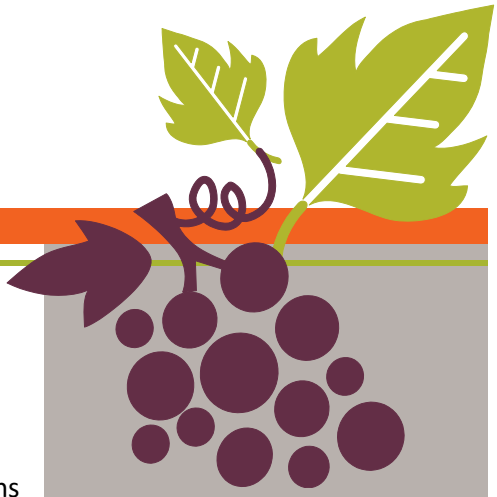
Fall 2017

Oregon Wine Research Institute
Viticulture & Enology
Technical Newsletter



Welcome to the Fall 2017 Newsletter

Our latest edition of the OWRI Technical Newsletter contains research updates and a comprehensive list of publications summarizing research conducted by faculty of the Oregon Wine Research Institute at Oregon State University. Dr. James Osborne, OSU Enology Extension Specialist and Associate Professor opens the newsletter with a research update on simultaneous malolactic fermentations. Dr. Patty Skinkis, OSU Viticulture Extension Specialist and Associate Professor provides valuable information on her vineyard floor management research. Lastly, Brent Warneke, OSU Graduate Research Assistant, and Dr. Walt Mahaffee's Foliar Pathology Lab at USDA-ARS, provide a timely article about fungicide timing for managing grape powdery mildew in light of fungicide resistance concerns.

To read this newsletter online, visit the OWRI website at https://owri.oregonstate.edu/oregon-wine-research-institute/extension-resources/owri-newsletters and bookmark this page for future reference.

Cheers,
The OWRI Team

Simultaneous Malolactic Fermentations: The Right Option for You?

Dr. James Osborne, Enology Extension Specialist and Associate Professor, OSU

Malolactic fermentation (MLF) is a vital step in the production of red wines as well as some white wines. MLF is performed by lactic acid bacteria, primarily *Oenococcus oeni* and results in the conversion of malic acid to lactic acid causing a decrease in acidity. For wines grown in cool climates that contain high levels of malic acid, this decrease in acidity is essential to the balance of the wine. In addition, MLF can modify certain wine flavors and aromas such as diacetyl. This compound has a buttery aroma and while at high concentrations (> 7 mg/L) it can be objectionable, at lower concentrations it may be desirable (depending on the wine style). Traditionally, this process has been conducted by indigenous wine lactic acid bacteria (LAB) present on the grapes or within the winery, and occurs during or after the alcoholic fermentation (AF). However, with the development of commercial starter cultures of *O. oeni*, winemakers now have more control over the timing of when this process occurs. This naturally leads to the question "when is the best time to conduct the MLF?"

IN THIS ISSUE

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MLF is most commonly conducted after the completion of the AF (sequential inoculation). There are a number of reasons for this. Firstly, it may be logistically advantageous to separate the two processes of AF and MLF so that wines in which you wish to retain acidity can be more easily prevented from undergoing MLF. Secondly, there is concern that the addition of *O. oeni* into juice or must (rather than wine) can lead to an increase in volatile acidity (VA) since *O. oeni* can convert sugar into acetic acid. However, several studies report that MLF in the presence of sugars does not necessarily lead to an increase in VA if the AF starts well and has no issues completing (Beelman and Kunkee 1985; Jussier et al. 2006). Others have also shown that *O. oeni* metabolism is significantly impacted by pH, and that at pH < 3.50 the bacteria will begin to consume sugar only when malic acid has been degraded. This means that in wines where the pH is < 3.50 acetic acid production by *O. oeni* would likely only be an issue if AF was sluggish and resulted in residual sugar still being present when the bacteria had completed malic acid degradation (Krieger-Weber and Silvano 2015).

At higher pH (> 3.50), the risk of acetic acid production by *O. oeni* is greater as sugar metabolism may occur concurrently with malic acid consumption. Recent work in our laboratory confirms what others have found regarding acetic acid production during simultaneous MLFs (Sereni 2016). Chardonnay wines were produced where MLF was conducted simultaneously or sequentially. Fermentations (AF and MLF) were performed at either 15 or 21°C with the pH values of the wines being relatively low (pH < 3.50). At each temperature, there were no significant differences in the acetic acid concentrations of wines produced with simultaneous or sequentially MLF (Table 1). Instead, acetic acid concentration was more dependent on fermentation temperature, with wines fermented at 15°C containing significantly higher acetic acid concentrations than wines fermented at 21°C no matter how MLF was conducted (Table 1).

Table 1. Time to complete alcoholic and malolactic fermentation and basic chemistry of Chardonnay wines produced where MLF was performed simultaneously or sequentially using *O. oeni* Beta at 15 or 21°C. Different letters within a row indicate significant differences at p<0.05.

	Fermentation Temperature (°C)	Days to complete Alcoholic and malolactic fermentation	Alcohol % (v/v)	Acetic acid (g/L)	Wine pH
Co-inoculation	15°C	26[a]	14.14[a]	0.72[a]	3.37
Sequential	15°C	68[b]	14.64[b]	0.70[a]	3.44
Co-inoculation	21°C	26[a]	14.18[a]	0.58[b]	3.42
Sequential	21°C	62[b]	14.55[c]	0.56[b]	3.44

An additional concern when conducting simultaneous fermentations is the potential inhibition of yeast by the bacteria leading to stuck or sluggish AF. While there are reports of this occurring (Munoz et al. 2014), the issue was yeast strain specific, and highlighted the importance of choosing the right combination of yeast and ML bacteria strains if a simultaneous MLF is being conducted. Regardless of when you decide to conduct the MLF, using a compatible yeast and ML bacteria strain is important as certain yeast strains can be inhibitory to ML bacteria and cause problematic MLF (Henick-Kling et al. 1994, Osborne and Edwards 2006). Many wine yeast and ML bacteria producers provide recommendations for combinations of yeast and ML bacteria strains to use, and these may differ depending on whether you wish to perform a simultaneous or sequential MLF.

Loss of red wine color due to simultaneous MLF may also be a concern that may discourage a winemaker from using this technique. However, recent studies in our lab demonstrated that color loss due to MLF occurs whether MLF is simultaneous or sequential (Fig. 1). Color loss is primarily due to the lower concentration of polymeric pigments in wines that have undergone MLF compared to those that have not (Fig. 1), and wines that underwent simultaneous MLF show the same trend. Degradation of acetaldehyde by

O. oeni is thought to be responsible for the decreased levels of polymeric pigments as this compound is involved in

the formation of these stable color pigments. Because *O. oeni* degrade acetaldehyde during simultaneous and sequential MLF it does not matter when MLF is conducted (Burns and Osborne 2013).

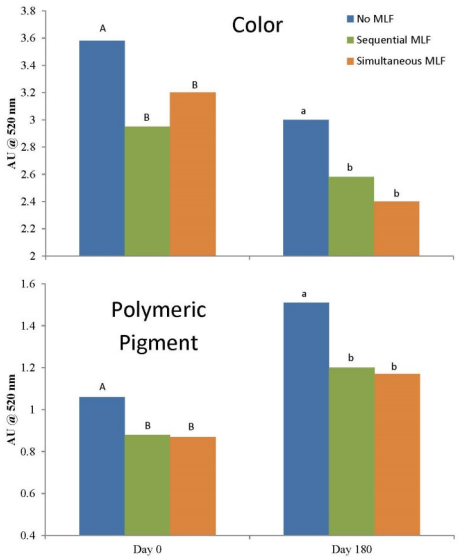

Figure 1. Color and polymeric pigment in Pinot noir wines that did not undergo MLF or underwent a simultaneous or sequential MLF using *O. oeni* VFO. Wines were analyzed 0 and 180 days post completion of MLF. Different letters indicate significant differences at $p<0.05$. Adapted from Burns and Osborne (2013).

While many of the reasons given for why MLF should be conducted sequentially rather than simultaneously are not necessarily backed up by research, are there any compelling reasons why you may want to conduct your MLF simultaneously? The major advantage with a simultaneous MLF is the reduced time needed to complete both the AF and MLF. From an efficiency point of view this is important, allowing wines to be stabilized with SO_2 sooner and minimizing the risk of microbial spoilage issues such as *Brettanomyces*. For example, in our Chardonnay study, simultaneous fermentations were completed in 26 days at both 15 and 21°C while sequential fermentations took 68 days to complete at 15°C and 62 days at 21°C (Table 1). This meant that wines produced by simultaneous MLF could have SO_2 added up to 40 days earlier than wines produced by sequential ferments. Notably, the wines produced in this study contained relatively high alcohol content (> 14% v/v) and yet did not have any issues completing MLF if the MLF was simultaneous. A successful MLF is often difficult to complete in high alcohol wines (Krieger-Weber and Silvano 2015). However, the addition of ML bacteria at the beginning of AF allows the bacteria to acclimate to increasing alcohol concentration as fermentation proceeds rather than being directly added to a high alcohol wine at the end of AF. In a similar manner, simultaneous MLF has also been shown to work well in low pH white wines that can also be problematic for MLF (Knoll et al. 2012).

MLF timing will also impact several wine flavor and aroma qualities. In particular, the concentration of the buttery aroma compound diacetyl will depend on whether MLF is simultaneous or sequential. Diacetyl can be produced by *O. oeni* during the MLF with the amount produced being dependent on *O. oeni* strain, fermentation conditions (pH, oxidative-reductive potential, temperature), and citric acid concentration. Under reductive conditions, diacetyl can be reduced to acetoin and then further to 2,3-butanediol, which can have little to no sensory impact. The reduction of diacetyl occurs during AF as the fermenting yeast create a very reductive environment. Because of this, diacetyl produced by *O. oeni* during a simultaneous fermentation will quickly be reduced to acetoin and potentially to 2,3-butanediol resulting in low diacetyl concentrations in the wine (Krieger-Weber and Silvano 2015). Therefore, if your goal is to produce a wine with buttery diacetyl aromas, you should not conduct a simultaneous MLF. Rather, perform a sequential MLF with a high diacetyl-producing *O. oeni* strain. On the other hand, if you wish to avoid having diacetyl in your wine, then consider conducting a simultaneous MLF with a low diacetyl-producing strain.

When choosing when to conduct the MLF in your wines, consider the advantages and disadvantages of conducting a simultaneous MLF. For some wine types and styles this option may provide a number of benefits. For others, a sequential MLF may still be the best option, particularly in the case of higher pH wines. If you choose to conduct a

simultaneous MLF check with your yeast and bacteria suppliers to ensure good compatibility between yeast and *O. oeni* strains. Also, keep in mind that *O. oeni* are more sensitive to low temperature and SO_2 concentrations, so you may have to adjust your winemaking procedures to ensure the success of the MLF.

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To till or not to till?

Dr. Patty Skinkis, Viticulture Extension Specialist & Associate Professor, OSU

Significant time and effort are devoted to managing grapevine canopies and preventing disease each year. As a result, other practices, such as vineyard floor management, becomes an afterthought and growers rely on standardized procedures, including maintaining resident vegetation or grassed alleys, under-vine herbicide use, tillage or a combination thereof. However, vineyard floor management can be an effective tool in controlling vegetative vigor which may have implications for both canopy and disease management. Many applied research studies have been conducted to better understand vineyard floor management practices, and as we experience warmer, drier seasons, it is important to consider results of these studies for their potential application to effectively manage vine growth, yield, water use, and pest issues.

Growers often use tillage in dry years, assuming that it will conserve soil moisture by removing competitive cover (weeds, resident vegetation or cover crop). Studies in arid regions have shown that resident vegetation or cover crops may lead to grapevine water stress (Celette and Gary 2013, Tesic et al. 2007). In contrast, Steenwerth et al. (2016) found that, compared to tilled plots, cover cropped plots had lower soil water content but did not have more water stress. However, this study took place in a deficit-irrigated vineyard in Lodi, CA. For higher rainfall regions like the Willamette Valley, research has shown that cover crops often do not compete for soil moisture, possibly due to their shallow root system or seasonal quiescence. For example, Sweet and Schreiner (2010) found lower soil water content with various cover crops compared to tillage in

two Oregon Pinot noir vineyards, but vines grown with cover crops did not have greater water stress than tilled treatments.

Research conducted by my lab has provided a good understanding of the impacts of common floor management practices for vigorous vineyards in the Willamette Valley. We found no differences in soil moisture or plant water status during the 9-years (2007-2015) comparing grassed alleys to tilled or alternate grass/tilled alleys in a grafted Pinot noir vineyard. The vineyard was located in the Dundee Hills and was on Jory soils. Under-vine soil moisture differed by grapevine phenology (growth stage) and year but not by the vineyard floor management treatments being evaluated (Figure 1). Furthermore, there were no differences in plant water stress during the growing season of any year. Even in the warmest, driest years (2014 and 2015), vines never reached midday stem water potential lower than -8.5 bars from bloom to veraison (Figure 2). Vines also never fell below -10.5 bars during ripening, indicating a lack of water stress in any treatment between 2007-2015. The lack of competition with grassed alleys may be due to alteration of vine rooting patterns over time, thereby allowing vine roots to access sufficient water resources (Celette et al. 2008).

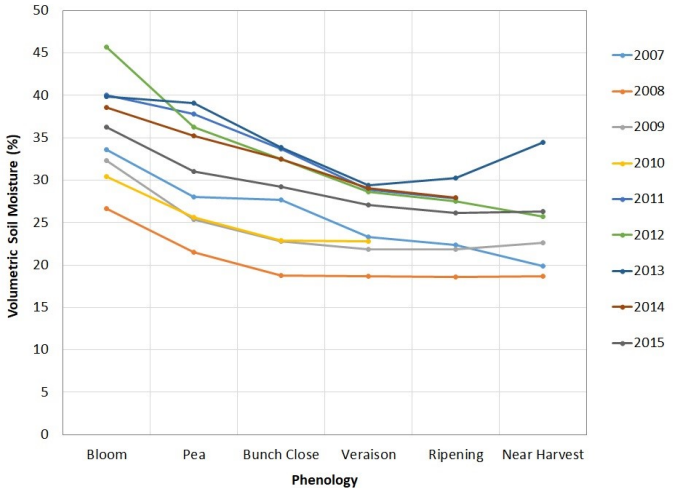

Figure 1. Soil moisture for the soil profile (to 76 cm depth) during key phenological stages each growing season from 2007 to 2015. Data points represent the mean across all vineyard floor management plots since there were no statistical differences between treatments (p>0.05).

Although there were no differences in vine water stress, floor management treatments led to differences in vine vegetative growth and fruit yield. By the end of the first year (2007), vines with grassed alleys had 20% smaller cane weights than vines grown with tilled or alternate grass/tilled alleys, and pruning weights were lower in all years that followed. Based on pruning weights, vines with grassed alleys were of moderate vigor compared to high vigor in alternate and tilled treatments. By year three, leaf area at veraison was 14% lower in vines with grassed alleys, and leaf area was 45% lower by year seven compared to tilled and alternate treatments (Reeve et al. 2016). Yield decline first occurred in vines with grassed alleys in year four of the study (2010) and was consistently lower in the years that followed (except 2012, a low yield year when inflorescence necrosis occurred in alternate and tilled treatments). By the end of the study, vines with grassed alleys had 26-30% lower yields than tilled or alternate treatments, but yields were always sufficient to meet the region's yield targets for premium Pinot noir production. Vine growth effects were associated with reduced vine nitrogen (N) status in vines with grassed alley compared to the other treatments. Although, vine N status never fell below our regionally defined deficiency thresholds. Other studies have also shown reductions in vine N status with perennial grass cover (Celette and Gary 2013) or resident vegetation (Tesic et al. 2007).

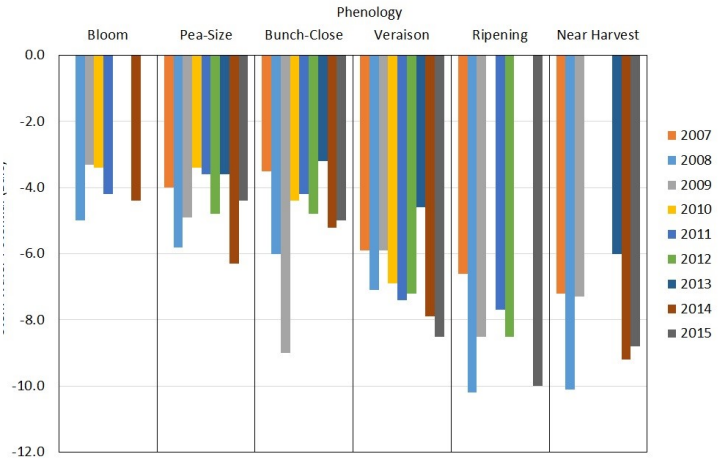

Figure 2. Midday stem water potential measured during key phenological stages in each growing season from 2007 to 2015. Bars represent the mean across all vineyard floor management lots since there were no statistical differences between treatments (p>0.05).

In our study, vines grown with tillage had greater vegetative growth that required more canopy management passes (hedging, leaf/lateral removal) than vines grown with grassed alleys, but yield and fruit composition were not compromised. In fact, vines with tilled and alternate alleys had better yeast assimilable nitrogen (YAN) concentrations in juice compared to vines grown with grassed alleys (Reeve et al. 2016). Furthermore, there were few differences in fruit ripeness or berry phenolics during this long-term study. While tilling the vineyard floor was not required to retain soil moisture or avoid vine water stress, it helped maintain optimum juice YAN. The disadvantage was greater vegetative growth that required presumably more canopy management to reduce the risk of powdery mildew or Botrytis infection. Although, differences were not found for infection of either of these two diseases during our study. Overall, growing vines with grassed alleys is an efficient way to manage vegetative vigor in dry-farmed vineyards without creating plant water stress, although it may lead to declines in yield and fruit YAN over time.

While in-season tillage remains a common management technique, especially with recent occurrences of warm, dry seasons, tillage can create dusty conditions that may result in problematic mite infestations. A number of vineyards across western had spider mite infestations that coincided with vineyard floor tillage and increased dusty conditions in 2017. The results of spider mite outbreaks is complex, and may be ameliorated, in part, by reduced tillage and growing cover crops in alleys to reduce dust and serve as refuge for natural enemies that may provide biological control (Hoy et al. 2011).

Many organic, biodynamic and sustainable-certified vineyards rely on soil tillage as a means to control weeds in-season in lieu of herbicide use. However, this can cause weed management concerns. Repeat tillage causes weed species shifts (Steenwerth et al. 2016) toward annual species that are taller (Armengot et al. 2016) and may create issues for canopy and fruit zone management as compared to no- or reduced-till practices. In addition, tillage can lead to greater issues in controlling weed species that spread or grow more aggressively with tillage. For example, Canada thistle can regrow from underground buds when tilled.

While tillage may cause some issues with mite outbreaks or weed control, avoiding tillage is not the answer. No-till soils tend to shift to perennial weed populations (Armengot et al. 2016), including hard-to-control weed species that may deplete soil fertility over time. I have encountered mature dry-farmed vineyards in the Willamette Valley with soil that has been undisturbed for decades with the exception of the requisite under-vine herbicide applications. These vineyards often show symptoms of nutrient deficiency (particularly N), including stunted growth, chlorotic leaves and reduced yields. However, this may be rectified by tillage as the first effort to increase vine vigor and productivity. The tillage process can promote vine growth due to increases in available N from decomposition of incorporated vegetation and/or through increased water infiltration.

Based on the results of the vineyard floor management trial, we found that alternating grass and tillage in the alleys flanking vine rows was the best long-term approach to vineyard floor management. Alternate and tilled treatments often did not differ in vine vigor (based on leaf area or pruning weights); however, the alternate treatment vines maintained yields and YAN levels without posing the potential pitfalls of repeated tillage. While devigoration with grassed alleys was a positive outcome in this high vigor vineyard, vine growth became more variable over time compared to the alternate and tilled treatments. Long-term, the grass treatments would require fertilizer supplementation or the use of some tillage and new cover crop establishment to maintain desired productivity. The results of this work confirms that complete vineyard tillage is not required to ensure healthy vine growth under dry summer conditions in the Willamette Valley, but the use of some perennial grass cover and/or tillage may allow the best

compromise for vine growth and fruit YAN depending on vineyard site.

The long-term study was funded, in part, by the following: Oregon Wine Board, Northwest Center for Small Fruits Research, and the Agricultural Research Foundation. We thank vineyard collaborators at Stoller Family Estate Vineyard for their cooperation throughout the project.

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Grape Powdery Mildew Fungicide Application Timing: The Interaction Between Inflorescence Stage and Fungicide Chemistry

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Tara Neill, Biological Science Technician, USDA-ARS
Dr. Walt Mahaffee, Research Plant Pathologist, USDA-ARS

Introduction

Grape Powdery Mildew (GPM) is present in Oregon vineyards every year and can wreak havoc when the right environmental conditions are met. Thus, numerous fungicide applications are made, typically on a calendar basis, to keep cluster infection to a minimum. However, recent marketing and consumer preference trends emphasize sustainably-produced products which require optimized fungicide use to produce disease-free grapes.

Whatever the vineyard management philosophy, making the most of each fungicide application is critical. Flowering is an important time to manage GPM, and general recommendations are to apply the most efficacious materials at the shortest spray intervals during this period. Reasons for intensive GPM management around grape bloom include the high susceptibility of inflorescences to infection, and the potential for inflorescence architecture to increase fungal spore deposition, resulting in cluster infections. Optimization of fungicide selection and application timing during bloom could increase the efficiency of GPM management. The use of fungicides that redistribute around plant tissues after application could provide more uniform coverage on intricate tissues, such as a grape inflorescence, resulting in better GPM control. To investigate fungicide application timing during bloom and the influence of fungicide redistribution on disease control, a small plot experiment was conducted on 19-year old Pinot Noir vines trained to bilateral cane VSP on 5' vine by 6' row

spacing at the OSU Botany and Plant Pathology Farm in Corvallis during the 2015 and 2016 growing seasons.

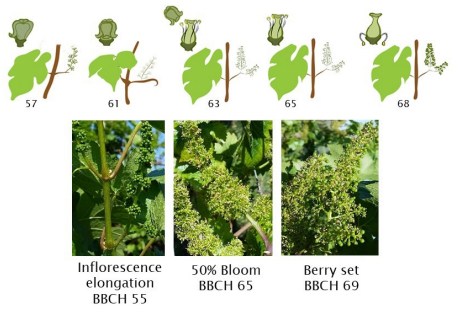

Figure 1. Top: Graphics showing the progression of grapevine flowering as denoted by the BBCH scale. Bottom: Three flowering growth stages to which fungicide applications were applied and their corresponding BBCH numbers. Photos by Brent Warneke, graphics by Javier Tabima.

Methods

Redistributing fungicides (Table 1) were applied to plots when > 50% of the research vineyard had reached one of three flowering stages based on inflorescence architecture (Figure 1).

Table 1. Selected fungicides, mechanisms, and application rates due.

Fungicide Name		Fungicide Mechanism			Application Rate (/Acre)
Trade	Technical	FRAC Group	Mode of Action	Redistribution Properties	
Quintec	Quinoxyfen	13	Inhibition of cell signaling and appressorium development	Xylem systemic, vapor phase	4 fl oz
Toledo	Tebuconazole	3	Sterol demethylation inhibition	Xylem mobile	4 oz
Luna Privilege	Fluopyram	7	Succinate dehydrogenase inhibition	Translaminar, xylem, and vapor phase	4 fl oz
Flint	Trifloxystrobin	11	Q_oI inhibitor of mitochondrial bc1 complex	Translaminar, vapor phase	2 oz
Microthiol	Sulfur	M2	Unknown multi-site activity	Vapor phase	3 lb

Five fungicides were chosen based upon their widespread use in industry and varied redistribution profiles (Table 1). All fungicides were applied on a 14-day schedule (Figure 2). Sulfur was applied prior to initiation of redistributing fungicide × growth stage treatments. Beginning at each growth stage, a redistributing fungicide was applied twice on the 14-day schedule, and then sulfur was applied until veraison. This resulted in 3 separate treatments for each redistributing fungicide for a total of 15 treatments (3 growth stages × 5 fungicides).

These growth stage × fungicide treatments were compared to two different control treatments, a non-treated control that had water applied during each fungicide application, and a calendar-based sulfur program that had 3 lb/A of sulfur applied every 14 days at a volume of 50 gal/A at full canopy. The 17 total treatments were replicated 4 times and arranged in a randomized complete block design. To concurrently investigate fungicide redistribution under field conditions, a subset of clusters from every growth stage × fungicide treatment were individually covered with plastic bags to prevent fungicide deposition during fungicide applications.

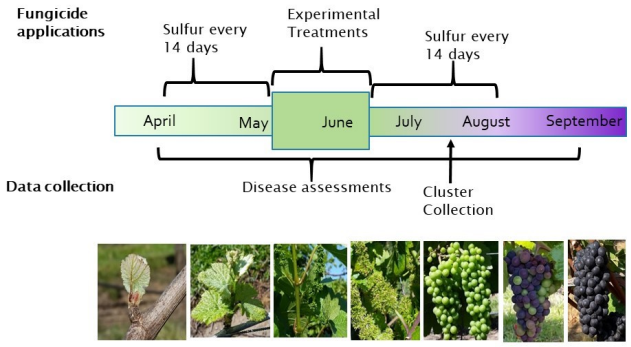

Figure 2. Timeline of the fungicide timing experiment. Photos by Brent Warneke.

These clusters did not receive any direct fungicide exposure, so any disease control was hypothesized to be a result of fungicide redistribution.

Leaf incidence of GPM was assessed weekly starting at 12" of shoot growth and ending at veraison. To quantify berry disease incidence, 10 green clusters per treatment were collected prior to veraison and 25 berries per cluster were examined under magnification for the presence of GPM.

Results

The 2015 and 2016 growing seasons were warm and started early. Bud break occurred at the BPP research vineyard in late March 2015 and early April 2016. This early start led to rapid vegetative growth as both springs were warm with summer-like weather. Flowering lasted 14 days in

2015 (5/29 – 6/12) and 8 days in 2016 (5/29 – 6/6). Throughout both summers, there were multiple days over 100ºF with average high temperatures consistently above historical averages. Disease pressure was higher in 2016 than in 2015 as evidenced by leaf disease levels (Figure 3).

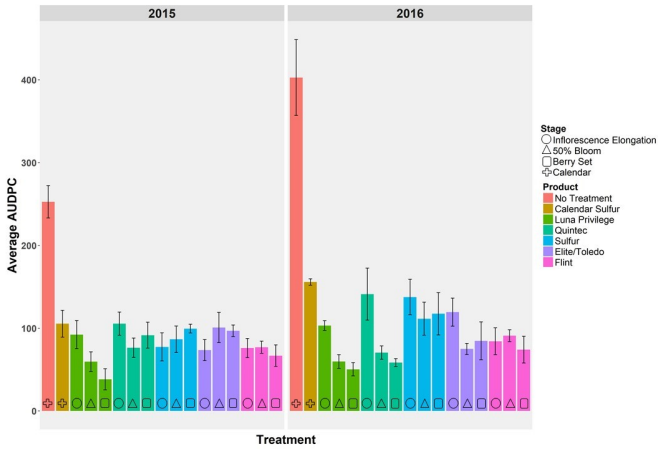

Figure 3. Area under the disease progress curve (AUDPC) by treatment in 2015 (left) and 2016 (right). The colors show the fungicide used, and the shape within each bar indicates the timing of the fungicide application. Bars and whiskers represent the mean ± one standard error, respectively.

Leaf GPM infection

To compare leaf disease levels between treatments, area under disease progress curves were calculated using leaf incidence data. Some fungicides showed variable disease levels among the three application timings while others had a trend towards less disease when fungicides were applied later in inflorescence development (e.g. Luna Privilege, Fig. 3). Overall leaf disease levels of the fungicide timing treatments were similar to or lower than the calendar application of sulfur.

Berry GPM infection

The mean number of berries infected was used to compare the probability of berry infection for each treatment. Berry infection probabilities from wettable sulfur and Toledo treatments showed no consistent trend related to application timing in both 2015 and 2016, with probabilities similar to or greater than the calendar sulfur control. Conversely, the bloom and berry set applications of Quintec, Flint, and Luna Privilege had consistently lower disease incidence than the calendar sulfur control and their respective inflorescence elongation timing application, resulting in average berry infection probabilities of less than 0.15 (Figure 4). Flint, Luna Privilege and Quintec bloom and berry set applications were the most effective at reducing berry infection in both years, often with statistically significant reductions in berry incidence compared to calendar application of sulfur ($P<0.05$).

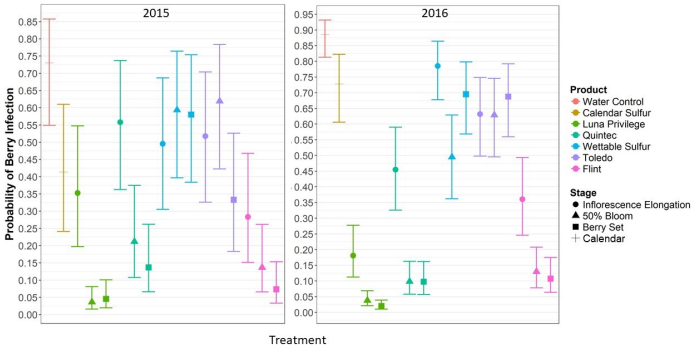

Figure 4. Probabilities of berry infection from 2015 and 2016. Points are the mean probability of berry infection, bars are 95% confidence intervals.

Fungicide Redistribution

The majority of clusters that were covered with plastic bags during fungicide treatments had significantly reduced disease levels compared to the non-treated control. This result suggests that there was redistribution of the fungicides from treated tissues surrounding the bagged cluster, but there could also be an effect of the reduced leaf infection observed in these plots. Regardless of the mechanism for reduced berry incidence, these data indicate that applying redistributing chemistries during bloom and berry set significantly reduces disease development on berries.

Discussion

Similar trends in berry infection probabilities among fungicide products were observed during the two years of this study with varying GPM pressure, which indicates that late in grape bloom is an opportune time to apply redistributing fungicides. All three fungicides that effectively reduced the proportion of berries infected when applied mid-bloom to berry set (Flint, Quintec, Luna Privilege) exhibit varying degrees of translocation and vapor phase redistribution (Warneke et al. 2017). The efficacy of these late-

bloom applications may be due to the fungicide penetrating the developing berry and/or rachis, the increased surface area available for fungicide deposition in the later applications, the timing of the fungicide application reducing leaf disease at an opportune time, or any combination therein. During early bloom, fungicide applied to the developing inflorescence may have adhered to the cap and was then lost when the cap fell off during bloom, while in later treatments the fungicide may have penetrated the developing berry and/or rachis. This could be due to epicuticular wax accumulating as berries develop, facilitating fungicide retention and redistribution in the cluster (Edgington 1981; Klittich 2014; Rosenquist and Morrison 1988). Furthermore, the surface area available to receive fungicide in a cluster increases as berries set and begin to swell, allowing for more fungicide deposition. Fungicide application at bloom and berry set may also slow leaf infection at a time when the developing clusters are most susceptible to infection, delaying infection pressure to a time when the berries are more developed and thus, less susceptible to infection (Gee et al. 2008). Further testing is needed to determine the mechanisms responsible for reducing GPM infection when applying redistributing fungicides late in bloom. In 2017, demonstration trials were conducted in research and commercial vineyards to assess the applicability of timing redistributing fungicide applications to bloom stages, with results forthcoming.

This work was supported by the Oregon Wine Board (Project Number 1826) and USDA-ARS CRIS 5358-22000-039-00D. The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the United States Department of Agriculture, the Agricultural Research Service, or Oregon State University of any product or service to the exclusion of others that may be suitable. The authors thank Andy Albrecht, Chris Gorman, Bailey Williams, and Carly Allen for their technical assistance throughout the project.

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Research Publications

Results of research conducted in viticulture and enology are published in peer-refereed academic journals, peer-reviewed reports, or books, which validates the scientific work of the authors. The following articles describe research conducted by members of the Oregon Wine Research Institute at Oregon State University.

Disease Management

Thiessen LD, Neill TM, and Mahaffee WF. 2017. Timing Fungicide Application Intervals Based on Airborne *Erysiphe necator* Concentrations. Plant Dis 101:1246-1252 doi:10.1094/pdis-12-16-1727-re.

Grapevine Nutrition

Schreiner RP. 2016. Nutrient uptake and distribution in young Pinot noir grapevines over two seasons. Am J Enol Vitic 67:436-448.

Schreiner RP and Scagel CF. 2017. Leaf blade versus petiole nutrient tests as predictors of nitrogen, phosphorus, and potassium status of 'Pinot Noir' grapevines. Hort Science 52:174-184.

Viticulture

Bailey BN and Mahaffee WF. 2017. Rapid measurement of the three-dimensional distribution of leaf orientation and the leaf angle probability density function using terrestrial LiDAR scanning. Remote Sensing Environ 194:63-76 doi:10.1016/j.rse.2017.03.011.

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Practical Guides

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