive aromas perceived in red and negatively perceived aromas in blue. The zero result represents more even or neutral sensory perceptions. At a glance, the lower levels of leaf retention are associated with the most negative wine aroma compounds.

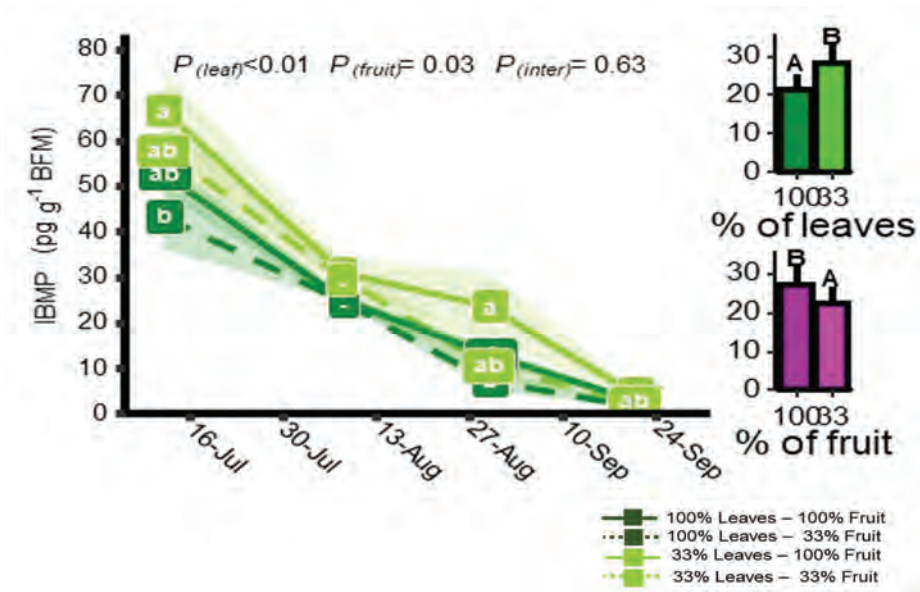
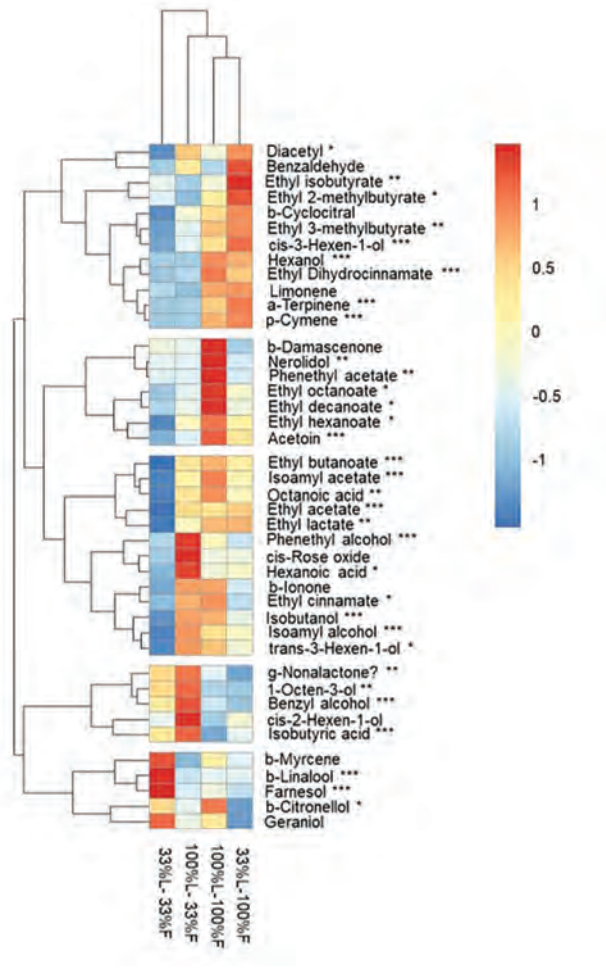


FIGURE 5 Vegetal aroma analyses (IBMP) by treatment type



Post-Mort Q&A

What was the motivation to conduct this trial? Why were you interested in the relationship between leaf area and crop load?

Kurtural: This was a request by growers that was funded by the American Vineyard Foundation for three years. They wanted to understand the sweet spot for quality and yield for Cabernet Sauvignon in Napa County. Growers wanted to increase production efficiency while maintaining yield quality. We met with them and designed this trial.

Which grape varieties did you study? Why did you pick those?

Kurtural: Cabernet Sauvignon is grown across California. Growers like Cabernet because it retains its value, is productive, tolerant to disease and grows well in the heat.

How did you design your experiment? What parameters did you measure?

Kurtural: The experiment was designed with yield targets in mind because it is a key business deliverable, as is quality. Addressing common thresholds, such as 1.5 to 3.5 tons, we saw ranges from 1 to 12 tons per acre. The goal was to determine what quality factors are limiting yield. We also wanted to understand the carry-over effects of the practices, so we needed a three-year trial.

In mid-June, we prepared 36 vines for this trial, pulling leaves and dropping clusters with peppercorn-sized grapes. We compared three levels of leafing versus three levels of cluster thinning at low, medium and high levels. All lots hung out in the vineyard until they reached roughly 25.5 °Brix. The treatments with the most leafing even hung on the vine until November. We not only measured the leaf area versus the cluster weights harvest at the same Brix: we

measured all the related chemistries and even dug out the plants to measure the root mass to make sure that we weren't missing anything. This was a very thorough and labor-intensive trial.

Who else worked with you on this trial?

Kurtural: I had a postdoc by the name of Dr. Johan Martinez working on this project. He did a nice job. He is now a faculty member at the University of Navarre in Pamplona, Spain. We are also very thankful to Suzanne Groth who coordinated the making of our trial wines through her winemaking team at Groth Winery here in Oakville.

What were you and your team's initial hypotheses before beginning the experiment?

Kurtural: The collective understanding is that lower crop yields make a better product. Our hypothesis at UC Davis was that yields can be as high as you want, so long as you can feed the fruit. We wanted to be sure that we could arrange the leaves on the canopy to ensure sun capture. We were able to identify an optimum threshold for leaf area versus crop load.

Did you encounter any difficulties during the study? If so, how did you address these complications?

Kurtural: Yes, we did. When you create these types of canopy arrangements, you tend to overexpose the fruit. Initially, we tried dipping the clusters in kaolin clay, which is like sunblock for the grapes, but that didn't work so well. We ended up putting up shade netting, which let in about 60 percent ambient light. Also, at the end of the trial, we dug up the vines because we wanted to see if we were reducing the root mass using these treatments. We destructively harvested 36 vines and their roots and dried them out in an oven to get their dry mass. That was a lot of work. On the bright side, we had to learn to use an excavator, and now that is a common practice.

How did you evaluate and measure the effectiveness of these canopy management practices? What was the most important outcome of the trial that growers/winemakers can use?

Kurtural: Leaf area was easy to measure. We have an app for that. The clusters were counted. We measured photosynthesis in terms of stomata conductance, using an infrared gas analyzer. The effectiveness of these treatments over these years was measured. It allows you to see how much carbon was produced, specifically glucose, fructose, sucrose, raffinose and starch.

Results? Myth busted! Over cropping is not the cause of low yields in the following years. It's lack of leaf area. Just to get the word out that there is no benefit to removing leaves. If you don't have leaves, you don't have the sugar you need to trigger the color intensity you want. It's sugar influx into the berries that kicks off phenolic biosynthesis. Might as well start this sooner than later in the season. It's also the shortest path to getting the ripe flavors that you desire with the lowest level of alcohol.

Were the results as you predicted or did anything unexpected occur?

Kurtural: There were unexpected things. We were thinking that manipulating leaf area would not affect photosynthesis. Nope! We found that the least amount of leaf area had the most amount of photosynthesis and the most stomatal conductance because they were always open. After all, they were doing triple duty in some cases. Even so, they just couldn't keep up. Any time that you left 33 percent of the leaves on the vines, the clusters would not fully set. We'd lose between 22 to 30 percent of the berries per cluster compared to those with more leaf area.

What was your and your team's impression of the resulting wines?

Kurtural: We made wines out of these treatments at Groth Vineyards and Winery. The results were quite surprising to us. The lots with more leaves generally came in at reasonable times throughout harvest. The lower leaf counts, however, were significantly delayed to the point that some were not harvested until November. Not only were they late but the heavily thinned treatments resulted in the least pleasant wines and had lower color intensity because the additional hangtime degraded more anthocyanins. The treatments with the 100-percent leaf area had the most ripe and complex flavors.

Do you plan to conduct a follow-up trial to re-test these results?

Kurtural: Using our optimized leaf area to crop load numbers from this trial, we followed up with an irrigation trial to find the sweet spot of yield ranges in drought years. Long story short: more water applied equals the more crop you can grow at 50 to 65 percent of crop evapotranspiration replacement.

For Oakville, this means less than 6 inches of precipitation. At that point the soils crack compared to a regular year. Regular year....haha. In 2019, we almost had 36 inches of rain. It's hard to predict anything anymore. **WBM**

References:

[1] Martínez-Lüscher J., Kurtural SK (2021) Same season and carry-over effects of source-sink adjustments on grapevine yields and non-structural carbohydrates. Front Plant Sci 12:695319. *https://doi.org/10.3389/fpls.2021.695319*