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, 2023.

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 resulted in poor powdery mildew control. In 2023 trials, treatments were focused on evaluating biological fungicides applied before and after flowering (Figure 1). Sulfur is an effective material for management of powdery mildew and was used in the program during the critical powdery mildew management period of bloom and early berry development (Figure 1). This type of fungicide regime was also evaluated in 2021 and 2022 and was found to be a more realistic way to evaluate the activity of biological fungicides than their application alone. 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.

The sprayer used (50 gallon Pak-blast, Rears Mfg., Coburg, OR) was a standard air blast 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 make up the ISS that adjusts pesticide application volume in real time to match plant canopy characteristics. In doing so, the sprayer can minimize 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.

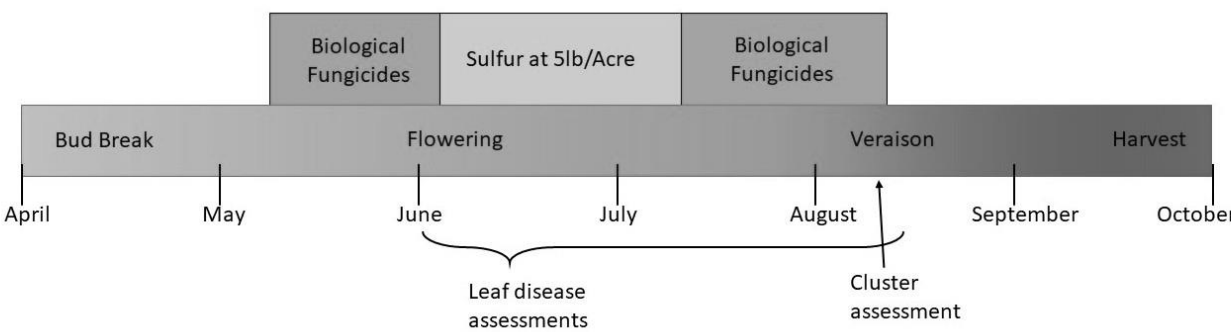

Figure 1. Fungicide application and data acquisition timings in the Pinot noir and Pinot gris trials.

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 detected through intensive scouting in late May. Until 50% bloom, biological fungicides (Table 1) were applied to vines. Upon 50% bloom, 5 lb/A Microthiol Disperss (MD) micronized sulfur was applied to vines (Table 1). Included in the treatments was a 5 lb/A MD control whereby MD was only applied during the bloom period, and outside of this interval no other treatments were applied (Table 1). After 4 weeks post flowering (5 applications) the fungicide program for each cultivar reverted to application of the biological fungicide treatment (Figure 1).

The fungicide schedule used in the study was based on the different stages of a grape powdery mildew (GPM) epidemic. Initially, before grapevines flower, fungicide programs are focused on preventing GPM infections 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 the most critical stages for management of GPM, as this is when the inflorescences and subsequently the developing berries, are most susceptible to infection. After three weeks post flowering fungicide programs focus on keeping GPM levels low on both leaves and fruit to keep overall inoculum to a minimum. Fungicide program intensity is usually not as aggressive after bloom and early fruit set as the earlier two sections of the season as both leaves and fruit develop ontogenic resistance to infection as they age. The trial regime allowed testing of whether using biological products to manage the leaf infection and the early epidemic period would lead to effective GPM management, while not overwhelming the biological fungicide products with the high disease pressure of the research vineyard.

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
5 lb/A Sulfur bloom-early berry development	Standard	5 lb/A Sulfur bloom-early berry development	Standard
LifeGard 4.5 oz/100gal	Standard	Theia 3 lb/A[z]	Standard
	Intelligent high		Intelligent high
	Intelligent low		Intelligent low

[x]Treatments applied at 80psi at approx. 430 PTO rpm and 3 mph.
[y]Intelligent high and low treatments applied at 0.12fl oz/ft^3 and 0.06fl oz/ft^3 of grape canopy, respectively.
[z]Treatment 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.

The blocks used consisted of 'Pinot noir' or '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 27 Mar. Shoot thinning by hand occurred from 9 to 25 May and sucker removal by hand was continuous throughout the season. Shoots were cut above the top wire on 15 Jun 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.

Spring weather conditions were normal to dry in Apr and first week of May but then became very dry with little rainfall for the remainder of the season. Symptoms of powdery mildew were first found on 22 May as a few individual colonies on scattered vines. Flag shoots were not observed in this block. Bloom took place from approximately 6 to 14 Jun with caps rapidly detaching due to warm, dry weather.

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 12 Jun through 10 Aug. The severity of powdery mildew on clusters was taken on 8 Aug. 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 modeled with linear models. Cluster severity percentages were modeled using a generalized linear mixed model with block fitted as a random effect. Cluster severity treatment contrasts were 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.

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 2023.

Pinot noir			Pinot gris		
Treatment[xy]	**AUDPC[z]**	**Percent Infected Berries[z]**	**Treatment[xy]**	**AUDPC[z]**	**Percent Infected Berries[z]**
Non-treated	2456 (2144-2767) A	67.2 (57.1-75.9) A	Non-treated	2369 (2015-2723) A	49.7 (38.4-61.0) A
5 lb/A Sulfur bloom-early berry development	1878 (1567-2190) AB	44.4 (34.2-55.2) B	5 lb/A Sulfur bloom-early berry development	1911 (1557-2265) AB	46.5 (35.4-57.9) A
LifeGard 4.5 oz/100gal Standard	1778 (1467-2089) B	27.1 (19.4-36.4) C	Theia 3 lb/A Standard	1125 (771-1479) C	20.8 (14.2-29.4) B
LifeGard 4.5 oz/100gal Intelligent High[z]	1699 (1388-2010) B	43.7 (33.5-54.4) B	Theia 3 lb/A Intelligent High[z]	1712 (1357-2066) ABC	27.9 (19.6-38.0) B
LifeGard 4.5 oz/100gal Intelligent Low	1658 (1347-1970) B	32.2 (23.6-42.2) BC	Theia 3lb/A Intelligent Low[z]	1444 (1089-1798) BC	21.2 (14.5-29.9) B

[y]All treatments were applied at 80psi at approx. 430rpm PTO; intelligent high and low sprayer treatments applied at 0.12 fl oz/ft^3 and 0.06fl oz/ft^3 of grape canopy, respectively.
[z]Estimates are followed by asymptotic 95% confidence intervals in parentheses. Treatments followed by different letters are significantly different from each other, marginal means contrast ($p<0.05$) with p values adjusted using Tukey method.

In the Pinot noir and Pinot gris trials the AUDPC value was significantly higher from the non-treated plot than all biological fungicide treated plots, however it was not significantly different from not the bloom MD control (Table 2). All fungicide treated plots in the Pinot noir trial had AUDPC values that were not significantly different from each other. In the Pinot gris trial, both Theia intelligent mode treatments resulted in AUDPC values that were not significantly different from the 5 lb/A MD at bloom treatment, but also not significantly different from the Theia standard treatment. The Theia standard mode treatment resulted in significantly lower AUDPC value than the 5 lb/A MD at bloom treatment.

In the Pinot noir trial all fungicide treatments resulted in significantly lower cluster severity than the non-treated control, however in the Pinot gris trial only the 5 lb/A MD at bloom treatment resulted in cluster severity that was not significantly different from the non-treated control (Table 2). In the Pinot noir trial both of the Lifegard intelligent treatments resulted in higher cluster severity than the Lifegard standard treatment, however, Lifegard intelligent low resulted in cluster severity that was not significantly different than Lifegard standard mode. The Lifegard standard treatment resulted in the lowest observed average cluster severity (Table 2). In the Pinot gris trial all fungicide treatments resulted in cluster severity values that were significantly lower than that of the non-treated control and the 5 lb/A MD at bloom treatment but none were significantly different from each other.

Spray volume applied in the Pinot noir and Pinot gris trials were very similar due to using the same settings in both trials. For standard mode treatments the volume applied remained close to 60 gallons per acre (GPA) for the entire season, and just over 60 GPA during the bloom period (Figure 2A and 2B). Intelligent mode treatments in both trials started the season at 12 GPA and 19 GPA for intelligent low and high, respectively, with both quickly trending up to just under 30 GPA and 40 GPA at the beginning of bloom, respectively. After bloom, intelligent high mode remained at around 45 GPA while intelligent low mode remained at around 36 GPA (Figure 2A and 2B). In the Pinot noir trial, Lifegard standard mode resulted in approximately 2.6 oz/A at each application throughout the trial, while in intelligent mode a lower than recommended rate of 1 oz/A to 4.5 oz/A was applied for the first application in intelligent high and low modes. From the second application onwards application rates were within the suggested range with Intelligent high resulting in about 0.2 oz/A more than Intelligent low (Figure 3A). In the Pinot gris trial, 3.5 to 4 lb/A of Theia were applied in standard mode, with the first application resulting in the highest amount applied on a per-acre basis. In intelligent mode the amount ranged from 0.8 lb/A and 1.3 lb/A for intelligent low and high, respectively, to around 2.0 lb/A and 2.4 lb/A after the bloom period for intelligent low and intelligent high, respectively (Figure 3B). The suggested product application rate range for Theia is from 1.5 to 5 lb/A, so most applications made using intelligent high mode were above the lowest rate except for the first one, while the first two pre-bloom applications using intelligent low mode were below the lowest label rate (Figure 3B). During the bloom period when Microthiol Disperss was applied to all treated plots in both studies close to 6 lb/A was applied for the duration of the bloom period.

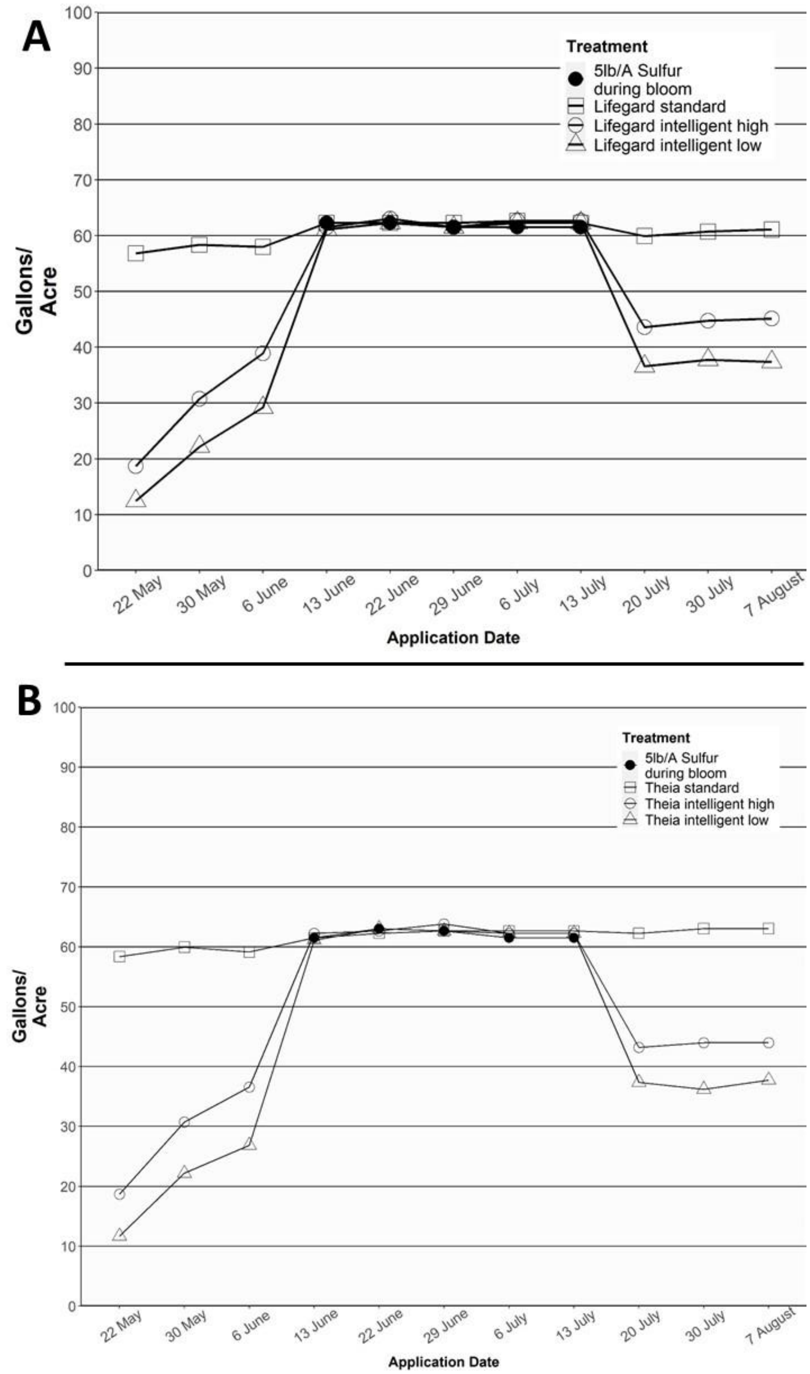

Figure 2. Spray volume applied to Pinot noir (A) and Pinot gris (B) vines.

Lifegard and Theia are both biological fungicides with live organisms that colonize the plant tissue. However, the two products differ in their mode of action. Theia contains live spores of a *Bacillus* bacterium that colonize the plant tissue and directly exclude fungi from infecting the plant, in addition to production of anti-microbial compounds and activating plant defense responses. Lifegard does not have any direct activity on the target plant pathogenic fungi and instead works solely by activating plant defense responses. The differing modes of action of these products could explain the different disease levels observed on leaves and clusters in this study. In the Pinot noir trial, the Lifegard could have mainly primed the plant defense response, with the amount of priming depending on the dose of product applied. Leaf incidence AUDPC values depend heavily on how quickly disease takes off and stays elevated in a given treatment area. The trend of leaf incidence in Pinot noir plots was very similar for all Lifegard treatments (data not shown). The leaf incidence curves for the Pinot gris trial look much different, with visible separation between the different Theia treatments. This could indicate that the quantity of Lifegard applied pre-bloom did not influence leaf infection levels, while the amount of Theia made a difference in managing pre-bloom GPM infections.

Cluster infection in the Pinot noir study was lowest among the Lifegard standard mode plots, which had the highest quantity of Lifegard applied during the study. In contrast, all three Theia treatments resulted in cluster infection levels that were not significantly different from each other. These data could indicate that the quantity of Lifegard applied was important for how much it primed the plant defense responses. This effect could have been building during the pre-bloom phase of the study and remained a factor to prevent or slow GPM infections during the bloom phase of the study. In contrast, the quantity of Theia applied was likely more important during the pre-bloom stage of the study to prevent infections to leaves through its various modes of action. These effects may have been more reliant on its actively excluding the pathogen and production of anti-microbial compounds than activating plant defense responses, as there appeared to be no carry-over in efficacy into the berry data as there was for Lifegard. However, both leaf AUDPC and cluster severity levels were generally lower in the Pinot gris study, indicating that Theia may be more effective at managing GPM infections overall than Lifegard. Theia was also observed to result in lower infection levels compared to Lifegard in trials conducted in 2022.

Future trials could investigate other products in the same phenological regime to determine if any had similar efficacy to Lifegard or Theia. Additionally, testing of the viability of biological products before and after application could further elucidate any effects on efficacy due to product viability. Further testing of similar regimes with different rotations or combinations of products could determine other effective strategies when using biological fungicides.

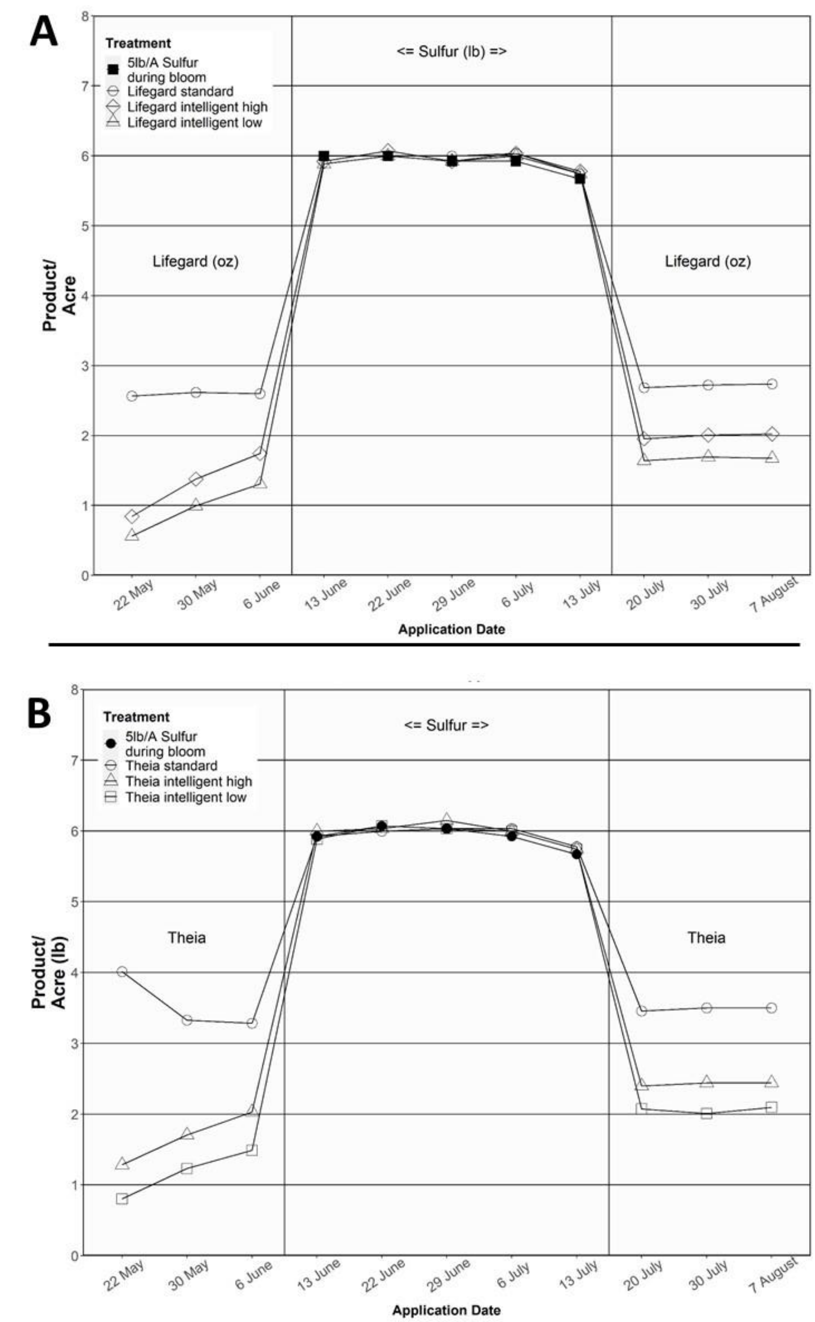

Figure 3. Amount of formulated product applied to Pinot noir (A) and Pinot gris (B) vines.