GRAPE (*Vitis vinifera* 'Pinot noir')

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Effect of vine growth on spray coverage of grape leaves and clusters using an Intelligent Sprayer, 2019.

During the 2019 growing season spray coverage trials were conducted at three developmentally important growth stages (pre-bloom, bloom, and mid-season) of wine grape using water sensitive cards. The trials were conducted on 'Pinot noir' vines at the Botany and Plant Pathology Field Laboratory in Corvallis, OR using the Intelligent Spray System (ISS). The ISS uses a Lidar laser sensor, Doppler speed sensor, and individual pulse width modulation valves at each nozzle to dynamically adjust pesticide volume according to the canopy density, with the goal of minimizing pesticide use and off target drift while keeping pest management similar to standard sprayers. In doing so, early in the season when there is a small amount of plant canopy, sprayer output using the ISS is much lower than when the plant canopy is full mid-way through the season. Spray volume output is known to play a large role in spray coverage, with less volume typically associated with lower coverage. Spray coverage is critical when using contact pesticide products that must be in contact with the pest to be effective. This goal of this trial was to determine if the varying volume of pesticide applied using the ISS was adequate to cover wine grapes through the course of the season.

The sprayer used in the study (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, which together made the ISS. A spray console wired to the system allowed use of either the Intelligent Spray System (ISS) components or standard operation mode (fully on/off as for a normal sprayer). 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 in the 2019 Intelligent Sprayer Pinot noir phenological coverage trial.

Treatment[y]	Sprayer Setting
1	Automated[z]
2	Standard

[y]All treatments were applied at 80psi at tractor PTO rated speed.
[z]Applied at a spray volume setting of 0.06fl oz/ft^3

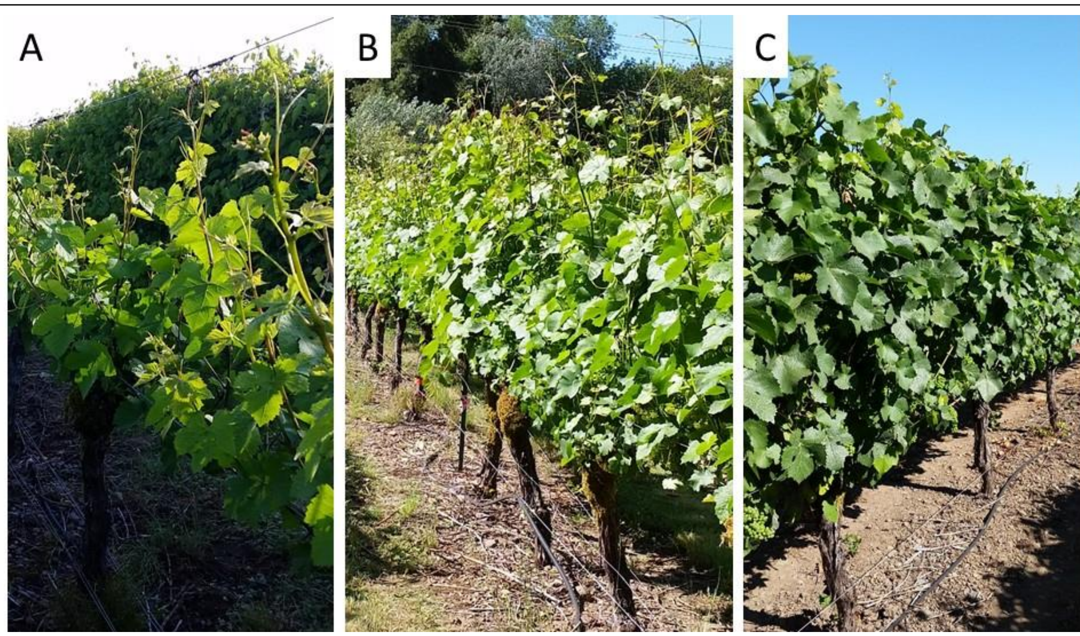

Figure 1. Growth stages when the phenological applications were made (A) pre-bloom (30 May, BBCH 57), (B) bloom (18 June, BBCH 65), (C) mid-season (26 July, BBCH 79).

At each growth stage only nozzles that would provide meaningful coverage on shoots were kept open, as would be standard practice for a grower. Out of seven total nozzles on one side of the sprayer, at pre-bloom four nozzles were open, and at bloom and mid-season five nozzles were open.

Treatments (Table 1) were arranged in a randomized complete block design within each growth stage, and applied to vines when they reached pre-bloom (30 May 2019, BBCH 57), bloom (18 June 2019, BBCH 65), and mid-season

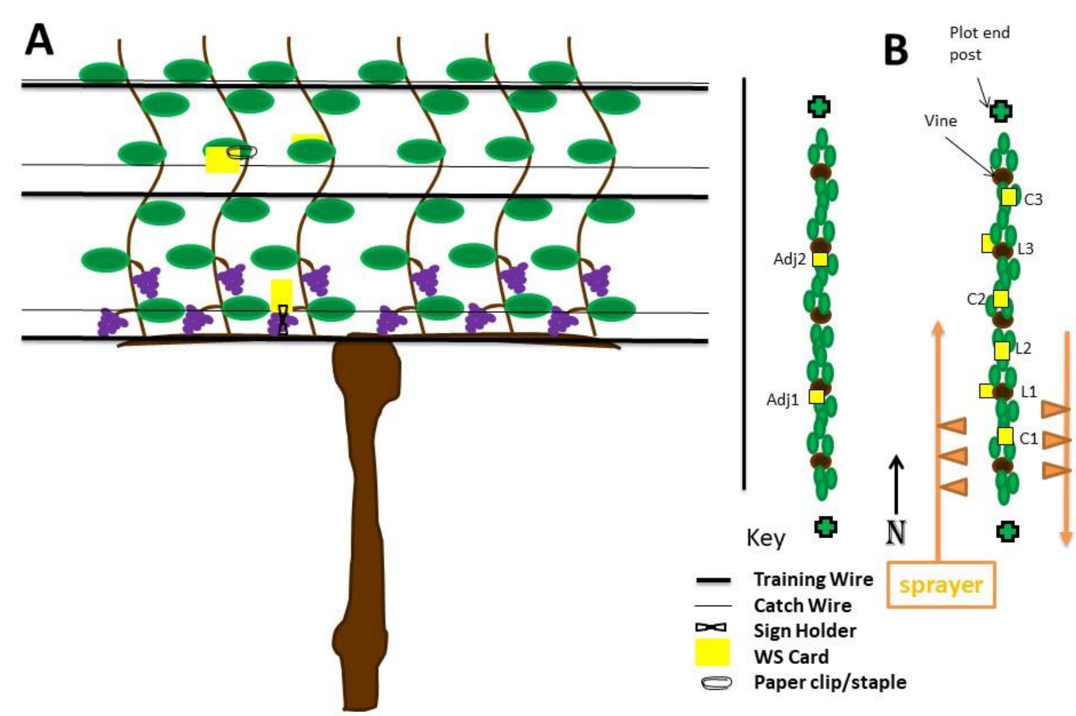

Figure 2. Illustration of card placement in the cluster zone and on leaves in a representative vine (A) and illustration of card placement in a plot (B).

(26 July 2019, BBCH 79). The blocks used consisted of 'Pinot noir' 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 1 to 10 May and sucker removal by hand was continuous throughout the season. Shoots were cut above the top wire on 20 June and maintained at this height throughout the growing season.

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 59.2^{o}F. 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 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.

Two 1.5 x 2" water sensitive cards (TeeJet Technologies, Wheaton, IL) were placed back-to-back so that the water sensitive side was facing outwards on each card, then were clipped with a double sided sign holder in that position in the cluster zone of the grape canopy (Figure 2A). Cards were clipped so that the pair of cards were vertically oriented and so that one was facing east in the cluster zone and one was facing west. Three sets of cluster zone cards

Table 2. Percent coverage on water sensitive cards in the cluster zone and adjacent row and spray volume used in each growth stage.

Trial	Sprayer Setting	Cluster zone[v]	Adjacent Row Cards[xy]	Spray Volume (GPA)[xz]
Pre-bloom	Standard	71 (64-77)	46 (±3.4)	111 (±2)
	Automated	39 (32-46)*	13 (±1.1)*	23 (±1)*
Bloom	Standard	69 (62-74)	11 (±3.0)	110 (±0.4)
	Automated	32 (26-38)*	2 (±0.5)*	42 (±2)*
Mid-season	Standard	67 (53-79)	0.5 (±0.3)	110 (±1)
	Automated	35 (24-49)*	0.2 (±0.1)	43 (±2)*

[v]Overall averages of east and west side cards. Means followed by asymptotic 95% confidence intervals. Asterisk indicates significantly lower coverage, $p<0.05$, Z test.
[x]Mean gallons per acre (GPA) followed by standard error in parentheses
[y]Asterisk indicates significantly lower coverage, $p<0.05$, Mann-Whitney U test.
[z]Asterisk indicates significantly lower volume, $p<0.05$, two sample t-test.

were placed in each plot (Figure 2B). Three 1.5 x 2" water sensitive cards were attached to the top of a grape leaf about 5' off the ground near the middle of the grape canopy using a standard office stapler, and another three were attached to the bottom of leaves using staples at approximately the same height (Figure 2). Additionally, two 1.5 x 2" water sensitive cards were oriented vertically and placed approximately 4 -5' off the ground in the row adjacent to the west of the treatment row using a clothespin or binder clip (Figure 2B). These cards served to detect any spray not intercepted by the grape canopy (drift). Spray volume data was collected at each growth stage using the embedded computer of the ISS, which calculates estimated sprayer output based on nozzle parameters entered into the user interface. Canopy density data was collected at each growth stage of the study by driving the ISS by the plot of interest with the lidar sensor on, and the data was stored on the embedded computer until it was transferred to a separate laptop for analysis. Shoot length, canopy width, and the number of leaves on the shoot were recorded at each growth stage in the study. At the end of the season, the number of shoots per linear foot and canopy length was measured. Shoot length was measured by choosing a shoot at random in the grape canopy and measuring from its base on the cane to its tip, in addition to the shoot length, the number of unfolded leaves on the shoot was recorded. A leaf was considered unfolded was if the leaf was fully unfolded (not curled) and the pubescence had largely dispersed (approximately 3" in diameter). The canopy width was measured by inserting a tape measure through the canopy at approximately mid-canopy height and measuring from the furthest leaf out on one side to the furthest leaf out on the other side. The number of shoots per linear foot of canopy was measured by affixing a tape measure to the fruiting wire at random and counting the number of shoots (including those on the vine head) in a three foot section of the plot. The canopy length was recorded as the distance from the end of the cane on the furthest grape vine in the plot to the end of the cane on the furthest grape vine on the other side of the plot. To calculate the total canopy volume, the plot length was multiplied by canopy width and shoot height. In addition, leaf area data was calculated by collecting two fully mature leaves from the base of shoots and two leaves from lateral shoots, then photographing them and subsequently analyzing the photos using imageJ. To calculate total leaf area, it was assumed that at pre bloom, bloom, and mid-season approximately 25%, 50%, and 75% of leaves would be fully expanded, while the remaining percentages for each of those respective growth stages would be made up of lateral size leaves. Under those assumptions, the measured number of leaves for each growth stage was multiplied by the respective percentage proportion, to get the total amount of lateral and fully expanded leaves for each plot and growth stage. Finally, the number of lateral and fully expanded leaves were multiplied by their respected measured leaf areas (data not shown) to obtain leaf areas for each plot, which were then averaged into the total per-plot leaf area.

Table 3. Coverage on water sensitive cards on leaves and each side of the cluster zone.

Trial	Card Orientation	Standard[x]	Automated[x]	Card Orientation	Standard[y]	Automated[y]
	Coverage on Leaves			**Coverage on clusters**		
Pre-bloom	Top	30 (22-40) A	10 (6-16) B	East	66 (57-74) A	33 (26-42) A
	Bottom	54 (44-64) A	24 (17-33) B	West	76 (68-82) B	45 (36-54) B
Bloom	Top	55 (44-64) A	41 (32-51) B	East	62 (54-69) A	26 (20-33) A
	Bottom	29 (21-39) A	19 (13-28) B	West	75 (67-81) B	38 (31-46) B
Mid-season	Top	62 (46-77) A	44 (29-60) A	East	60 (43-75) A	29 (16-46) A
	Bottom	35 (21-51) A	20 (10-35) A	West	74 (57-86) A	43 (27-60) A

[x]Means followed by asymptotic 95% confidence intervals. Comparisons were conducted between sprayer settings within card orientation. Different letters signify values are significantly different at p<0.05.
[y]Means followed by asymptotic 95% confidence intervals. Comparisons were conducted between card orientation within sprayer setting groups. Different letters signify values are significantly different at p<0.05.

Each growth stage of water sensitive coverage data was analyzed separately. Additionally, cards placed in the cluster zone, leaf zone, and adjacent row were analyzed separately. Generalized linear models were fit to cluster zone and leaf area water sensitive card data using a quasibinomial distribution due to overdispersion when using a binomial distribution. Marginal means were used to make pairwise comparisons among treatment groups in both cluster and leaf card groups. For cluster zone card comparisons, east and west side cards were compared within treatments in addition to comparing overall treatment averages (i.e. automated vs. standard). For leaf cards, coverage on tops and bottoms of cards from each treatment were compared to each other. For cards placed in the adjacent row a Mann-Whitney U test was used to compare standard and automated treatment groups at each growth stage. All data was analyzed in R version 3.5.1.

Using overall averages (averaging over the east and west side groups) at all three growth stages there was significantly lower coverage in the cluster zone cards treated in automated mode vs those treated in standard mode (Table 2). Within each sprayer setting group, for both pre-bloom and bloom, the west side of the cluster zone received significantly higher coverage than the east side of the cluster zone (Table 3). However, at mid-season coverage between east and west side card groups was not significantly different in both automated and standard treated plots (Table 3). At both pre-bloom and bloom growth stages coverage on water sensitive cards when the sprayer was in automated mode was significantly lower on both tops and bottoms of leaves than when the sprayer was used in standard mode (Table 3). However, at the mid-season growth stage, coverage on water sensitive cards on both the tops and bottoms of leaves was not significantly different when the sprayer was used in standard or automated mode. (Table 3). Coverage on water sensitive cards placed in the adjacent row was significantly lower when the sprayer was used in automated mode for the pre-bloom and bloom growth stages (Table 2). At all three growth stages spray volume applied using the sprayer in automated mode was significantly lower volume compared to standard mode (Table 2). At all three growth stages there were no significant differences in canopy density, shoot height, canopy width, or the number of leaves per shoot between automated mode and standard mode plots (Welch t-test, P>0.05, Table 4).

Table 4. Manual measurements taken over the course of the trial, values averaged from the block level to the treatment level.

Trial	Sprayer Setting	Canopy Density[uz]	Mean Shoot Length (in)[z]	Mean Leaf Number per Shoot[vz]	Mean Canopy Width (in)[z]	Canopy Volume (ft^3)[xz]	Average Total Leaf Area (ft^2)[yz]
Pre-bloom	Standard	0.35 (±0.03)	25.3 (±1.2)	9 (±0.3)	15.3 (±1.6)	62 (±7)	65 (±3)
	Automated	0.33 (±0.02)	25.8 (±2.0)	9 (±0.4)	13.7 (±1.8)	61(±14)	65 (±4)
Bloom	Standard	0.60 (±0.02)	54.6 (±1.2)	14 (±0.1)	18.7 (±1.4)	164 (±21)	140 (±8)
	Automated	0.61 (±0.01)	55.9 (±2.9)	14 (±0.4)	18.4 (±1.1)	171 (±22)	160 (±8)
Mid-season	Standard	0.66 (±0.02)	54 (±1.4)	15 (±1.6)	19.8 (±1.1)	172 (±17)	192 (±22)
	Automated	0.64 (±0.01)	54.3 (±1.4)	14 (±0.8)	21.5 (±1.1)	194 (±21)	202 (±19)

[u]Canopy density as measured with the Lidar laser sensor. Values are a unitless proportion (eg. Ft^3/ft^3). Means followed by standard error in parentheses.
[v]Rounded to the nearest whole number.
[x]Canopy volume at each growth stage calculated as: canopy width x shoot height x plot length.
[y]Total leaf area per plot calculated by designating 25%, 50%, and 75% of leaves as "fully expanded" leaves for each respective growth stage, with the remaining percentage designated as "lateral leaves", then taking the number of leaves and multiplying by the respective percentage proportion, and finally multiplying that by the average leaf area for that leaf size.
[z]Means are followed by standard error in parentheses.

Given that all Lidar and manual measurements between automated and manual plots were not significantly different, the results of this study indicate that when the ISS was used in automated mode at a spray volume setting of 0.06fl oz/ft^3, it was less effective at covering cards in the cluster zone than when the sprayer was used in standard mode. The difference in coverage is likely primarily due to the significantly lower volume applied when using the sprayer in automated mode (79%, 62%, and 61% less volume for pre-bloom, bloom, and mid-season, respectively). In addition, when the sprayer was used in standard mode, both the tops and bottoms of leaves had higher coverage than when the sprayer was used in automated mode at pre-bloom and bloom. However, at mid-season coverage was not significantly different between automated or standard mode on both the tops and bottoms of leaves. Similarly, for cluster cards, both in standard and automated mode groups there was significantly lower coverage on the east side of the grape rows compared to the west side at pre-bloom and bloom, but not mid-season. Prevailing westerly winds cause vine rows to hang more to the east side of the row, possibly causing a larger number of leaf layers to be present on the east side of the rows, which could have shielded the cards on that side more. Additionally, during each trial setup, the water sensitive cards were placed in the vines from the west side of the grape row, which may have biased the coverage on them towards the west side of the cluster cards. The absence of a significant difference between top and bottom leaf cards, and east and west cluster cards at mid-season could be possibly due to the higher variation observed on water sensitive card cluster data. Coverage on leaf and cluster cards treated in automated mode could likely have been improved by adjusting the spray rate parameter in the ISS user controls upwards, so that a larger amount of spray would be applied per unit canopy. In another study (see "Efficacy of an Intelligent sprayer on grape powdery mildew, 2018 and 2019"), when powdery mildew disease severity was evaluated on clusters using the same ISS settings as in this study, a contact fungicide (sulfur) did not provide effective disease control but a synthetic fungicide rotation provided good powdery mildew control. When using the ISS at a low volume as in this study, better disease control will likely be achieved using systemic fungicide materials rather than contact fungicide materials such as sulfur. Future trials should test higher spray rates using the ISS system and assess coverage on clusters using dyes or spray tracers to estimate the quantity as well as quality of deposition.