GRAPE (*Vitis vinifera* 'Pinot noir', 'Pinot gris')
Powdery Mildew; *Erysiphe necator*

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Efficacy of phenologically based fungicide programs using biological products and micronized sulfur while using an Intelligent and airblast sprayer for management of grape powdery mildew, 2021.

Micronized sulfur and biological fungicides were applied during critical periods for powdery mildew management on Pinot noir and Pinot gris vines at the Botany and Plant Pathology Field Laboratory in Corvallis, Oregon. In the past, use of biological products all season long generally resulted in poor powdery mildew control. In this trial, treatments were focused on evaluating biological fungicides only during the critical period of flowering (Pinot gris), or before and after flowering (Pinot noir, Figure 1). Sulfur is an effective material and was used in the program outside of when the biological fungicides were used (Figure 1). Additionally, each of the biological fungicide treatments were applied using the Intelligent Spray System (ISS) to compare the efficacy of using the system with the same program.

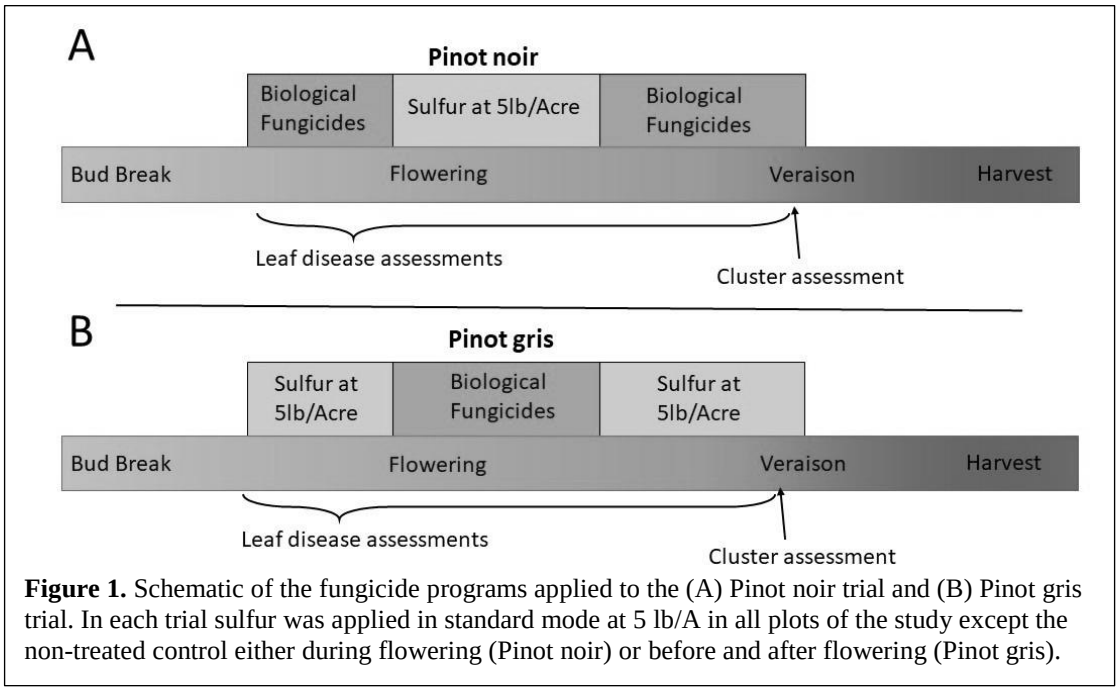


Figure 1. Schematic of the fungicide programs applied to the (A) Pinot noir trial and (B) Pinot gris trial. In each trial sulfur was applied in standard mode at 5 lb/A in all plots of the study except the non-treated control either during flowering (Pinot noir) or before and after flowering (Pinot gris).

The sprayer used (50 gallon Pak-blast, Rears Mfg., Coburg, OR) was a standard "off-the-shelf" sprayer retrofitted with a Lidar laser sensor, Doppler speed sensor, embedded computer, and individual pulse width modulation (PWM) solenoid valves at each sprayer nozzle. These components adjust pesticide application volume in real time to match plant canopy characteristics, with the goal of minimizing pesticide use and off target drift while keeping pest management similar to standard sprayers. A spray console wired to the system allowed use of either the ISS components or standard constant-rate operation mode. When the ISS was used it was referred to as "intelligent mode," and when the system was off and standard operation occurred it was referred to as "standard mode." The sprayer was operated using a Kubota M5N-111 tractor and the nozzles in the sprayer were TeeJet ceramic D3 discs and DC25 cores.

Treatments (Table 1) were arranged in a randomized complete block design in each cultivar. For both the Pinot noir and Pinot gris trials, fungicide programs were initiated just after powdery mildew was located in a nearby block in mid-May. Until 50% bloom, biological fungicides (Table 1) were applied to Pinot noir vines, while 5 lb/A Microthiol Disperss (MD) was applied to Pinot gris vines. Upon 50% bloom, 5 lb/A MD was applied to Pinot noir

Table 1. Biological fungicide treatments applied to Pinot noir or Pinot gris vines.

Pinot noir		Pinot gris	
Treatment[x]	Sprayer Mode[y]	Treatment[x]	Sprayer Mode[y]
Non-treated	N/A	Non-treated	N/A
LifeGard 4.5oz/100gal[z]	Intelligent	Aviv 30fl oz/100gal[z]	Intelligent
LifeGard 4.5oz/100gal	Standard	Aviv 30fl oz/100gal	Standard
Theia 3lb/A[z]	Intelligent	Serenade ASO 4qt/A[z]	Intelligent
Theia 3lb/A	Standard	Serenade ASO 4qt/A	Standard

[x]Treatments applied at 80psi at approx. 430 PTO rpm and 3 mph.
[y]Intelligent mode treatments applied at 0.12fl oz/ft^3 of grape canopy.
[z]Treatments mixed at the rate indicated if the sprayer was used in standard mode. Actual rates applied by the ISS were lower due to the lower volume applied in intelligent mode.

vines and biological fungicides (Table 1) were applied to Pinot gris vines. After 4 weeks post flowering (5 applications) the fungicide program for each cultivar reverted to what was applied before bloom (Figure 1).

These schedules were based on the different stages of a grape powdery mildew (GPM) epidemic. Initially, before grapevines flower fungicide programs are focused on preventing GPM infections from occurring, primarily on leaves. During flowering and for approximately 3 weeks thereafter, fungicide programs are focused on preventing infection of the grape clusters. Flowering and fruit set are generally seen as the most critical time for management of GPM. After three weeks post flowering fungicide programs focus on keeping GPM levels low on both leaves and fruit. -Fungicide program intensity is usually not as aggressive mid-summer as the earlier two sections of the season. The periods before and after bloom are generally thought of as managing leaf infections while the period from bloom to shortly thereafter is thought of as the critical time to manage cluster infection. The Pinot noir and Pinot gris trials allowed testing of whether using biological products to manage the leaf infection periods or the cluster infection period was the better strategy, while not overwhelming the biological fungicide products with the high disease pressure of the research vineyard.

The blocks used consisted of 'Pinot noir' and 'Pinot gris' planted in 1998 on *V. rupestris* x *V. riparia* 101-14 rootstock with 7x8 ft spacing. A single buffer rootstock vine was trained between each set of treatment vines and a buffer row of rootstock vines separated each varietal row, which helped minimize plot-plot interference. Vines were trained to a Guyot (vertical shoot position) system and pruned by 15 March. Shoot thinning by hand occurred from 22 April to 15 May and sucker removal by hand was continuous throughout the season. Shoots were cut above the top wire on 10 June and maintained at this height throughout the growing season. Fungicide treatments were applied every 7-10 days. Each treatment was replicated on 4 sets of 5 vines.

Rainfall for the dormant season (Oct 2020 to March 2021) was close to normal but spring rainfall was the second lowest ever recorded. Spring weather was mild with a few rain events to initiate ascospore release and subsequent primary infection. Signs of powdery mildew were first found on 13 May as a few scattered lesions on a neighboring vineyard block. Bloom took place from approximately 1 to 10 June with most caps detaching from 1 to 4 June.

Leaf and cluster data were taken on the middle three vines of each experimental plot by randomly examining either 25 clusters or leaves on both the east and west side of the row for a total of 50 units examined per plot. The incidence of powdery mildew on leaves was recorded weekly from 16 June through 18 August. The severity of powdery mildew on clusters was taken on 3 August. Leaf incidence data was analyzed by calculating the area under disease progress curve (AUDPC) which was calculated by multiplying the mean incidence from two observation dates by the number of days between observations ($\Sigma[Y_{i+1} + Y_i)/2][X_{i+1}-X_i]$ where Y_i is incidence of mildew at i*th* observation and X_i is the day of the i*th* observations) and adding together the values. AUDPCs were calculated using the agricolae package and a modeled with a linear model. Cluster severity percentages were modeled using a generalized linear mixed model with block fitted as a random effect. Cluster severity treatment contrasts were

Table 2. Area under disease progress curve (AUDPC, leaf disease) and percent infected berries from Pinot noir and Pinot gris biological fungicide Intelligent Sprayer trials at the Botany and Plant Pathology field lab in 2021.

Pinot noir			Pinot gris		
Treatment[xy]	**AUDPC[z]**	**Percent Infected Berries[z]**	**Treatment[xy]**	**AUDPC[z]**	**Percent Infected Berries[z]**
Non-treated	2969 (2753-3184) A	75.2 (69.5-80.2) A	Non-treated	2964 (2916-3011) A	74.0 (68.0-79.2) A
LifeGard Intelligent	741 (526-957) B	9.8 (7.5-12.7) B	Aviv Intelligent	2266 (2081-2451) B	13.8 (10.7-17.7) B
LifeGard Standard	706 (491-922) B	9.1 (7.0-11.8) BC	Aviv Standard	2231 (1982-2480) B	16.1 (12.5-20.4) B
Theia Intelligent	661 (445-876) B	7.5 (5.7-9.7) BC	Serenade ASO Intelligent	1974 (1552-2396) B	14.6 (11.3-18.7) B
Theia Standard	417 (202-633) B	5.5 (4.2-7.3) C	Serenade ASO Standard	2236 (2004-2467) B	18.2 (14.2-23.0) B

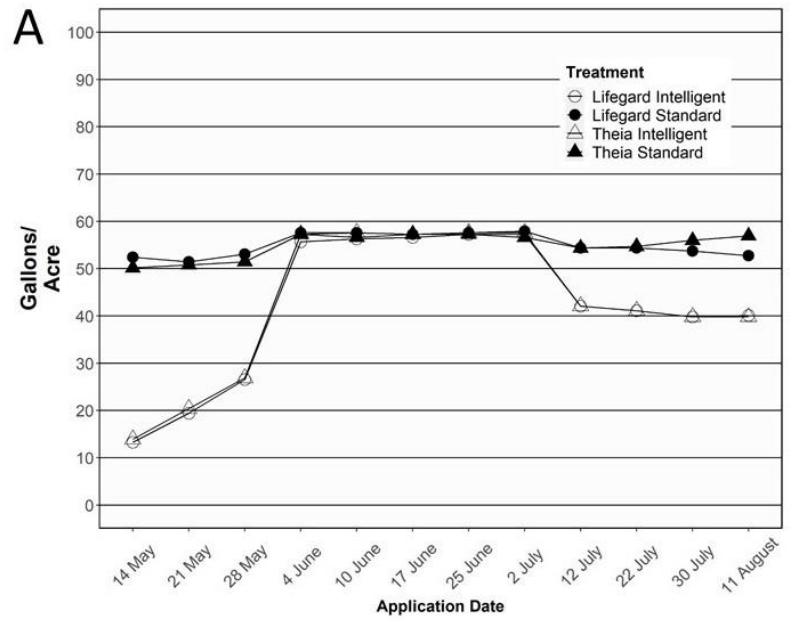
[y]All treatments were applied at 80psi at approx. 430rpm PTO; intelligent sprayer treatments applied at 0.12fl oz/ft^3 of grape canopy.
[z]Estimates are followed by asymptotic 95% confidence intervals in parentheses. Treatments followed by different letters are significantly different than each other, marginal means contrast ($p<0.05$) with p values adjusted using Tukey method.

conducted using the emmeans package and model fit was checked with the DHARMa package. Uncertainty was estimated using asymptotic 95% confidence intervals. All data was analyzed in R version 4.0.3.

In both the Pinot noir and Pinot gris trials AUDPC values were significantly higher in the non-treated plots than all fungicide treated plots (Table 2). All fungicide treated plots had AUDPC values that were not significantly different than each other in both trials. In the Pinot noir trial, average cluster severity of the non-treated control was 75.2% which was significantly higher than all other treatments. All fungicide treatments in the Pinot noir trial resulted in average cluster severity of less than 10% with LifeGard intelligent and standard and Theia intelligent not significantly different from each other (Table 2). Theia standard had the lowest observed cluster severity at 5.5%, which was significantly lower than LifeGard intelligent although not significantly lower than the LifeGard standard or Theia intelligent treatments. In the Pinot gris trial the non-treated control resulted in an average of 74% cluster severity which was significantly higher than all other fungicide treatments (Table 2). Aviv and Serenade ASO treatments both in intelligent or standard mode resulted in average cluster severities between 13.8% and 18.2%, all of which were not significantly different from each other.

Spray volumes applied in the Pinot noir trial remained at or slightly above 50 gal/A for both standard mode treatments (Figure 2A). Pinot noir intelligent mode treatments started the season at about 13 gal/A then jumped to 27 gal/A before bloom, and stayed fairly consistent after the bloom period sprays at about 40 gal/A (Figure 2A). Spray volumes applied in the Pinot gris trial remained between 50 and 60 gal/A for the season in standard mode (Figure 2B). In the bloom period intelligent mode treatments resulted in volumes applied of between 36 and 40 gal/A. In the Pinot noir trial LifeGard standard mode resulted in higher than the recommended rate of 2.25 oz/A when 50 gallons of water was applied throughout the trial, while in intelligent mode a lower than recommended rate was applied before bloom but after bloom the listed amount of 2.25 oz/A was applied (Figure 3A). For Theia there is no label rate range at this time but in standard mode more than the use rate of 3 lb/A was applied for the whole season, while in intelligent mode the amount ranged from about 1 lb/A at the first application to around 2.5 lb/A after the bloom period (Figure 3A). In the Pinot gris trial when biological fungicides were applied during bloom the amount of Serenade ASO applied ranged from 2.9 to 3.2 qt/A and 4.3 to 4.5 qt/A in intelligent mode and standard mode, respectively, both within the label recommended rate of 2 to 4 qt/A (Figure 3B). For Aviv, 12.9 to 14.7 fl oz/A and

19 to 19.9 fl oz/A were applied in intelligent and standard mode, respectively, with intelligent mode being below the label recommended rate of 15 to 25 fl oz/A (Figure 3B).



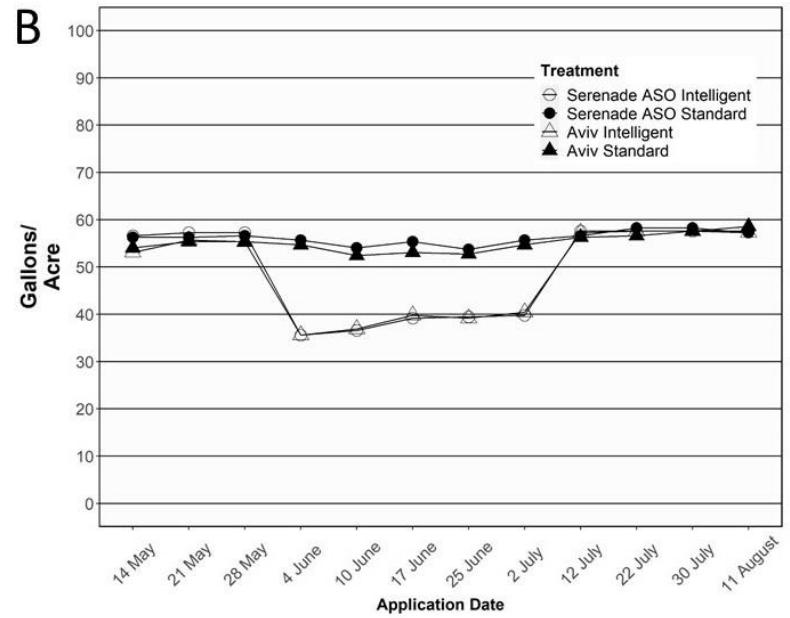


Figure 2. Spray volume applied (gallons/A) on each application date in the 2021 Pinot noir (A) and Pinot gris (B) trials.

Biological fungicides generally have a few similar modes of action. Some products contain live microorganisms that when sprayed onto plant surfaces, grow and proliferate, thus excluding pathogens because of lack of free space on the plant surfaces and/or production of natural anti-microbial compounds. Other products do not necessarily need live organisms but contain compounds derived from them that inhibit the pathogen and/or activate plant defense responses so that infection attempts by the pathogen are less successful. While live organisms are needed to colonize plant tissue in the first mode of action, these products may also activate plant defense responses in addition to the live organisms colonizing the tissue. Aviv, Serenade ASO and Theia contain live bacterial spores that colonize leaf tissue while also activating plant defenses. It is known that the bacteria in Serenade do not need to be viable to maintain the product's activity. LifeGard has live bacterial spores, but acts solely by activating plant defenses and has no direct activity on pathogens. All of these products work in a preventative manner, with little to no curative activity.

While the fungicide schedules in both the Pinot noir and Pinot gris trials resulted in much lower cluster severity than the non-treated controls in those studies, the Pinot noir trial where sulfur was applied during bloom resulted in lower average cluster severities among fungicide treatments than those from the Pinot gris trial where biologicals were used during bloom.

The more effective strategy when using biological fungicides was likely applying them early in the growing season as in the Pinot noir trial because they were used first while GPM levels were still low in the vineyard, and likely primed the defense responses of the plant leading up to bloom. Sulfur is known to be an effective fungicide against powdery mildew so using it during the critical period of bloom at a known effective rate (~5 lb/A) likely provided an effective barrier to infection during bloom and thereafter. Flipping the application times of biological fungicides and sulfur as in the Pinot gris trial was less effective at protecting grape clusters because sulfur, the most effective fungicide against GPM in this study, was not used during the critical window of bloom through early berry development.

While the strategies of when the biological fungicides were applied had an effect on the resulting level of GPM on clusters and leaves, the sprayer mode (intelligent or standard) did not. The products used in both trials were mixed at a rate assumed to be applied in standard mode and as a result when the sprayer was used in intelligent mode, a lower quantity per area of these products was applied (Figure 3). When Aviv and LifeGard were used in intelligent mode during bloom, and prior to bloom, respectively, that resulted in an amount of each product applied per acre that was near or below the label recommended rate. For these products it could be that the amount of each product that was applied was sufficient for each to effectively express their mode of action to a similar extent as the label rate range. This could be in part due to the systemic acquired resistance (SAR) aspect of these products whereby they activate the defense responses of the plants. When purely contact based fungicide materials are applied, lower volumes applied typically result in poorer disease control, however when systemic materials are used typically their ability to translocate in plant tissues can make up for the typically lower coverage seen in lower volume applications (Warneke et al. 2022, in press). A similar phenomenon may be see here with biological fungicides that activate the SAR response being less sensitive to application volume than purely contact materials.

Future trials could test the use of other biological fungicides in the same schedules to see if similar trends are observed. Additionally, adding a control where sulfur was applied during the prescribed time in the schedule without any biological fungicide applied would more clearly show the effect of using the biological in the spray program.

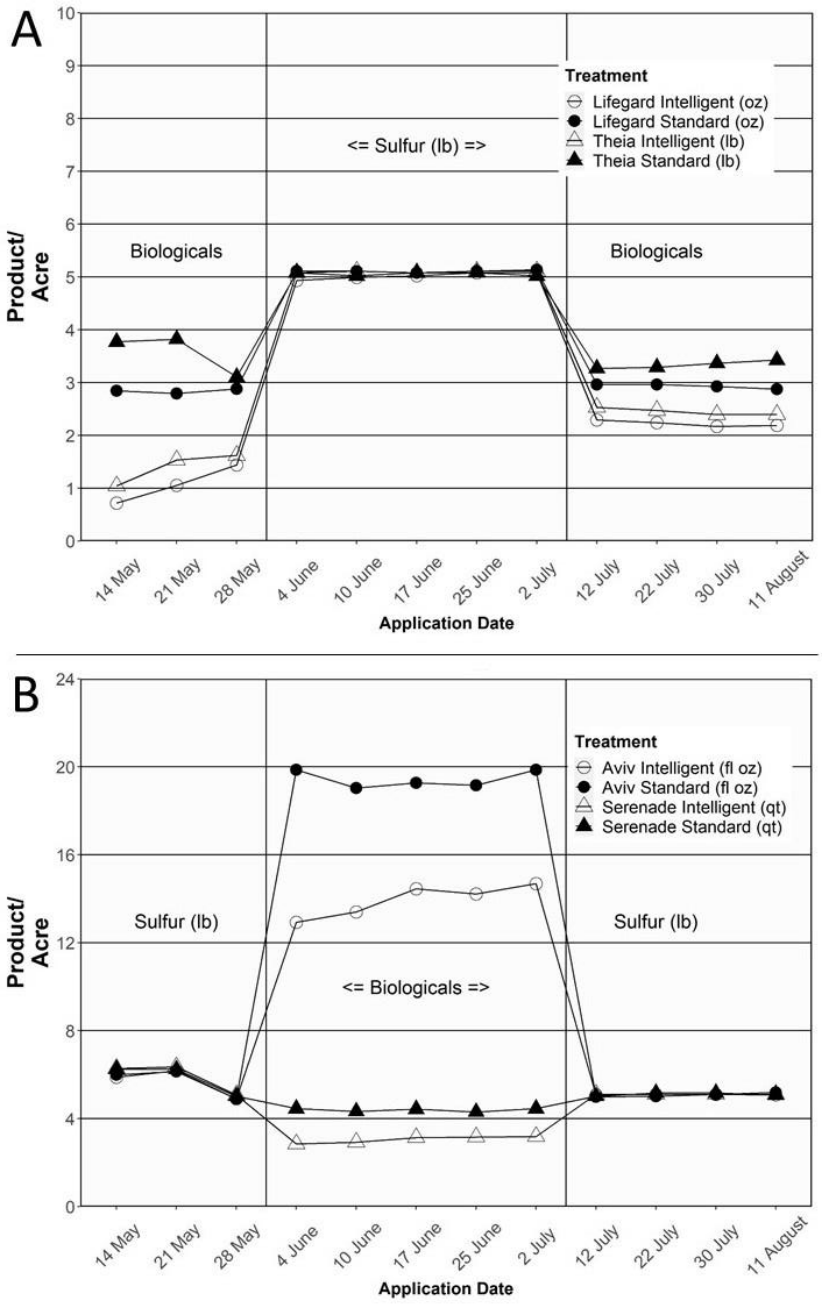


Figure 3. Pesticide quantity applied (quantity/A) on each application date in the 2021 Pinot noir (A) and Pinot gris (B) trials. Units for each product are indicated in the legend of each graph, and only apply to the "biologicals" panel in each graph. Outside of the biologicals panel in each graph sulfur was applied and values reflect that in pounds (lb/A).

Literature cited:

Warneke, B. W. Nackley, L. L., Pscheidt, J. W. 2022. Management of grape powdery mildew with an intelligent sprayer and sulfur. Plant Disease. (in press)