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

J. W. Pscheidt[1], B. W. Warneke[1], R. Rosetta[2] and L. Nackley[2]
all of Oregon State University
[1]Dept. of Botany and Plant Pathology
Corvallis, OR 97331-2903
[2]NWREC
15210 NE Miley Rd, Aurora, OR 97002

Efficacy of an Intelligent sprayer on grape powdery mildew, 2018 and 2019.

Over the course of two years fungicides were applied for powdery mildew management to Pinot noir and Pinot gris vines using an Intelligent Spray System (ISS) at the Botany and Plant Pathology Field Laboratory in Corvallis, OR. The treatments focused on evaluating the efficacy of different sulfur rates and output volumes from the Intelligent Spray System on management of grape powdery mildew on leaves and clusters. The Intelligent Sprayer Project consists of a multi-discipline research team from across the USA working on improving spray application technology in specialty crops. 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 Intelligent Spray System (ISS) components or standard operation mode. When the ISS was used it was referred to as "automated 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.

Table 1. Treatments applied to vines during the 2018 and 2019 seasons.

2018 Pinot noir			**2019 Pinot noir**			**2019 Pinot gris**		
Tractor Speed (mph)	**Sprayer Mode**	**Treatment[w]**	**Tractor Speed (mph)**	**Sprayer Mode**	**Treatment[w]**	**Tractor Speed (mph)**	**Sprayer Mode**	**Treatment[w]**
N/A	N/A	Non-treated	N/A	N/A	Non-treated	N/A	N/A	Non-treated
1.9	Automated	5#/100gal Microthiol Disperss Auto low[x]	1.9	Automated	5#/100gal Microthiol Disperss Auto low[x]	1.9	Automated	5#/100gal Microthiol Disperss Auto low[x]
1.9	Standard	5#/100gal Microthiol Disperss	1.9	Standard	5#/100gal Microthiol Disperss	1.9	Standard	5#/100gal Microthiol Disperss
1.9	Standard	5#/Acre Microthiol Disperss	1.9	Automated	20#/100gal Microthiol Disperss Auto low[x]	1.9	Automated	5#/100gal Microthiol Disperss Auto high[y]
4.5	Standard	20#/100gal Microthiol Disperss	4.5	Standard	20#/100gal Microthiol Disperss	1.9	Automated	Vivando-Endura alt. Quintec-Torino Auto low[xz]

[w]All treatments were applied at 80psi at tractor PTO rated speed.
[x] Auto low treatments applied at spray rate of 0.06fl oz/ft^3 of grape canopy.
[y]Auto high treatments applied at spray rate of 0.12fl oz/ft^3 of grape canopy.
[z]Treatment applied at the highest label rates per acre.

In both 2018 and 2019, treatments (Table 1) were arranged in a randomized complete block design. The blocks used consisted of ‘Pinot noir’ (2018 and 2019) and ‘Pinot gris’ (2019) 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 each year. Shoot thinning by hand occurred from 1 to 10 May each year and sucker removal by hand was continuous throughout the season. Shoots were cut above the top wire on 20 June each year and maintained at this height throughout the growing seasons. Sulfur treatments were applied every 7 to 10 days depending on phenology and disease pressure as measured by the Gubler-Thomas powdery mildew risk index. Shorter intervals (7-8 day) corresponded to bloom and times of high disease pressure and longer (10-12 day) intervals corresponded to times of fruit development and lower disease pressure. Each treatment was replicated on 4 sets of 5 vines.

In 2018, spring weather conditions were considered warm and dry with below normal rainfall. Symptoms of powdery mildew were first found on 14 May as a few individual colonies on scattered vines (one flag shoot was also observed in a nearby Pinot gris block). Rainfall for the growing season (Oct 2018 to Sep 2019) was approximately 5 inches below the 115 yr average but temperatures were at the average of 59.2ºF. March precipitation was 3 in below normal while April was 3 in above normal which led to localized flooding from April 9 to 11 in parts of the vineyard prior to bud break Flooding inundated 3 plots of one Pinot gris row and 2 plots of one Pinot noir row from 7 April until 12 April. Vine growth and health was monitored after flooding and was not determined to be markedly different from that of other rows over the course of the season. Symptoms of mildew were first found on 13 May as a few individual colonies on scattered vines, and a flag shoot was found in a Pinot gris row and removed promptly by hand.

Leaf and cluster data was 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 22 June through 16 August 2018 and from 18 June through 15 August in 2019. The severity of powdery mildew on clusters was taken on 11 July and 1 August 2018 and on 31 July 2019. Treatments were also evaluated using the area under disease progress curve (AUDPC) which was calculated by multiplying the mean incidence or severity 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 severity 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 in R version 3.5.1 and a modeled with a linear model in 2018. In 2019 Pinot noir AUDPCs were modelled with a linear model and Pinot gris AUDPCs were modeled with a generalized linear model due to violation of the equal variance among treatments assumption. Cluster severity percentages in both years 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.

In 2018 spray coverage was evaluated on 22 June using water as the spray mixture on the same vines where sulfur treatments were applied. Water sensitive cards (TeeJet Technologies, Wheaton, IL) were clipped back-to-back with a sign holder (VersaGrip, Deflecto LLC, Indianapolis, IN) and attached to vines on the east and west side of the row in the cluster zone so that one card was facing east and one card was facing west. Cards that were clipped to the outside of the row were termed “outer facing” cards, and cards that were clipped to the inside of the row were termed “inner facing” cards. Tractor and sprayer settings tested included automated at 1.9 mph, standard at 1.9 mph and standard at 4.5 mph which mirrored the settings in the sulfur trial. Spray coverage percentages were modeled using a generalized linear model. Treatment contrasts were conducted using the emmeans package. Uncertainty was estimated using asymptotic 95% confidence intervals.

Table 2. Area under disease progress curve (AUDPC, leaf disease) and percent infected berries from the 2018 and 2019 Intelligent Sprayer trials at the Botany and Plant Pathology field lab.

2018 Pinot noir			**2019 Pinot noir**			**2019 Pinot gris**		
Treatment[v]	**AUDPC**[w]	**Percent Infected Berries**[w]	**Treatment**[v]	**AUDPC**[w]	**Percent Infected Berries**[w]	**Treatment**[v]	**AUDPC**[w]	**Percent Infected Berries**[w]
Non-treated	2689 (2338-3040) A	93 (88-96) A	Non-treated	2739 (2498-2979) A	97 (95-98) A	Non-treated	2699 (2234-3163) A	93 (90-95) A
5#/100gal Microthiol Disperss Auto Low[x]	2194 (1843-2545) B	55 (40-69) B	5#/100gal Microthiol Disperss Auto Low[x]	1996 (1755-2237) B	75 (68-81) B	5#/100gal Microthiol Disperss Auto Low[x]	1731 (1267-2196) B	69 (59-77) B
5#/Acre Microthiol Disperss Std	942 (590-1293) C	10 (6-16) C	20#/100gal Microthiol Disperss Auto Low[x]	777 (536-1017) C	36 (28-45) C	5#/100gal Microthiol Disperss Auto High[y]	1173 (709-1638) BC	37 (28-47) C
20#/100gal Microthiol Disperss Std	938 (587-1289) C	10 (6-17) C	20#/100gal Microthiol Disperss Std	848 (608-1089) C	28 (21-36) C	Vivando-Endura alt. Quintec-Torino Auto Low[x]	102 (-362-566) D	11 (8-16) D
5#/100gal Microthiol Disperss Std	1210 (859-1561) C	10 (6-16) C	5#/100gal Microthiol Disperss Std	691 (451-932) C	22 (17-29) C	5#/100gal Microthiol Disperss Std	1022 (558-1486) C	29 (21-38) C

[v]All treatments were applied at 80psi at tractor PTO rated speed.
[w]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.
[x]Treatment applied at spray rate of 0.06fl oz/ft^3 of grape canopy.
[y]Treatment applied at spray rate of 0.12fl oz/ft^3 of grape canopy.
[z]Treatment applied at the highest label rates per acre.

Among all trials all fungicide treated vines resulted in significantly lower cluster severity than the non-treated control. In addition, the 5#/100gal Microthiol Disperss (MD) Auto low treatment resulted in significantly higher grape powdery mildew (GPM) severity on clusters than all other fungicide treatments (Table 2). When the 5#/100gal MD was applied using the Auto high sprayer setting as in the 2019 Pinot gris trial, significantly lower GPM severity on clusters than the 5#/100gal MD auto low treatment was achieved that was similar to the 5#/100gal MD standard treatment. In 2018 and 2019 Pinot noir trials all fungicide treatments other than 5#/100gal MD Auto low resulted in lower and similar cluster severity levels (Table 2). In the 2019 Pinot gris trial the synthetic fungicide rotation resulted in the lowest overall GPM levels on clusters (11%), which was significantly lower than all other treatments (Table 2).

When looking at AUDPC values similar results were obtained to those in the clusters where all fungicide treatments across trials resulted in significantly lower AUDPCs than the non-treated control. In 2018 and 2019 Pinot noir trials the 5#/100gal MD Auto low treatment resulted in significantly higher AUDPCs than all other fungicide treatments, while in the 2019 Pinot gris trial it was not significantly different from the 5#/100gal MD Auto high treatment. However, in the 2019 Pinot gris trial the 5#/100gal MD Auto high treatment AUDPC was also not significantly different from the 5#/100gal MD standard treatment. In the 2019 Pinot gris trial the synthetic fungicide rotation resulted in a significantly lower AUPDC from all other treatments. No phytotoxicity was observed on vines over the course of either the 2018 or 2019 seasons.

In the 2018 coverage trial, among all three tractor settings within the outer facing group there were no significant differences in percent coverage of water sensitive cards (Figure 1). In the inner facing group, the standard sprayer mode applied at 1.9mph resulted in significantly higher percent coverage of water sensitive cards than automated mode at 1.9mph and standard mode at 4.5mph (Figure 1).

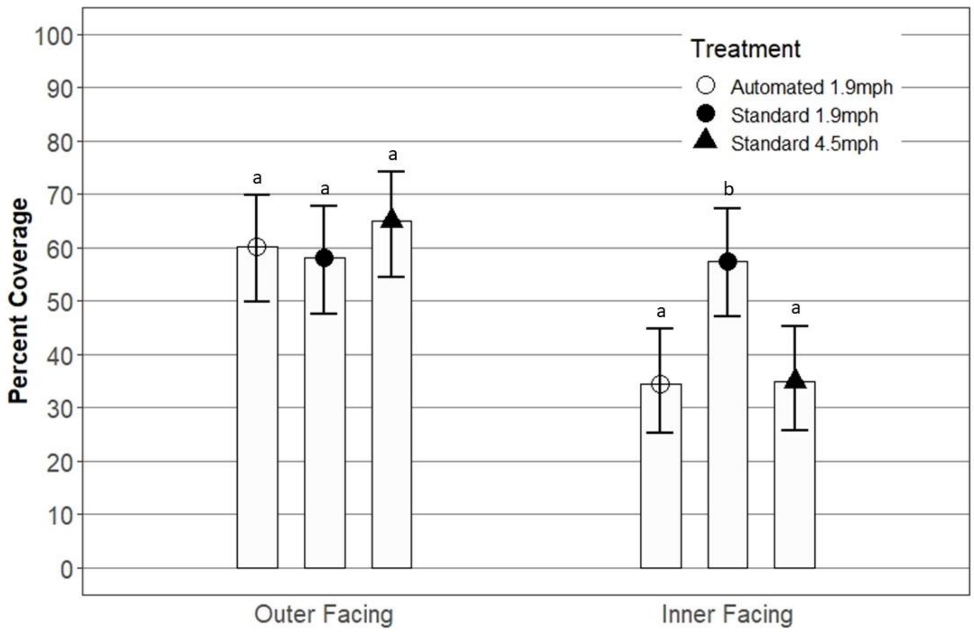

Figure 1. Percent coverage on water sensitive cards placed in the cluster zone in the 2018 water sensitive card coverage trial. Bars with different letters within groups do not significantly differ from each other at $p<0.05$ (pairwise test on least squared means, p value adjusted using Tukey method for 3 estimates).

In the 2018 Pinot noir trial sulfur applications occurred on 18 May (BBCH 16), 28 May (BBCH 53), 7 June (BBCH 62, early flowering), 14 June (BBCH 64), 21 June (BBCH 71, fruit set), 29 June (BBCH 73), 10 July (BBCH 77), 19 July (BBCH 79), 30 July (BBCH 80) and 10 August (BBCH 81, beginning of veraison). Application volumes ranged from 105 to 115 gal/Acre in standard mode treated plots at the slower 1.9 mph speed and 46 to 47 gal/Acre at the higher 4.5 mph speed; volumes were lower in automated low mode and ranged from 18 to 47 gal/Acre (Figure 2B).

Note: In the 2018 Pinot noir trial the 20 # MD treatment went out at 100 gal/A with the first application which meant it was over the labeled rate of 10 lb/A. A lower gal/A was achieved by adjusting to a faster (4.5mph) tractor ground speed.

In the 2018 Pinot noir trial the amount of MD applied during each application ranged from to 5.4 to 5.7 lb/Acre for 5#/100gal standard mode and 0.9 to 2.4 lb/Acre for 5#/100gal automated low mode, 5.1 to 6.1 lb/Acre for 5#/Acre in standard mode treated plots at the slower speed and 9.3 to 9.5 lb/Acre for 20#/100gal standard mode at the higher speed (Figure 2A).

In the 2019 Pinot noir and Pinot gris trials fungicide applications occurred on 16 May (BBCH 18), 24 May (sulfur treatments only, BBCH 55), 31 May (synthetic rotation only, BBCH 57), 4 June (BBCH 60), 13 June (BBCH 66), 20 June (BBCH 71), 3 July (BBCH 74), 12 July (sulfur treatments only, BBCH 75), 18 July (synthetic rotation only, BBCH 77), 23 July (BBCH 77), 1 August (BBCH 79), and 9 August (BBCH 81). Application volumes ranged from 97-106 gal/Acre in standard mode treated plots at the slower 1.9 mph speed and 15 to 43 gal/Acre at the higher 4.5

mph speed. Volumes in the automated low mode ranged from 14 to 48 gal/Acre, and volumes in automated high mode ranged from 18 to 70 gal/Acre over the course of the season (Figure 2B).

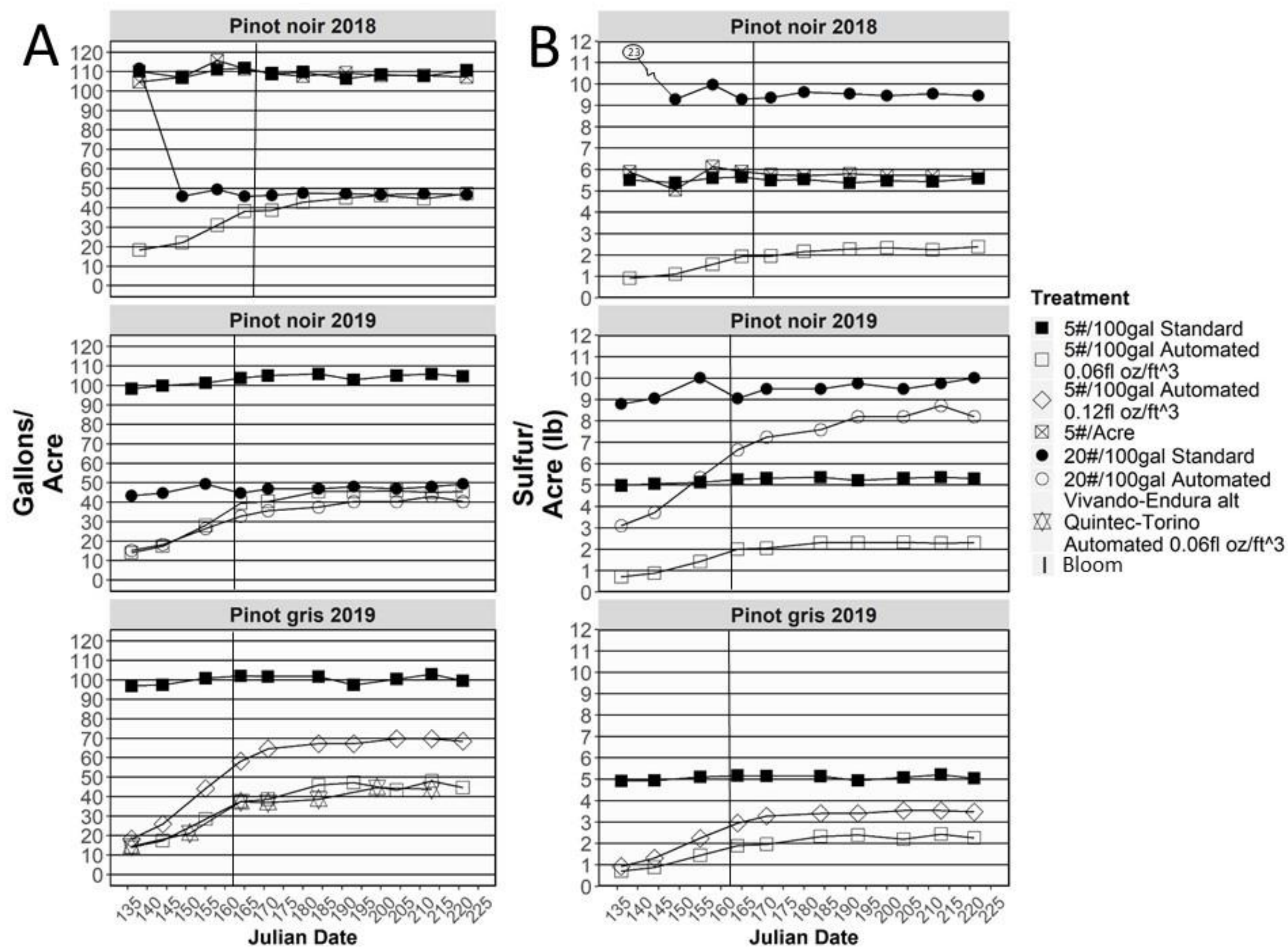

Figure 2. Amount of sulfur (A) and application volumes (B) applied during the 2018 and 2019 Grape Powdery Mildew management trials at the Botany Field Laboratory in Corvallis, Oregon.

In the 2019 Pinot noir trial the amount of MD applied during each application ranged from 5.0 to 5.4 lb/Acre for 5#/100gal standard mode, 0.7 to 2.3 lb/Acre for 5#/100gal automated low mode, 8.8 to 10.0 lb/Acre for 20#/100gal standard mode, and 3.1 to 8.7 lb/Acre for 20#/100gal automated low mode (Figure 2A). In the 2019 Pinot gris trial the amount of MD applied during each application ranged from 4.9 to 5.2 lb/Acre for 5#/100gal standard mode, 0.7 to 2.4 lb/Acre for the 5#/100gal automated low mode, and 0.9 to 3.5 lb/Acre for the 5#/100gal automated high mode treatment (Figure 2A). In the 2019 Pinot gris trial the synthetic fungicide rotation treatment (auto low) was applied at the highest label rate per acre for each product (15.4 fl oz for Vivando, 4.5 oz for Endura, 6.6 fl oz for Quintec, 3.4 fl oz for Torino) mixed in 3.5gal of water for the first two applications, then 5 gal of water for the rest of the season.

When the intelligent spray system (ISS) was received in May 2018 it was used with its initial settings (out of the box – off the shelf) in the GPM management program. Using those settings (automated low) in 2018 and sulfur as a fungicide the ISS did not control powdery mildew on leaves and clusters as well as a standard sprayer. When spray coverage was evaluated in 2018, treatments among water sensitive cards in the outer facing group were not significantly different from each other, however in the inner facing group the standard mode 1.9mph treatment resulted in significantly higher coverage than both the 1.9mph automated and 4.5mph standard mode treatments. The higher level of spray coverage in the inner facing group could have explained some of the higher disease levels observed in automated mode treated plots, however, mildew levels in the standard mode 4.5mph treated plots was significantly lower than the automated treated plots in that trial. The coverage trial in combination with the disease data indicate that a main factor leading to higher disease levels in automated treated plots in 2018 could have been low spray volume (not enough sulfur/A) applied with the ISS. This hypothesis was tested in the 2019 Pinot noir trial and 2019 Pinot gris trial. In the 2019 trials the 5#/100gal MD auto low treatment resulted in poor GPM control on leaves and clusters as it did in 2018, but when the concentration of sulfur was increased from 5#/100gal to 20#/100gal and the same settings were used, GPM severity and AUDPCs were significantly lower. Increasing the concentration of sulfur from 5#/100gal to 20#/100gal resulted in 3.3 to 4.4 times more sulfur being applied in the 20#/100gal treatment in each application than the 5#/100gal treatment. The rate of sulfur applied in the 20#/100gal Auto treatment was within the recommended range (3#-10# per Acre) for the entire season, while the 5#/100gal Auto treatment resulted in below 3#/Acre of sulfur the entire season.

Another way to increase the amount of sulfur applied using the intelligent sprayer is by adjusting the spray rate parameter in the ISS user controls. This increases the duty cycle of the individual PWM valves leading to an increase in spray output per unit volume of canopy. This setting was tested in the 2019 Pinot gris trial. When the spray rate parameter was the default of 0.06fl oz/ft^3 of canopy (auto low), poor GPM control on leaves and clusters was achieved, but when the spray rate was doubled to 0.12fl oz/ft^3 of canopy (auto high), it resulted in significantly lower cluster severity. While this did not double the amount of spray applied, it increased the amount of formulated sulfur applied during the course of the season from 0.7lb/A to 2.4lb/A (at 0.06fl oz/ft^3) to the range of 0.9lb/A to 3.5lb/A (at 0.12fl oz/ft^3), a 29% to 46% increase. Adjustment of sulfur output upwards by either increasing the concentration of sulfur in the spray tank or adjusting the ISS settings to allow more volume are simple ways to improve the efficacy of sulfur treatments using the ISS. These studies showed that when using a contact fungicide such as sulfur that requires thorough coverage for efficacy, both coverage on tissues and the quantity of product applied per unit area is important in ensuring the efficacy of the fungicidal product.

While using contact fungicidal material such as sulfur with the default settings of the ISS did not result in acceptable GPM control, using synthetic (and systemic) fungicide products and the default ISS settings was shown to be the most effective treatment in the 2019 Pinot gris trial at managing GPM on clusters and leaves. The products used in that fungicide rotation redistribute around tissues, for example if one side of the leaf was well covered and the other side was not, the fungicides could penetrate through the leaf and provide protection against infection to both sides. This ability could have aided in the efficacy of that treatment as compared to the sulfur treatment applied with the same settings. While redistribution is a valuable aspect of synthetic fungicides, getting adequate coverage is still of utmost importance in disease management. When using a low volume precision sprayer such as the ISS, a careful balance between contact and synthetic fungicide materials is likely warranted to achieve good disease control. Future trials with the ISS should compare usage of synthetic fungicide products at different duty cycle rates and in standard mode, while also examining using a mixture of synthetic and contact materials through the course of the season. Other possibilities include testing of different nozzle sets and combinations thereof. Additionally, spray coverage should be evaluated in conjunction with the tests to confirm adequate coverage.