**Adjusting Air-Assistance and Nozzle Style for Optimized Airblast Sprayer Use in Eastern Washington Vineyards**

**Summary**

**Goals:** There are many ways to optimize an airblast sprayer for use in vineyards. Three techniques growers use include: 1) changing nozzle type, 2) reconfiguring or adjusting the nozzles, and 3) adjusting the air-assistance to the droplets during an application. This study evaluated the effects of nozzle type and air-assistance use in airblast sprayers on canopy spray deposition and drift in a Washington winegrape vineyard that is trained to a modified vertical shoot-positioning system.

**Key Findings:**

- The one-piece nozzle with air assistance showed consistently high total collected canopy deposition regardless of time of season (early or mid-season). However, drift was reduced when air-assistance was not used.
- The air induction nozzle had the most total collected canopy deposition when using air-assistance during the early season, but had the most deposition mid-season without using air-assistance. Drift was reduced when air assistance was not used.
- Early in the growing season, maximum spray deposition in the fruiting zone of the canopy was achieved using air induction nozzles with air-assistance. However, using the air induction nozzle without air optimized fruiting zone spray deposition while reducing captured aerial drift.
- Mid-growing season, maximum fruiting zone spray deposition without high drift was achieved using air induction nozzles without air-assistance.

**Impact and Significance:** An airblast sprayer optimized through changes in nozzle or use of air-assistance can improve spray deposition into the canopy while minimizing drift. Growers can compare and adopt these drift-reduction techniques, such as using air induction nozzles and/or turning air-assistance off, to determine which are best suited for their farming practices. Such an approach will allow better optimization of the sprayer for their vineyard spray application needs and reduces possible negative impacts associated with off-target chemical deposition on humans and the environment.

**Key words:** air induction nozzle, air-assistance, airblast sprayer, drift reduction, one-piece nozzle, spray deposition

**Overview**

Multiple sprayer styles are available for applying foliar pesticide or fertilizer sprays across perennial cropping systems. For every $1 USD spent on chemicals for pesticide applications, a grower's return-on investment is typically between $3 and $5 USD. Yet many producers of perennial crops currently use spray equipment and practices, such as the airblast sprayer, that may be inefficient or increase human exposure risks due to drift if used improperly. In Washington State, which is the second largest producer of winegrapes in the United States, the axial fan airblast sprayer, hereafter referred to as “airblast sprayer”, is still used widely in vineyards, even though newer spray technologies are available.
The airblast sprayer was originally engineered as a solution to the issue of achieving adequate chemical applications to tall orchard trees. The use of “air-assistance” was designed to propel spray droplets into large, bulbous canopies in nut and fruit orchards, but can produce more drift. However, modern vineyard canopies and orchard trees are a fraction of the historic size, leading to the use of large volumes of air from the sprayer in relation to the reduced volume of canopy. This mispairing has shown that nearly half of the spray application from an airblast sprayer with hydraulic (exchangeable) nozzles are lost to non-target deposition. Also, axial fan sprayers, even those with air straighteners, produce an asymmetric air pattern which results in an uneven pattern of spray deposition in the canopy.

Over the years, there has been significant investment in research and extension to better adapt the airblast sprayer technology in various cropping systems to help overcome inherent flaws of the machinery. These have included the use of air straighteners, deflectors, smaller or larger fans, and improved, low-drift nozzles. Moving beyond basic sprayer calibration to focus on matching air volume to the canopy size or adjust the number of open nozzle positions during application can generate more-efficient spray application. Simple changes in nozzle selection, such as using nozzles with a well-defined droplet size at set pressure outputs or low-drift nozzles, can reduce aerial drift while providing adequate spray deposition. Airblast sprayers have hydraulic (exchangeable) nozzles, meaning that the nozzles are easily removed and replaced. For visualizations of different nozzle types, please see WSU Extension FS352E, “Common Interchangeable Nozzles for Perennial Crop Canopy Sprayers.”

Typically, airblast sprayers use disc-core type nozzles, which consist of an inner core or spinner plate and an outer disc. These nozzles produce a wide range of droplet diameter sizes (Dv0.1 to Dv0.9 of 100 to 340 µm). Droplet size can also change because of change in pressure or chemical corrosion of the nozzle material over time with use. Modern improvements to nozzle design include the use of a single-piece, molded body nozzle that houses a ceramic orifice with a smaller droplet size range. This single body design also allows easy identification of the nozzles, as manufacturers color-code the nozzle body to indicate spray output (defined as gallons per minute [GPM] in standard units and liters per minute [LPM] in metric units). Another option is the air induction nozzle. This nozzle design introduces air bubbles into spray droplets, creating enlarged droplets. Such larger droplets have more drag when traveling through the air, and are therefore less prone to drift. The air bubbles inside these droplets allow them to “splatter” rather than rebounding or bouncing as they hit the target, which can occur with solid droplets produced by non-air induction nozzles.

Though the airblast sprayer technology has not changed significantly over the years, that does not make it an obsolete technology to use in vineyards. With improved nozzle selection and air assistance optimized to canopy size, airblast sprayers could be used more efficiently in vineyards. Furthermore, their adaptability makes them a viable option for diversified farms with multiple crops and canopy shapes. This project compared two axial fan airblast sprayer optimization techniques with the goal of improving canopy deposition and reducing captured ground deposition and aerial drift. Sprayer performance was optimized for typical early or mid-season grapevine canopies grown under Eastern WA conditions, where vineyards are trained to a modified vertical shoot-positioning system. A Rear Manufacturing Powerblast Pul-Tank airblast sprayer was used in this study with 1) two different nozzle types, a standard single-body hollow-cone nozzle and an air induction nozzle; with 2) the air-assistance either on or off.

**Major Observations and Interpretations**

**Early-season spray deposition and drift.** In the early season, there was an interactive effect between nozzle type and the use of air on the total amount of spray deposited in the canopy (p = 0.01). The air induction nozzle (AI) with air-assistance configuration had the greatest total canopy spray deposition. The one-piece nozzle without air-assistance had the least (Figure 1).

There was also an interactive effect between nozzle type and air-assistance on spray deposition in the upper canopy zone (p < 0.0001). Using air induction nozzles with air-assistance resulted in greater upper canopy spray deposition; however, it was not significantly different than one-piece nozzles with air and AI with no air. Only the one-piece nozzles without air-assistance had significantly less deposition in the upper canopy (Figure 1). Spray deposition in the fruiting zone was influenced by the individual effects of nozzle type (p < 0.0001) and air-assistance (p = 0.0006). Using either air induction nozzles or air-assistance increased spray deposition in the fruiting zone.

We also looked at captured aerial drift at three different heights above the canopy, and at three different distances from the sprayed row. Aerial drift was collected two to four rows away from the sprayer. There was an interactive effect between nozzle type and air-assistance on total captured aerial drift in the early season...
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Overall, applications with no air-assistance had the least drift, and one-piece nozzles without air-assistance had the least overall captured aerial drift. The greatest captured aerial drift for either nozzle occurred when using air-assistance (Figure 2). These results affirm that air moves droplets further. Height above the canopy did not influence the amount of captured aerial drift collected ($p = 0.93$), but distance from the sprayed row did ($p < 0.0001$). Furthermore, there was an interactive effect between nozzle type and use of air-assistance for the amount of captured aerial drift collected from the sprayer at row two ($p = 0.004$), row three ($p = 0.0008$), and row four ($p < 0.0001$) from the sprayer. Applications made with one-piece nozzles without air-assistance had the least captured aerial drift in all rows; air induction nozzles with air-assistance had the greatest captured aerial drift in rows two and three from the sprayer, and one-piece nozzles with air-assistance had the greatest drift into row four from the sprayer (Figure 2). This is because smaller droplets in wind (or air) can move farther than larger droplets in the absence of wind.

Total ground deposition was influenced by an interactive effect between nozzle type and air-assistance ($p < 0.0001$). Using the one-piece nozzle without air-assistance resulted in the least total ground deposition, while using the air induction nozzle without air-assistance had the greatest total deposition to the ground (Figure 3). There was also an interactive effect between nozzle type and the use of air-assistance on ground deposition collected one row ($p < 0.0001$), two rows ($p = 0.002$), and three rows ($p = 0.002$) from the sprayer. When air-assistance is used with the larger droplets, such as with air induction nozzles, they are blown farther, resulting in more ground deposition in rows two and three from the sprayed row. These droplets were blown past the ground collectors in the first row and landed in the further rows because the air pushing the larger droplets created a larger falling arc.

Even though the sprayer was optimized for the canopy size by using only nozzles directed into the canopy, droplets can still go past the intended target during an application. Droplet size can significantly influence...
drift: small droplets can drift upward and farther downwind.\textsuperscript{4,11} In this study, the one-piece nozzle produced smaller droplets than the air induction nozzle, so one would expect to see the most captured aerial drift with one-piece nozzles. This was not always the case as there was an interaction with air. Despite droplet size differences, more aerial drift was captured when air was used. This emphasizes the importance of matching air volume and direction to the canopy being sprayed when optimizing a sprayer. These results seem intuitive, given the small size of the vine canopy during the early season (average height 48.6 cm [19.2 inches] and width 41.8 cm [16.5 inches]; average density 724 m\textsuperscript{3}/ha [10,347 ft\textsuperscript{3}/acre]). Small, sparse vine canopies would have increased blow-through due to less foliage to capture spray droplets. This canopy structure also influences the ground deposition patterns seen with air induction nozzles. The droplets are larger, less prone to captured aerial drift than smaller droplets, but clearly resulted in more ground deposition because the canopy was sparse.

Spray deposition into the canopy is important for pest control early in the season. Air induction nozzles with air-assistance resulted in the greatest spray deposition in the canopy during prebloom spray applications, but the one-piece nozzle without air-assistance had the least aerial drift captured at this time. More specifically, the greatest captured deposition in the fruiting zone, the economically important zone in a vine canopy, was seen with air induction nozzles and the use of air. When considering the factors of deposition and aerial drift, air induction nozzles without air in this early season may provide adequate spray coverage while reducing captured aerial drift. It is important to note that ground deposition in the early season was greater when using this nozzle and air combination, but overall ground deposition was low in this study, ranging from 15 to 170 times less than what was captured in the canopy. Ground deposition is considered less of an environmental and human health risk, and the amount collected from the air induction sprayer configurations, with or without air assistance, is minimal. Therefore, the optimal choice between these two configurations may not be practically different. Additionally, we only tested two air configurations (on or off), but in future vineyard applications, the fan could be slowed further to produce lower air volume and determine whether that configuration could result in similar canopy spray deposition with less ground deposition.

**Mid-season spray deposition and drift.** The vine canopy at this time had an average height of 77.2 cm (30.4 inches) and width of 81.3 cm (32.1 inches) over all data collection dates. During mid-season spray applications, the total spray deposited to the canopy was influenced by the combined effects of nozzle choice and air-assistance (\(p = 0.0005\)). There was no statistical difference in total collected canopy deposition when using air induction nozzles without air-assistance or one-piece nozzles with or without air-assistance. Air induction nozzles with air-assistance had the least total collected canopy deposition (Figure 4). When canopy spray deposition was divided by zone, deposition in the upper canopy was influenced by the individual effect of nozzle type (\(p = 0.0006\)), but not by air-assistance (Figure 4). Applications made using...
configurations with one-piece nozzles resulted in greater collected spray deposition to the upper canopy than applications using the air induction nozzles (Figure 4). There was an interactive effect of nozzle type and air-assistance on collected spray deposition in the fruiting zone ($p < 0.0001$). Applications made with the air induction nozzles without air-assistance resulted in greater canopy deposition, while applications using the one-piece nozzles without air-assistance had the least fruiting zone spray deposition (Figure 4).

In mid-season, total captured aerial drift was influenced by the interactive effect between nozzle type and air-assistance ($p < 0.0001$). The air induction nozzles with air-assistance had the most drift, while one-piece or air induction nozzles without air-assistance had the least captured aerial drift (Figure 5). The height above the canopy did not influence total captured aerial drift ($p = 0.54$), but distance from the sprayed row did ($p < 0.0001$). In the second row from the sprayer, there was an interactive effect between nozzle type and air-assistance ($p < 0.0001$), however, the overall pattern is that nozzles used with air-assist resulted in significantly more drift. One-piece or air induction nozzles without air-assistance configurations resulted in 59 to over 500 times less captured aerial drift than one-piece or air induction with air-assistance (Figure 5). Captured aerial drift in rows three and four from the sprayer was only influenced by air-assistance ($p < 0.0001$), with less drift occurring without air-assistance (Figure 5).

Total spray drifting to the vineyard ground during mid-season was also influenced by the interactive effect between nozzle type and air-assistance ($p < 0.0001$). One-piece or air induction nozzles without air-assistance had the least ground deposition collected; the air induction nozzle with air-assistance had the most ground deposition, though it was still relatively low (Figure 6). There was also an interactive effect between nozzle and air-assistance on the amount of ground deposition collected in rows one and two from the sprayed row ($p < 0.0001$). Air induction and one-piece nozzles without air-assistance...
had the least ground deposition in the rows adjacent to the sprayer; air induction with air-assistance had the most ground deposition in these rows. Ground deposition increased significantly in row three when air-assistance was used ($p < 0.0001$) (Figure 6). Overall ground deposition during mid-season applications was reduced when the sprayer was operated without air-assistance, as expected because added air movement away from the sprayer increases the distance droplets can travel from the sprayed row.

In mid-season, the best sprayer configuration to maximize spray deposition to the canopy, while minimizing captured aerial drift and ground deposition, was the air induction nozzle without air-assistance. However, mid-season-captured aerial drift was much less than in the early-season, suggesting that the primary focus for sprayer configuration should be to optimize canopy deposition, rather than to reduce drift, if the sprayer air volume and direction are appropriately matched to canopy size and density. As such, a one-piece nozzle with air-assistance may be optimal, particularly in larger canopies, as it has equally high canopy and fruit zone spray deposition as the air induction nozzle without air-assistance. Although not measured directly in this experiment, the smaller droplets may have a greater likelihood of penetrating into tight clusters.

Airblast sprayers often have a rotating nozzle body that can accommodate two or more nozzles at the same location. If air induction nozzles are used in early season, they can be on one side of the nozzle body, while a one-piece is installed on the other for later season. If other management decisions require only one type of nozzle to be used, the one-piece nozzle early season did have comparable, although slightly less, coverage to air induction. However, excess wind and high temperatures should be avoided during applications to not exacerbate the greater captured aerial drift. In regions with high winds or rural-urban interface, the constraints of using a single nozzle could be achieved with the air induction nozzles without air-assistance, as there was comparable coverage to one-piece nozzles and even more deposition in the fruit zone with less drift.

**Broader Impact**

There are many different approaches to optimize an airblast sprayer for vineyard use. Two such techniques are nozzle selection and whether air-assistance is used. With applicable information on how these approaches affect deposition and drift within a vineyard, growers can make more informed decisions on which approaches to apply at their sites. In addition, this information can help determine whether they are in compliance with local and national regulations regarding spray drift, particularly as it relates to application exclusion zones within the farm business’ boundaries. Application exclusion zones are determined by sprayer type, and airblast has the largest zone, i.e., 30.5 m (100 ft) in every direction from the sprayer. This US regulation requires growers to update their practices to adjust spray applications so that drift is within these zones. As the canopy grows and changes throughout the season, the sprayer configuration should adapt to keep droplets directed

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**Figure 6** Mid-season ground deposition collected in rows one, two, and three from the sprayed row for the Rears Manufacturing Pul Blast airblast sprayer during trials in 2018 and 2020. Arrows indicate that spray occurred on both sides of the canopy. Lettering after reported average deposition (nanograms per centimeter$^2$; ng/cm$^2$) indicate significant difference in means using Tukey’s honest significant difference at $\alpha = 0.05$ within each canopy zone. AI: air induction nozzle; 1P: one-piece nozzle; +: with air-assistance; -: without air-assistance. Only effects that were statistically significant are shown.
into the canopy. Growers often use air to compensate for the increasing size of a grape canopy, but the information presented here shows this may not be necessary to achieve adequate canopy deposition. Without blowing through the canopy, the droplets have an opportunity to swirl within the leaf space and be deposited inside the canopy instead of getting caught in wind currents and drifting off.\(^2\) Similarly, the nozzle types used at different times of the season with large canopy differences can change deposition and drift, as seen with air induction nozzles, which had the most ground deposition in the early season and the least in mid-season. Steps to advance this research would include data on biological efficacy of chemical applications.

**Experimental Design**

**General experimental design.** Sprayer operation information, including dates of sprays, specific vine growth stage at the time of application, and sprayer-specific operating metrics, are presented in Table 1. Evaluations of each sprayer setup and timing were repeated four times. The early-season evaluations were conducted on day of year (DOY) 143 and 144 in 2019 and on DOY 140 and 147 in 2020. Mid-season evaluations were conducted on DOY 194 and 198 in 2018 and on DOY 192 and 196 in 2020.

**Site and equipment descriptions.** *Site description.* The trial occurred in a research vineyard at Washington State University’s Irrigated Agriculture Research and Extension Center (Prosser, WA) in the Yakima Valley AVA (46°15’N; 119°43’W). The vineyard was planted in 2010 in a north-south row orientation to own-rooted *Vitis vinifera* Chardonnay on a 1.8 × 3.1 m vine by row spacing and trained to a modified vertical shoot-positioned system with a set of single catchwires at ~34 cm above the cordon, and a structural trellis wire at ~60 cm above the cordon. Industry-standard irrigation and pest management programs were followed.

**Sprayer description.** The Powerblast Pul-Tank airblast (Model 4S), a single row, axial fan sprayer manufactured by Rears Manufacturing was used in this study (Figure 7). It was operated by a John Deere 2355N in 2018 and a New Holland T4.75V in 2019 and 2020. Per industry standard, a rate controller was not used. The sprayer had a 0.84 m fan at a 20° pitch and was operated at 90 psi (6.2 bar) for all years of the experiment. Each side of the sprayer had 12 available nozzles with individual manual valve controls. Early-season data was collected with three nozzles open per side during applications and mid-season data was collected with four nozzles open per side during applications (Table 1). We increased the number of nozzles used in our later season applications to accommodate the larger and higher canopy growth. Heights of nozzles above the ground were: nozzle 1: 100 cm, nozzle 2: 116 cm, nozzle 3: 125 cm, and nozzle 4: 133 cm.

**Nozzle description and application approach.** Two types of hollow cone pattern nozzles were used in these trials: the Teejet Conejet VisiFlo (one-piece) and Teejet air induction. Nozzle model information is provided (Table 1). Each treated section of vineyard was sprayed on both sides of the canopy. With the one-piece nozzle, the eastern side of the canopy was sprayed on the first pass, and

| Year | Application timing | Nozzle type | DOY (vine growth stage-BBCH)\(^a\) | Tractor travel speed (km/hr / MPH) | Application water volume (LPH / GPA) | Engine Speed (RPM) |
|------|-------------------|-------------|----------------------------------|---------------------------------|-------------------------------------|-------------------|
| 2019 Early | Teejet VisiFlo TX-VK12 | 143 and 144 (57) | 5.3 / 3.3 | 233.9 / 25 | 1900 |
| 2020 Early | Teejet AITX-8002VK | 140 and 147 (57) | 3.7 / 2.3 | 467.7 / 50 | 1800 |
| 2018 Mid | Teejet VisiFlo TX-VK12 | 194 and 198 (77) | 3.7 / 2.3 | 467.7 / 50 | 1800 |
| 2020 Mid | Teejet AITX-8003VK | 193 and 196 (77) | 5.3 / 3.3 | 250.0 / 25 | 1900 |

\(^a\)Airblast sprayer consists of two consecutive half-row spray applications. See Figure 2.

\(^b\)Growth stages based on the extended BBCH scale.\(^2\) BBCH 55 was defined as early season application timing; BBCH 77 was defined as mid-season application timing.
the western side of the canopy was sprayed on the second pass. For the air induction nozzle, the western side of the canopy was treated on the first pass, and the eastern side of the canopy was treated on the second pass. Since axial fans have a lopsided air volume output\textsuperscript{13,15} on either side, it is important to note how the applications were made in case a systematic difference is uncovered through sample analysis. No such difference was found in the sample data collected, but to account for this inherent machinery characteristic, both sides of the canopy were averaged across canopy zones.

**Travel speed calculations.** The tractor speed, calculated before each spray trial application, was timed over a set-length course (91.44 m) and calculated as kilometers per hour (km/hr). During speed calculation trials, the tractor was operated at the same settings during an experimental application with the power take-off (PTO) engaged at the rotations per minute (RPM) of the intended application and with a full sprayer tank (Table 1). The spray volume was adjusted to account for changes in canopy size through the growing season.

**Weather and canopy measurements.** Environmental parameters including wind speed (km/hr), wind direction (°), relative humidity (RH, %), and air temperature (°C), were collected continuously during spray applications. An all-in-one weather station (ATMOS 41, METER Group Inc.) connected to a data logger (CR1000, Campbell Scientific) was used to acquire environmental data at 0.02 Hz. The weather station was mounted ~3 m above ground level. On days that the all-in-one ATMOS 41 weather station did not record weather data, the corresponding weather data was pulled from Washington State University’s AgWeatherNet (weather.wsu.edu) weather station network for “Prosser NE”. The AgWeatherNet “Prosser NE” station was used for early-season DOY 143 in 2019 for the first sprayer set-up and on DOY 147 in 2020 during applications. This station is located within 1 km (0.6 miles) of the site, and has an elevation difference of <50 m (165 ft). Collected environmental parameters conformed to ISO standards, i.e., ±25\% deviation for wind speed, ±10\% deviation for RH, ±5\% deviation for temperature, and ±10\% deviation for wind direction between the tests being compared, for all spray trials in early and mid-season, except wind direction.\textsuperscript{25} Median wind direction for all trials came from a westerly direction (west, 270°), but did not conform to the ISO\textsuperscript{25} standard requirement of no more than 30\% of the collected data points being >45° from the perpendicular.

**Figure 7** Evaluation of different optimization techniques, such as nozzle type and the use of air-assistance, on a Rears Manufacturing Pul Blast airblast sprayer. The trials were conducted between 2018 and 2020 in the Yakima Valley AVA of Washington State.
ular spray track (early season: 55%; mid-season: 37%). All environmental data recorded during experiments is presented (Tables 2 and 3).

Canopy measurements were taken after each application was made in a 3-m section of vines not in a data row. Five canopy height measurements, from cordon to furthest vegetation at that particular section of vine, and five canopy width measurements, between the furthest vegetation on either side at that particular section of vine, were recorded per 3-m section of vine. These measurements were collected in two different places in the vineyard and then averaged to determine vine-row-volume of the canopy at time of application.

**Spray deposition and drift collection and processing.** The spray deposition and drift collection and processing methods described below were similar to those done by McCoy et al.\(^26\) with a few modifications as indicated below. As with that previous study, a fluorescent tracer (Keystone Pyranine 10G; Milliken) was used as a tracer dye for collecting spray droplet canopy deposition, captured aerial drift, and ground deposition on 5 × 5 cm plastic cards. Tracer concentrations were used to normalize collected data across spray dates using a pre- and post-spray tank sample.

**Canopy spray deposition – Experimental design.** Collection of canopy deposition was made possible using

| Year | Application experiment | Nozzle and air treatment | Avg. temp (°C) | Avg. relative humidity (%) | Avg. wind speed (km/hr) | Avg. wind direction (°) | Vine-row-volume (m³/ha) |
|------|------------------------|--------------------------|----------------|---------------------------|------------------------|------------------------|------------------------|
| 2019 | 1                      | 1-piece, air on          | 17.9           | 74.9                       | 4.2                    | *W (261)               | 850.7                  |
|      |                        | 1-piece, air off         | 18.7           | 78.1                       | 4.3                    | *S (170)               |                        |
|      |                        | AI, air on               | 19.4           | 75.0                       | 5.9                    | *N (10.8)              |                        |
|      |                        | AI, air off              | 19.1           | 72.9                       | 7.5                    | *S (171)               |                        |
|      | 2                      | 1-piece, air on          | 13.3           | 82.0                       | 6.5                    | WNW (283)              | 596.2                  |
|      |                        | AI, air off              | 13.7           | 82.7                       | 9.8                    | W (281)                |                        |
|      |                        | AI, air on               | 19.1           | 61.1                       | 3.8                    | ESE (103)              |                        |
|      |                        | AI, air off              | 15.8           | 78.3                       | 2.3                    | ENE (62)               |                        |
| 2020 | 3                      | 1-piece, air on          | 11.2           | 85.1                       | 6.8                    | W (270)                |                        |
|      |                        | AI, air on               | 11.4           | 86.8                       | 14.7                   | SW (221)               |                        |
|      |                        | AI, air off              | 11.7           | 88.4                       | 19.1                   | WSW (241)              |                        |
|      |                        | AI, air on               | 11.5           | 88.5                       | 16.9                   | SW (228)               |                        |
|      | 4                      | 1-piece, air on          | 15.1           | 72.2                       | 2.4                    | *NW (325)              |                        |
|      |                        | 1-piece, air off         | 16.7           | 68.4                       | 2.6                    | *S (191)               |                        |
|      |                        | AI, air on               | 16.7           | 58.8                       | 9.6                    | *SW (236)              |                        |

\(^a\)Early season collections occurred on DOY 143 and 144 in 2019 and DOY 140 and 147 in 2020. Weather data were collected from an on-site ATMOS weather station for DOY 144 and 140, and from Washington State University AgWeatherNet (weather.wsu.edu) “Prosser NE” station, located within 1000 m of the site, and an elevation difference of less than 50 m (as noted with an *).
15 PVC pipe poles down a single row to hold the plastic cards within the zones of interest (Figure 8A). Canopy deposition on the plastic cards had five zones per pole, but in data analysis, we combined these zones to represent the “upper canopy” (east, west, and middle of the upper canopy; n = 45) and the fruiting zone (east and west of canopy fruit zone; n = 30). Distance between plastic cards in the upper canopy and fruiting zone was ~17 cm.

Captured aerial drift and ground deposition – Experimental design. Captured aerial drift poles, also constructed of PVC (Figure 8B), were placed in rows two to four downwind from the sprayed row (Figure 8D) and collected drift at 0.3, 0.6, and 0.9 m above the canopy. Ground deposition was collected using wooden blocks (10 × 17 cm) placed in the middle of the interrow (Figure 8C), with plastic cards affixed under a rubber band. Each treatment replicate consisted of three drift poles in 2018 (n = 3) and nine drift poles in 2019 and 2020 (n = 9). Ground deposition blocks were placed in line with the drift poles and the same sampling pattern as captured aerial drift (n = 3 in 2018 and n = 9 in 2019 and 2020). Captured aerial drift and ground deposition data was increased between 2018 and 2019 to ensure a large enough sample size based upon previous data collection with other field trials.

Deposition quantification. An aliquot of deionized water was added to each individual sample then shaken for 1 min at 180 oscillations/min (Model: 6010, Eberbach shaker). A fluorometer (10-AU, Turner Design) was used to analyze a sample of the solution, with a reading in parts per billion (μg/L), via a borosilicate glass cuvette. Sample concentrations exceeding the upper limit of the fluorometer (1000 μg/L) were diluted and reanalyzed. Each sample reading was corrected using a calibration curve produced from tracer standards made from each chemical lot of tracer specific to a trial.

Statistical analysis. Fluorometry readings were normalized for tank sample concentrations and applications of each repetition in 2018 (n = 3) and from the center three vines of each repetition in 2019 and 2020 (n = 9).

Deposition and drift collection procedures. After an application, tracer solution was allowed to dry for ~10 min before being collected into an individual plastic bag (Uline). General best practice protocols (changing gloves and discarding compromised cards) were followed to prevent contamination between samples. After collection, all samples were placed in a dark, thermally insulated cooler with ice packs to avoid tracer degradation before being stored at 1.6°C and processed within 60 days of collection. At this temperature, samples can be stored up to 90 days with minimal deterioration.

### Table 3
Sprayer configurations, weather, day of year (DOY), and canopy volume during the mid-season application experiment conducted using Rears Manufacturing Pul Blast airblast sprayer in Washington State optimization trials between 2018 and 2020.

| Year | Application experiment | Nozzle and air treatment | Avg. temp (°C) | Avg. relative humidity (%) | Avg. windspeed (km/hr) | Avg. wind direction (°) | Vine-row-volume (m³/ha) |
|------|------------------------|--------------------------|----------------|---------------------------|------------------------|-------------------------|-------------------------|
| 2018 | 1                      | 1-piece, air on          | 15.7           | 67.0                      | 13.3                   | NW (321)                | 2056.1                  |
|      |                        | 1-piece, air off         | 17.3           | 67.4                      | 9.1                    | NWN (335)               |                         |
|      |                        | Al, air on               | 24.2           | 55.5                      | 8.1                    | SSE (158)               |                         |
|      |                        | Al, air off              | 22.1           | 58.6                      | 2.3                    | S (171)                 |                         |
|      |                        | 1-piece, air on          | 18.0           | 61.3                      | 11.4                   | WSW (237)               |                         |
|      |                        | 1-piece, air off         | 19.0           | 56.0                      | 10.2                   | WSW (247)               |                         |
|      |                        | Al, air on               | 23.1           | 47.3                      | 7.6                    | NWNW (330)              |                         |
|      |                        | Al, air off              | 21.2           | 52.1                      | 5.9                    | WNW (287)               |                         |
| 2020 | 3                      | 1-piece, air on          | 12.2           | 75.0                      | 10.9                   | NWN (334)               | 2486.3                  |
|      |                        | 1-piece, air off         | 16.2           | 65.2                      | 5.7                    | WNW (293)               |                         |
|      |                        | Al, air on               | 19.9           | 56.7                      | 12.4                   | SSE (156)               |                         |
|      |                        | Al, air off              | 18.1           | 59.8                      | 4.3                    | W (271)                 |                         |
|      |                        | 1-piece, air on          | 11.1           | 62.3                      | 11.8                   | N (351)                 |                         |
|      |                        | 1-piece, air off         | 14.4           | 56.9                      | 8.1                    | N (351)                 |                         |
|      |                        | Al, air on               | 18.8           | 46.0                      | 7.2                    | W (276)                 |                         |
|      |                        | Al, air off              | 18.0           | 50.5                      | 6.1                    | SW (226)                |                         |

*aMid-season collections occurred on DOY 194 and 198 in 2018 and DOY 192 and 196 in 2020. All weather data were collected from an on-site ATMOS weather station.*
across all application days to allow comparison among sprayer configurations. Deposition drift was analyzed using analysis of variance and least standard squares, with air-assistance, nozzle type, and their interaction as fixed effects, and experimental repetition (DOY) as a random effect. For captured aerial drift and ground deposition, height above the canopy and/or distance from the sprayer was also evaluated as a fixed effect. Post-hoc means separation was done using Tukey's honest significant difference, with \( \alpha = 0.05 \) as a significance threshold (JMP; ver. 15.0.0, SAS Institute, Inc.).

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