Coverage and Drift Produced by Air Induction and Conventional Hydraulic Nozzles Used for Orchard Applications

R. C. Derksen, H. Zhu, R. D. Fox, R. D. Brazee, C. R. Krause

Abstract. *A conventional, axial-flow, air-blast orchard sprayer was used to make applications to the outside row of a semi-dwarf apple block. Fluorescent tracer was applied at the same rate using either disc-core nozzle sets or air-induction nozzles fitted with flat-fan tips. The experiment included measuring the percent area of spray coverage on leaves after three variations in spray application method. Each of the variations used a different type of nozzle on the same conventional, axial-fan orchard sprayer. The three nozzle variations were a Spraying Systems D3-25 nozzle set, a Spraying Systems D4-25 nozzle set, and a TurboDrop 02 (TD02) air-induction nozzle set. Canopy spray deposits, downwind sedimentation, and airborne spray losses were also measured following treatment on the inside half of the outside row using D4-25 nozzles or TD02 nozzles. The small droplet spectrum D3-25 nozzle set produced the highest leaf surface coverage on both upperside and underside surfaces at 2.0 and 3.0 m heights in the canopy. The upperside leaf surface coverage produced by the D3-25 nozzle was only somewhat greater than the TD02 nozzle. It was, however, significantly higher than the D4-25 nozzle set at the 3.0 m height. Conversely, the underside leaf surface coverage produced by the D3-25 was significantly greater than the TD02 nozzle set at both 2.0 and 3.0 m heights and not statistically different from the D4-25 nozzle set at the lower sampling height. There were relatively few differences in canopy spray deposits between the D4-25 and TD02 nozzle sets. The TD02 treatment produced the lowest downwind sedimentation deposits on targets 8 to 32 m from the edge of the orchard. The D4-25 produced approximately three times higher deposits up to 9 m above the ground than the TD02 treatment on passive nylon screens located 8 m downwind from the edge of the orchard. The D4-25 treatment produced significantly higher airborne deposits on elevated, high-volume, air sampler filters out to 64 m. At 128 m, sedimentation and airborne deposits were similar for the D4-25 and TD02 treatments.*

Keywords. *Air-assist, Air-blast, Fruit, Orchard, Spray deposit.*

Off-target spray losses in orchards can arise from spray drifting through gaps between trees, through dormant canopies, or over the top of the canopy. This can occur because of the direction of spray discharge or deflection of the spray stream over the canopy. The most common recommendation for reducing drift is to produce larger droplets, which do not drift as far, and reduce the number of smaller, drift-prone droplets. However, this recommendation is usually in direct conflict with desirable methods for improving spray coverage and pesticide efficacy.

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Some field studies have attempted to determine the levels of sedimentation and airborne spray losses in orchard crops (Doruchowski et al., 1996; Fox et al., 1993; Ganzelmeier, 1993; May et al., 1994; Riley and Wiesner, 1990). All of these studies have shown a significant decrease in downwind deposits within 60 m of the outside edge of the orchard. Riley and Wiesner (1990) developed regression equations to predict downwind airborne spray losses resulting from multiple-row orchard applications. In 1998, the Spray Drift Task Force (SDTF), a consortium of 38 agricultural chemical companies, reported on a series of field experiments conducted using conventional, axial-flow, air-blast sprayers to treat vine and tree canopies. The STDF reported that 96% of the spray applied to the last six rows of a citrus orchard stayed within the orchard. Downwind ground deposits were somewhat higher when applications were made to a mature, semi-dwarf, apple canopy (SDTF, 1998).

Several machine-related factors can affect spray distribution in orchard trees and off-target losses. Raisigl et al. (1991), Furness and Pinczewski (1985), and Randall (1971), among others, demonstrated the role of the air delivery system. Outlet airjet speed significantly affects foliar spray deposits as well as sedimentation and airborne spray losses (Doruchowski et al., 1996). Derksen and Gray (1995) demonstrated the importance of the relative position of the spray discharge with the tree canopy using a conventional type of axial-fan, air-blast sprayer. Van Ee and Ledebuhr (1988) and

Steinke et al. (1992) showed that a tower-type sprayer utilizing cross-flow fans could produce more uniform spray deposits than axial-fan, air-blast sprayers. Horizontal spray delivery into tree and vine canopies produced higher canopy deposits and lower levels of off-target spray drift compared to axial-flow, air-blast sprayer applications (van de Werken, 1991; Fox et al., 1993; McFadden-Smith et al., 1993).

Increasing travel speed from 1.6 to 6.4 km/h has been found to increase deposition on the sprayer side of citrus canopies (Salyani and Whitney, 1990). Derksen et al. (1999a) found that increasing travel speed from 4.0 to 6.4 km/h did not significantly affect spray deposits in the red maple tree row nearest the sprayer or the coverage and deposits in the next two rows downwind. Salyani (2000) showed that, in general, increasing travel speed or reducing nozzle size increased deposition on targets mounted in an open area using a traditional, axial-fan, air-blast sprayer. However, he also found that deposition efficiency was higher for cases of lower volume applications (<900 L/ha) made with fewer smaller nozzles at lower travel speeds. Deposition efficiency increased at higher volume applications (>2500 L/ha) with increasing numbers of nozzles at higher travel speeds.

Various reports have suggested optimum droplet sizes for maximizing pesticide efficacy. Laboratory studies reported by Himel (1969), Wofford et al. (1987), Adams and Hall (1989), Hall et al. (1990), and Omar et al. (1991) generally found that smaller droplet sizes provided better insect control. However, Womac et al. (1994) and Ebert et al. (1999) found that small droplet sizes did not necessarily provide any better insect control. Studying deposition on vertical and horizontal canopy surfaces, Spillman (1984) reported that droplets 250 μm or larger had the highest deposition efficiency on leaves, while much smaller droplets (20 to 50 μm) produced the highest deposition efficiency on vertical surfaces as well as the undersides of leaves. Dubs et al. (1985) showed that, for the range of droplet sizes evaluated, the 115 μm diameter droplets produced the highest deposition efficiency on vegetation aligned perpendicular to the flight of the droplets. Laboratory studies conducted by Salyani et al. (1987) found that the highest deposition efficiency on citrus leaves was obtained by rather large droplets, approximately 400 μm in diameter. Salyani (2000) observed that lower volume citrus-type of applications made using smaller nozzle sizes resulted in higher deposition efficiency on targets placed in an open field around an orchard sprayer.

Droplet size is a significant factor in drift regulation. Most agricultural nozzle manufacturers have attempted to meet demands from the marketplace for alternate means of minimizing spray drift by introducing low-drift nozzles. The new nozzles have been primarily aimed at use on boom-type of broadcast sprayers used to treat field crops. Pre-orifice chambers and venturi designs have been integrated into nozzle body designs to meet this market demand. These nozzles are designed mostly for reducing the number of small, drift-prone droplets and creating larger droplets than comparable standard flat-fan (SFF) nozzles at the same flow rate and operating pressure.

In wind tunnel laboratory experiments, Derksen et al. (1999b) showed that an air-induction nozzle reduced downwind sedimentation and airborne spray losses compared to standard flat-fan nozzles. Reports of droplet size measurements made with a Malvern particle size analyzer (Derksen et al., 1999b; Womac et al., 1997) have shown that air-induction nozzles increase volume median diameter compared to similar flow rate standard flat-fan nozzles. Wicke et al. (1999), studying contamination on spray equipment operators, further illustrated that reduced off-target losses were possible through use of air-induction nozzles. In their work, they showed that applications made to tree canopies with a spray lance produced fewer deposits on the operators' clothing when air-induction nozzles were used compared to conventional cone nozzles. Heijne et al. (2002) compared drift losses from a cross-flow orchard sprayer using air-inclusion, hollow-cone, and standard hollow-cone nozzles. Air-inclusion nozzles did not reduce spray losses to the ground in the range of 3 to 7 m from the last tree row. Heijne et al. (2002) speculated that the air-inclusion nozzles reduced spray losses to the ground beyond 8 m from the last tree row compared to standard hollow-cone nozzles. However, these reports provide no information on the fate of air-induction nozzle sprays within the canopy. Air-induction nozzles have been shown to produce higher deposits in lower portions of peanut canopies (Zhu et al., 2004) and in dense tree canopies (Horst et al., 2002). In 2.6 m tall crabapple trees, Zhu et al. (2005) found no significant differences for deposits between conventional hollow-cone nozzles and air-induction nozzles.

Objective

The goal of this work was to evaluate the effects of different nozzle types on spray coverage, canopy spray distribution, and off-target spray movement produced by a conventional, air-blast orchard sprayer treating semi-dwarf apples trees.

Materials and Methods

The spray site for these experiments was located at the Ohio Agricultural Research and Development Center, Wooster, Ohio. The apple trees were Melrose variety primarily on Sargent, M7 rootstock and were planted in 1986. Row spacing was 6 m and tree spacing within the row was 4.5 m. The tallest trees were approximately 3.5 m and there were some open space between adjacent tree canopies, especially above 2.5 m. An overview of the test site is shown in figure 1. Downwind sampling distances were measured from the centerline of the tree row. The land sloped upward at about a 2% grade from west to east. All experiments were conducted post-harvest. Coverage experiments were conducted on October 20, 21, and 28. Canopy deposit and drift experiments were conducted on October 26.

All applications were made using a Myers air-blast orchard sprayer (model A36, Myers Co., Ashland, Ohio). The fan turned counter-clockwise as viewed from the rear of the machine. Only the left-hand side of the sprayer was used to make the applications. For the two drift treatments, the sprayer was fitted with either nine D4-25 stainless steel, disc-core nozzle sets (Spraying Systems Co., Wheaton, Ill.) or nine TurboDrop 02 (TD02) nozzle bodies (Greenleaf Technologies, Covington, La.) using Albuz ceramic, No. 5 (green) flat-fan tips. Nine D3-25 stainless steel, disc-core nozzle sets (Spraying Systems Co., Wheaton, Ill.) were used as a third treatment in the coverage experiments. The operating pressure measured on the manifold for each set was 1723, 896, and 1344 kPa, respectively, for the D3-25, D4-25, and TD02 nozzle sets and provided a nominal nozzle output of 1.63 L/min.

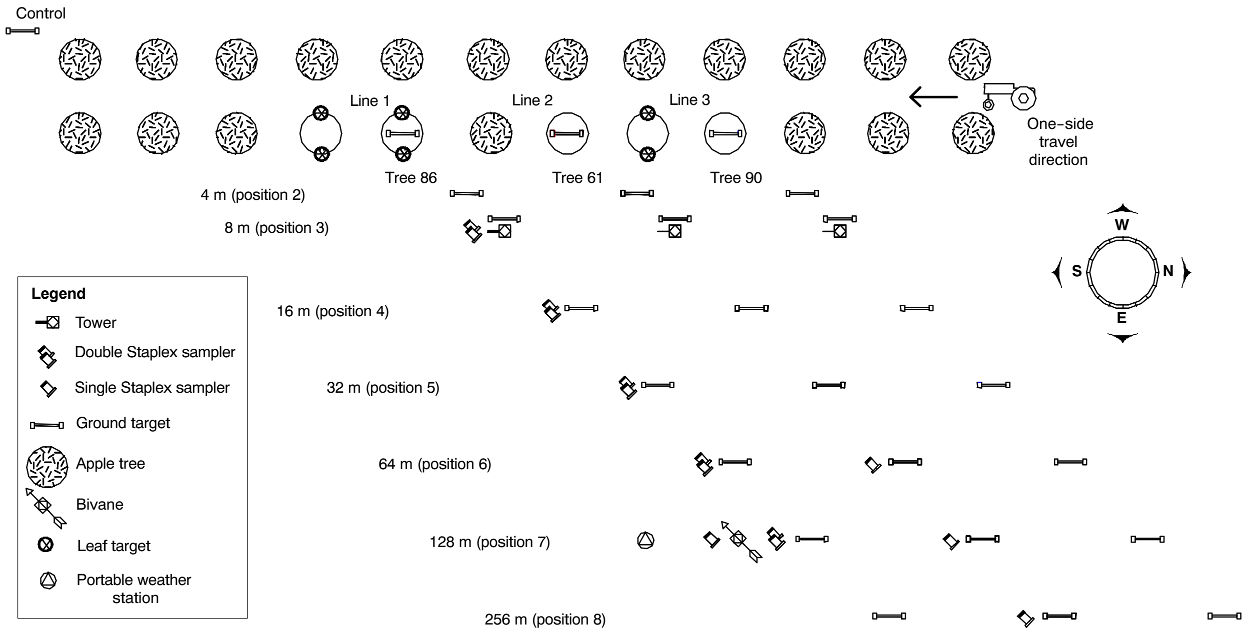

Figure 1. Overhead illustration of experimental orchard drift test site.

No direct measurements of spray spectrum characteristics were made for these experiments. The $D_{v.5}$ reported by Greenleaf Technologies for the TD02 nozzle spraying water at 1400 kPa is 253 µm. The $D_{v.5}$ reported by Spraying Systems Co. for the D3-25 nozzle spraying water is 125 to 155 µm for operating pressures from 2067 to 1378 kPa and for the D4-25 nozzle is 210 to 225 µm for operating pressures from 1034 to 689 kPa.

Percent of Area Spray Coverage

A tank mix containing 1.25 g/L of Tinopal CBS-X (Keystone, Chicago, Ill.) and a 0.1% concentration of X-77 (Loveland Industries, Greeley, Colo.), a non-ionic spreader, were used as the spray coverage tracer. Tinopal is highly soluble in water and has a high degree of contrast with apple leaves when excited by a short-wavelength, ultraviolet light source. The surfactant was added to the tank mix to simulate spreading produced by adjuvants added to commercial spray mixes. The addition of surfactants to the spray mix also appears to enhance the ability of air-induction nozzles, like the TD02, to produce air bubbles within droplets. Canopy spray coverage sampling was made at 2.0 and 3.0 m elevations, approximately 1.0 m from the trunk, on both sides of the trees. Untreated apple leaves from an untreated block were used as targets for spray coverage analysis. Three untreated apple leaves of similar size were placed in the target locations before each application. Electrical connectors were used to hold each leaf by the petiole in the target locations. This method of fastening permitted some natural leaf movement and flutter as the sprayer passed. Target leaf orientation was similar to that of neighboring leaves. All treatments and replications were made without having to move the leaf sample holders. Figure 2 shows the location where the sample holders were placed in the tree canopy. Each of the three treatments was repeated three times.

After allowing 10 to 15 min for the target leaves to dry, gloved workers placed individual target leaves in small paper bags. The risk of condensation, which could have altered the Tinopal deposits, was lower in paper bags compared to plastic containers. Sample bags were stored loosely to reduce smearing of deposits. Spray coverage evaluations were made in a laboratory using an epi-fluorescent microscope (Eclipse E-400, Nikon, Tokyo, Japan) with a 2× objective. Filter sets used for illuminating the dried tracer and limiting natural

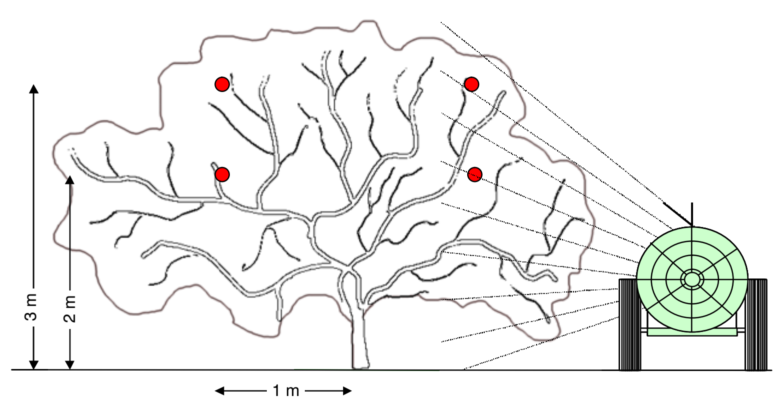

Figure 2. Foliar target locations within the tree canopy.

auto-fluorescence emitted from the leaves included an excitation filter (360 to 400 nm), a dichroic mirror (400 nm), and a barrier filter (460 to 510 nm) that limited fluorescent light generated by the specimen. A vacuum stage was used to hold the samples flat across the viewing under the microscope objective to minimize focusing errors. Images were captured and digitized using a black and white, digital, air-cooled camera (SenSys 1400, Photometrics, Ltd., Tucson, Ariz.). Images were saved and analyzed using Image-Pro Plus, ver. 4.0, software (Media Cybernetics, Silver Spring, Md.).

The sample area was approximately 7.1 × 5.6 mm (658 × 517 pixels). Dried droplet deposits or spots smaller than 363 μm^2 (approx. 2 pixels across) were rejected since it was not possible to know if these spots represented noise or actual deposits. One image was taken of each side of each target leaf. The camera operator attempted to use a viewing area that generally represented the type of coverage observed across the entire leaf surface. Before setting a thresholding level, each image was processed using two passes of a 3 × 3 median filter to sharpen the images. The percent area of spray coverage was calculated as the ratio of the area of dried droplets or spot deposits to the total area sampled.

No meteorological measurements were made during the coverage experiments. Winds reported in Wooster during these experiments were generally moderate, 4 to 5 m/s and from the west-southwest. It was felt that these wind conditions would not significantly affect coverage measurements in a canopy area so close to the sprayer.

Canopy Deposits and Spray Drift

As shown in figure 1, ground and airborne samplers were positioned along three different sampling lines, 10 m apart and 45° from the tree row and extending out from outside tree row. The sprayer made one pass for the canopy deposit and spray drift experiment, along the inside of outside row, spraying from the inside to the outside of the orchard.

Acid Yellow 7 (Caracid Yellow Extraconc, Carolina Color and Chemical Co., Charlotte, N.C.), mixed with well water, was used as the tracer in the canopy deposit and drift measurements. The tank mix tracer concentration was 0.79 g/L. A non-ionic spreader (X-77) was added to produce a 0.1% tank mix so that tank mixes for the coverage and drift experiments were similar in adjuvant content.

Canopy deposit measurements were made by analyzing one leaf sample located in each of the target locations shown in figure 2. These same sites were used for the coverage evaluations. Untreated apple leaves were harvested from another location upwind of the test site for use in these experiments. Treated leaves were placed individually in glass bottles that were used for tracer recovery. Distilled water (30 mL) was added to each bottle and then each bottle was shaken 30 s before removing a 5 mL sample of the rinsate for analysis. After rinsate samples had been drawn from leaf sample bottles, leaves were removed from their storage bottles and the area of each leaf was determined using a video system (Delta-T, Cambridge, U.K.). These area measurements were doubled to account for areas on both upperside and underside leaf surfaces.

Three types of collectors were used to make off-target drift measurements. Downwind ground deposits were collected on 5.1 cm wide plastic tape, held in 2.4 m long metal trays. The untreated tape was wound on a supply spool before the experiments and then pulled across the tray after each spray treatment and wound around a take-up reel on the opposite end of the tray. Figure 1 shows the position of the ground collectors in each spray line at 0, 4, 8, 16, 32, 64, 128, and 256 m. The 0 m position was located in the tree row with the trays centered under the tree, next to the east side of the tree trunk. The trays were held approximately 10 cm above the ground to minimize any shadowing effects of the grass in the collection area. Each ground collector spool held sufficient tape for three replicates for each treatment. Following completion of the field tests, each take-up reel was placed in a plastic bag to minimize contamination. The tapes were unwound and cut into individual test sections in the laboratory. Each treatment strip was wound and placed in a glass bottle for washing. Tracer was recovered from the tapes by adding 50 mL of water to each bottle and then spinning the roll of tape clockwise and counter-clockwise with an electric drill.

Nylon screen (50% open area, 20 × 20 cm) was used as a passive collector of airborne downwind spray material near the treatment area. Ten screen collectors were mounted on each of the three spray line towers, 8 m downwind from the treatment area. Screens were mounted at 1 m intervals, from 1 to 10 m above the ground. Following each treatment, individual screens were placed in glass bottles that would later be used for tracer recovery. The screen bottles, containing 30 mL of distilled water, were shaken for 30 s before removing the tracer solution.

High-volume air samplers (model TFIA, Staplex Air Sampler Division, Brooklyn, N.Y.) were also used to collect downwind airborne spray along spray line 1 at 8, 16, 32, 64, and 128 m downwind from the treatment area at 1 and 3 m elevations. Additional high-volume samplers were placed at 3 m along collection line 2 at 64 and 128 m downwind. Cellulose filters (10 cm diameter, model TFA41) were used as collectors in the high-volume samplers. The air samplers were allowed to run for 10 to 15 min following application while the targets dried and airborne particles moved away from the treatment area. After the samplers were shut down, filters were removed and placed in glass bottles that were later used to recover tracer. Each filter bottle, with 30 mL of distilled water, was shaken for approximately 30 s for tracer recovery.

A ground collector was placed approximately 50 m upwind of the test area. This collector was used for evaluating spiked samples. Each spike sample consisted of 15 μL of tank mix applied immediately before each sprayer pass. This ground target tape was handled in the same manner as those located along the downwind spray lines. In addition, 15 μL of tank mix was added to a clean, glass, recovery bottle before each treatment. These bottles were stored in a shaded area during testing. This spiked bottle test permitted comparison of recovery differences and tracer degradation between the ground tape and the bottle.

The concentration of tracer in each rinsate sample was measured using a luminescence spectrophotometer (model LS-50B, Perkin-Elmer, Norwalk, Conn.). Prior testing of the Acid Yellow 7 showed that the peak excitation wavelength was 475 nm. An emission wavelength setting of 500 nm was also used. Known concentrations were used to determine the relationship between tracer concentration and sample emission.

Meteorological measurements, including wind speed, direction, air temperature, and relative humidity, were made downwind of the treatment area. Figure 1 shows the location

Table 1. Meteorological conditions for drift experiments (standard deviations shown in parentheses).

Treatment	Time	Wind Speed (m/s)	Wind Direction (0˚-North, CW)	Temp. (˚C)	RH (%)
TD02	0934	4.6 (0.47)	227 (3.92)	7.9	52
	1043	4.9 (0.65)	236 (10.55)	10.3	45
	1124	4.9 (1.06)	244 (4.72)	10.5	46
D4-25	1207	4.8 (0.49)	242 (7.91)	11.8	42
	1337	4.5 (0.94)	243 (9.46)	14.0	39
	1423	4.9 (0.65)	254 (12.58)	14.8	36

Table 2. Percent leaf surface spray coverage by canopy evaluation.[a]

	% Upperside Leaf Surface Coverage		% Underside Leaf Surface Coverage	
Treatment	2.0 m Elevation	3.0 m Elevation	2.0 m Elevation	3.0 m Elevation
D3-25	59 a	56 a	13 a	18 a
D4-25	57 a	47 b	10 a	10 b
TD02	54 a	49 ab	6 b	9 b

[a] Values in the same column followed by the same letter are not significantly different ($p < 0.05$).

of these sensors. The site closest to position 7 of spray line 1 included a bivane anemometer (model 21003, R.M. Young, Inc., Traverse City, Mich.) mounted at 10 m and cup anemometers (model 901-LED, C.W. Thornthwaite Associates, Elmer, N.J.) mounted at 3 and 10 m elevations. Approximately 25 m south of the weather station near position 7 of spray line 1, a combination temperature probe and relative humidity sensor (model HMP-35C, Campbell Scientific, Inc.) was mounted on a portable tripod.

Meteorological measurements for each test are shown in table 1. The sky was clear and sunny throughout the duration of the drift measurements. Meteorological measurements were sampled each second and averaged and recorded each minute from the time the tractor operator was directed to begin spraying until 15 min after spraying was complete. Low humidity and a clear sky helped minimize drying times of the targets.

The coverage data were analyzed using SAS (SAS Institute, Inc., Cary, N.C.) to calculate the analysis of variance based on a general linear model for a complete randomized block design. Within each main plot of treatments, sides of trees, elevations within the trees, and leaf surfaces created a split-split-split plot design. After the analysis of variance, least significant differences were calculated at a significance level of $p = 0.05$. Spray deposit and drift findings were analyzed by one-way ANOVA, and differences among means were determined with Duncan's new multiple range test using ProStat version 3.5 (Poly Software International, Pearl River, N.Y.). All significant differences were determined at the 0.05 level of significance.

Results and Discussion

Percent Area of Spray Coverage

It was relatively easy to distinguish tracer deposits from the apple leaf backgrounds using the procedures and hardware described in this article. While the thresholding procedure was subjective and based on the operator's decisions, differences of one to two gray levels did not significantly affect results. A wide range of coverage values was observed for all treatments.

The analysis of variance showed that, overall, there were significant differences in the percent area of spray coverage between treatments. Averaged across upperside and underside leaf surfaces, the D3-25 treatment produced significantly higher leaf surface coverage than the other treatments. There were no significant differences in the overall average coverage between the D4-25 and TD02 treatments. As expected, there were no significant differences in coverage on either side of the trees following treatment on both sides of the row, but coverage in the middle tree (tree 2) was significantly lower than that found in either of the other trees. There were no significant differences in coverage on tree 2 between treatments. There were no significant differences in mean coverage found at the 2.0 m and 3.0 elevations.

Table 2 shows the percent area of spray coverage measured on the upperside leaf surfaces. There were no significant differences in coverage between leaves taken from the same location. The D3-25 treatment appeared to produce more, smaller droplet deposits than the other two treatments. There were no significant differences in upperside leaf surface coverage at either canopy elevation. Spray coverage was higher at the 2.0 m height than the 3.0 m canopy location for all treatments, although the differences were smallest for the D3-25 treatment. The D3-25 treatment produced significantly higher upperside leaf surface coverage at the 3.0 m location compared to the D4-25 treatment.

Spray coverage was lower on the back or underside leaf surfaces compared to the upperside surfaces (table 2). There were more, smaller, distinct deposit features on the underside surfaces compared to the upperside surfaces. The smaller droplet, D3-25 treatment produced the highest coverage on the underside surfaces and significantly higher coverage than the TD02 treatment at both elevations. Statistically, there were no significant differences in underside leaf surface coverage between the D4-25 and TD02 treatments. The underside leaf surface coverage was slightly higher at the 3.0 m elevation compared to the samples taken from the 2.0 m elevation. Based on the relative position of leaves at the 3.0 elevation compared to the spray discharge of the sprayer, the undersides of leaves at the higher elevation may have had more direct exposure than the undersides of leaves at the lower elevation.

Canopy Deposits and Spray Drift

When averaged across three replicates, mean tracer recovery from the glass rinse bottles was 98% on average for the TD02 and D4-25 treatments. Spray recovery from the upwind ground tapes that were exposed to direct sunlight was slightly lower (90%) than recovery from the bottles. The reduced recovery rate may have been the result of some slight photodegradation of the tracer. Because the recovery losses were considered relatively small and were consistent for both treatments, no corrections were applied to the data for the canopy or the off-target deposits.

The spray discharge produced by the TD02 treatment appeared to produce fewer fine droplets than the D4-25 treatment. Observers at the test site noticed very little material passing through the tree canopies for either nozzle treatment. Most the spray moving across the row appeared to come through gaps between trees or over the tops of the canopy.

Differences in foliar spray deposits were relatively small between nozzles (table 3). A combination of the delivery

Table 3. Foliar spray deposits following treatment from one side only by canopy elevation (CV in parentheses).[a]

Treatment	Near Sprayer Canopy Deposit (μg/cm²) 2.0 m Elevation	Near Sprayer Canopy Deposit (μg/cm²) 3.0 m Elevation	Outside Canopy Deposit (μg/cm²) 2.0 m Elevation	Outside Canopy Deposit (μg/cm²) 3.0 m Elevation
TD02	0.30 Aa (47)	0.29 Aa (65)	0.010 Ab (107)	0.040 Ab (126)
D4-25	0.26 Aa (79)	0.24 Aa (46)	0.006 Ab (108)	0.020 Ab (100)

[a] Means in a row followed by a different lowercase letter are significantly different ($p < 0.05$); means in a column followed by a different uppercase letter are significantly different ($p < 0.05$).

technique and canopy shading significantly reduced spray deposits on target on the far side of the canopy from the sprayer. Foliar spray deposits were 7 to 43 times higher on the side of the canopy closest to the sprayer compared to the deposits measured in the canopy on the side away from the sprayer. No differences in foliar deposits were observed between nozzle treatments by elevation on either side of the tree canopies. As shown in table 3, there were no differences in foliar deposits between the TD02 and D4-25 nozzle treatments at any specific target location.

Mean sedimentation deposits, measured on ground tape, averaged across the three spray lines are shown in table 4. Deposits were three to five times higher directly under the treatment row than deposits measured 4 m downwind. The TD02 treatment produced slightly higher deposits on the in-row targets than the D4-25 nozzle. However, from 8 to 32 m, significantly higher ground deposits were produced by the D4-25 treatment. At 32 m, the D4-25 treatment produced deposits that were three times greater than the TD02 treatment did at 16 m. This most likely resulted from the smaller, more drift-prone, droplet spectrum produced by the D4-25 treatment. There were no differences in ground deposits beyond 32 m.

Figure 3 shows the spray deposits collected on the passive, nylon screens for the TD02 and D4-25 treatments, 8 m downwind from the edge of the orchard. Table 5 shows the mean comparisons for deposits on the passive collectors. There were no significant differences in deposits by elevation for either nozzle treatment between the 1 and 6 m sampling heights. There were also no significant differences in deposits found on the targets at 8 to 10 m for either nozzle. The

Table 4. Comparison of mean spray deposits on ground targets at different distances from the tree-row centerline with Turbo Drop air-induction nozzles (TD02) and Spraying Systems disc-core nozzles (D4-25).[a]

Distance (m)	TD02 Mean Deposit (μg/cm²)	TD02 CV (%)	D4-25 Mean Deposit (μg/cm²)	D4-25 CV (%)
0	376.6 aA	18	360.0 aA	16
4	77.27 aB	78	122.7 aB	43
8	17.33 bC	81	53.78 aC	57
16	3.72 bD	78	25.67 aD	56
32	0.718 bE	99	9.45 aE	59
64	0.242 aE	55	1.30 aF	116
128	0.099 aF	41	0.108 aG	56
256	0.126 aF	41	0.108 aG	32

[a] Means in a row followed by a different lowercase letter are significantly different ($p < 0.05$); means in a column followed by a different uppercase letter are significantly different ($p < 0.05$).

D4-25 treatment produced almost three times more deposits than the TD02 treatment at all target heights up to 9 m, but there were no significant differences in deposits between treatments at the 9 and 10 m sampling heights. The smaller downwind airborne deposits produced by the TD02 nozzle treatment compared to the D4-25 nozzle is consistent with the smaller amount of sedimentation deposits found downwind on ground targets at the 8 m location (table 4).

Deposits on the filter paper in the high-volume air samplers also decreased significantly with downwind distance (table 6). Deposits found at 1.0 and 3.0 m sampling heights were similar at the same distance from the treatment area. From 8 to 64 m, the D4-25 treatment produced higher deposits on the airborne filters than the TD02 treatment. Figure 4 shows that differences between these nozzle treatments then decreased at the 128 m sampling distance. Deposits on filters were greater than airborne deposits collected on passive screen samplers (table 5) for the same elevation at 8 m from the spray row.

The D3-25 nozzle treatment was not included in the canopy deposit or drift measurements during these experiments. Because the D3-25 produced smaller droplets overall for the operating conditions used in these experiments, it is expected that spray airborne spray deposits, at least within 128 m, would be higher compared to either the D4-25 or TD02 treat–

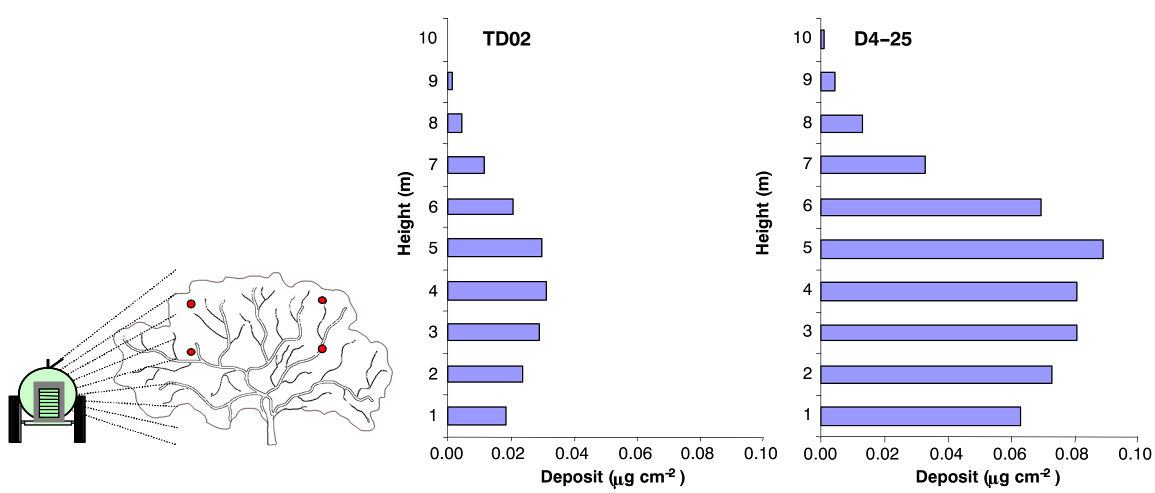

Figure 3. Vertical distribution of airborne spray loss measured on passive screen towers at 8.0 m downwind.

Table 5. Mean spray deposits on passive screen collectors at different heights above the ground in three lines when the spray was discharged with Turbo Drop air-induction nozzles (TD02) and Spraying Systems D4-25 disc-core nozzles at 8.0 m downwind from the tree-row centerline.[a]

	TD02		D4-25	
Height (m)	Mean Deposit (ng/cm^2)	CV (%)	Mean Deposit (ng/cm^2)	CV (%)
1	18.1 bAB	62	63.1 aA	60
2	23.4 bAB	63	72.9 aA	55
3	28.9 bA	75	80.8 aA	55
4	30.7 bA	71	80.8 aA	47
5	29.7 bA	60	88.8 aA	42
6	20.4 bAB	49	69.4 aA	39
7	11.3 bB	60	32.5 aB	37
8	4.2 bC	131	13.1 aBC	66
9	1.2 aC	177	4.1 aBC	108
10	0.4 aC	168	0.8 aC	93

[a] Means in a row followed by a different lowercase letter are significantly different ($p < 0.05$); means in a column followed by a different uppercase letter are significantly different ($p < 0.05$).

ments. Even though the D3-25 treatment generally produced the highest leaf surface coverage, it is not clear from these experiments how the use of the smaller droplet D3-25 treatment may have affected the total amount of tracer deposited in the canopy. It is possible that the overall spray spectrum was sufficiently small that more of this spray could have passed directly through the canopy. Salyani et al. (1987) demonstrated that the highest deposition efficiency was produced by spray droplets approximately 400 µm in diameter. Other reports, such as those of Spillman (1984) and Dubs et al. (1985) found that the highest deposition efficiency was obtained with various-size droplets depending on the orientation of the target and wind speed.

Table 6. Mean deposits found downwind on high-volume, air-sampler, filters.[a]

Distance from Treatment Row (m)	Filter Tracer Deposit ($\mu g/cm^2$)					
	1.0 m Height		3.0 m Height		10.0 m Height	
	TD02	D4-25	TD02	D4-25	TD02	D4-25
8	0.089 a	0.19 b	0.12 a	0.13 a	NA[b]	NA
16	0.029 a	0.083 b	0.029 a	0.097 b	NA	NA
32	0.014 a	0.092 b	0.012 a	0.086 b	NA	NA
64	0.0074 a	0.036 b	0.0077 a	0.041 b	NA	NA
128	0.0037 a	0.0090 a	0.0043 a	0.0084 a	0.009 a	0.0116 a

[a] Means in a row followed by a different lowercase letter are significantly different ($p < 0.05$).

[b] Not applicable because not measured during experiments.

Conclusion

While generally droplet size is regarded as the most important factor in determining drift potential, the same is not true for the percent area of spray coverage. Several different factors, including carrier rate and formulation as well as droplet size, can affect spray coverage. These series of experiments were conducted under conditions that limited differences between treatments to differences in nozzle type. Using the same carrier volume and spray formulation, the air-induction or venturi nozzles were shown to be able to provide similar upperside leaf surface coverage compared to traditional, hydraulic, disc-core nozzles. Coverage on the underside leaf surface appears to be more of a problem for large droplet nozzles, such as the air-induction nozzle, unless there is sufficient leaf movement or air turbulence within the canopy to create the opportunity for large droplet impact on the underside leaf surface. As shown by the D3-25 treatment experiments, a nozzle that produces smaller droplets can provide higher coverage than larger droplet nozzles on both upperside and underside leaf surfaces.

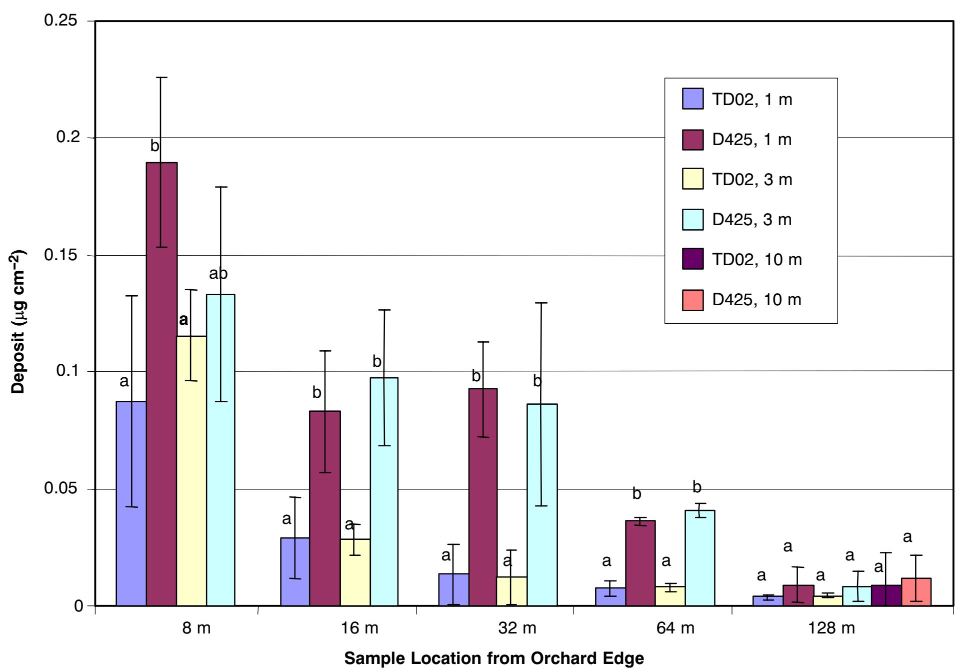

Figure 4. Mean deposits found downwind on high-volume, air-sampler, filters for two different nozzle treatments with targets at different sampler heights above the ground (means at a given location with different letters on bars are significantly different, $p < 0.05$). Error bars represent standard deviations of means.

Larger droplets can be expected to fall out of the airstream sooner than smaller droplets. The larger droplet spectrum, TD02 air-induction nozzle did not produce significant differences in spray distribution across the canopy compared to the D4-25 nozzle following treatment of the trees from one side only. The air capacity and discharge point of a particular sprayer could affect these results.

While spraying only the outside tree row from one side, a significant portion of the spray material released by a conventional, axial-flow, air-blast sprayer is lost on the ground near the treatment row. As used in these experiments, the TD02 nozzle treatment can keep more of the spray close to the target area than the conventional, disc-core nozzles. However, the TD02 air-induction nozzle does not eliminate downwind deposits; in fact, it produced airborne or sedimentation deposits similar to the D4-25 nozzle 128 m from the edge of the orchard.

These experiments indicate that air-induction nozzles may be suitable for use on traditional types of orchard sprayers to make applications to treat vine and tree crops. However, further studies are needed to clarify differences in efficacy between air-induction and conventional hydraulic or rotary nozzles for various application rates and formulations.

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