Effect of Application Variables on Spray Deposition, Coverage, and Ground Losses in Nursery Tree Applications[1]

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Abstract

An experimental cross-flow (CF) fan sprayer and a conventional, axial-fan (AF), orchard sprayer were used to treat multiple rows consisting of four year old, multi-stem, red maple trees, *Acer rubrum* L. and Turkish filbert trees, *Corylus colurna* L. The effects of sprayer type, fan orientation, application volume, and ground speed on canopy and ground spray deposits and canopy spray coverage across multiple target rows were evaluated. Variations in deposits and coverage across the canopies were generally smaller for the CF sprayer than the AF sprayer. The AF sprayer produced the highest overall deposits in the first row nearest the sprayer. Reducing fan speed kept more material in the tree row adjacent to the sprayer while decreasing spray volume did not affect the spray deposits in that row. Tower sprayer fan orientation did not affect canopy deposits but could be used to minimize spray drift. These results indicate that the most uniform spray distribution in a tree canopy is obtained by treating the canopy from each side. These findings also suggest growers should experiment with different spray volume and speed settings that can provide efficacious applications more efficiently.

Index words: drop size, drift, electron beam analysis, coverage, fungicide, disease, insect, pest.

Species used in this study: *Acer rubrum* L. 'Franksred' (Red Sunset); *Corylus colurna L.*

Significance to the Nursery Industry

The diversity of nursery production techniques creates special pest management problems for managers. The research reported in this work describes how different sprayer parameters influence spray deposition within two tree rows of the drive row. The effect of spray volume, travel speed, fan orientation, and sprayer type on spray retention and coverage in a canopy and spray losses to the ground near the target rows were investigated. Alternate row spraying was found to be a rather inefficient means for moving spray into rows beyond the one next to the sprayer. For the conditions of this work, faster travel speeds were no less efficient at delivering spray into the tree row next to the sprayer. A tower sprayer using cross-flow fans was more efficient at delivering spray into adjacent rows but over-powered spray through the row adjacent to the sprayer at the highest fan speed setting. Lower volume applications were as effective at delivering spray into the tree row next to the sprayer as higher volumes. Nursery managers can use these results to make more efficacious applications with minor adjustments to the operation of their sprayers to place more spray on target which could reduce the total amount of pesticide needed to provide biological control and reduce time spent making applications.

Introduction

Nursery and greenhouse crops represent an important part of U.S. agriculture. Most recent figures estimate that U.S. nursery production is valued at $9.1 billion (7). Not only are nursery sales increasing but also producers are coming under increasing pressure from neighboring urban areas to reduce pesticide inputs to the environment. On the other hand, since the cosmetic appearance of nursery stock is very important to sales, it is critical that nursery managers carefully monitor pest conditions and take action to keep pest levels and damage below economic thresholds. With the selectivity and timing of applications of new pesticide formulations becoming increasingly important, it is imperative that pesticides be applied as efficiently as possible when needed. The situation is made more difficult because of the variety of crops and crop techniques found in nurseries.

It is generally understood that sprayer operating parameters should be adjusted to match the target crop. These adjustments include spray volume as well as parameters associated with the air delivery system. Salyani (17) demonstrated that while deposition efficiency within a citrus canopy is dependent on spray volume, the size and number of nozzles as well as the travel speed that are used to set the spray application rate are also critical factors. Low volume applications (< 900 liters/ha (96 gal/A)) were made more efficient by reducing the number of nozzles and using smaller nozzles rather than traveling at higher ground speeds. In a series of experiments conducted in a semi-dwarf apple orchard using an axial fan orchard sprayer, Cross et al. (1) found that overall nozzle flowrate had little effect on canopy spray deposits and losses to the ground but significantly affected spray coverage. Cross et al. also reported (2, 3) that droplet size did not affect canopy deposits and that reducing air volumetric flow rate reduced drift without compromising overall spray retention in the canopy.

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Studies (9, 14, 15) have shown that the air system can influence spray distribution and deposits in tree canopies as well as off-target areas. Unfortunately, it is difficult to achieve uniform spray distribution and coverage in tree canopies. Herrington et al. (11) suggested that retention of spray by bush type trees was no more than 57% for a variety of application techniques and less than 63% for hedgerow type of tree forms. Sprays not accounted for on the trees was either blown away from the trees or fell on the ground. Miller et al. (13) reported 57% of spray material was retained within pecan rows adjacent to the sprayer path with 4.5% of the material passing over the top of the canopy and 22% lost to the ground near the sprayer path. Airjet speed was also shown to affect canopy deposits and losses to the soil and air (6). Losses to the soil decreased with increasing airjet speed but higher airjet speeds also resulted in increased in losses to the air. Being able to better control how much material is deposited on trees could reduce the impact of the spraying operation on the environment and reduce pesticide inputs.

The orientation and position of a spray delivery system relative to the target area can affect spray distribution. Redirecting the spray by using additional ductwork and changing the position of the delivery system relative to the tree canopy improves the uniformity of the spray distribution (4). One pass on each side of apple trees resulted in relatively uniform spray distribution across the canopy. The advantages of a vertical, air curtain type of sprayer were described by Van Ee and Ledebuhr (20). The air curtain sprayer with cross-flow fans produced more uniform deposits than the higher volume, conventional orchard sprayer used as a comparison in studies with a block of cherry trees. A sprayer utilizing cross-flow fans and directing spray horizontally along the entire vertical profile of the tree canopy provided higher spray deposits than traditional, axial flow fan sprayers (18). Other research with sprayers providing horizontal spray movement into tree or vine canopies have produced results of higher canopy deposits and lower levels of off-target spray drift (8, 12, 19). While nursery trees generally do not exceed 5.0 m (16.4 ft), they are still too large to be treated by an over-the-row spraying technique. There may also be too few of the larger trees to justify purchase of an over-the-row type of sprayer. Nursery production managers must work within application methodology constraints as well as cropping systems that do not permit travel of sprayers adjacent to both sides of each row. Most applications made to nursery tree crops or more vertical canopies are made using equipment that treats one side of a row only.

Air curtain techniques in a nursery can lead to greater losses of spray material to the ground (5). Also, a disparity in deposits from one side of the nursery tree to the other can occur when the trees are sprayed from one side only (5). This work did not evaluate the effect of the different spraying techniques on deposit further downwind from the row nearest the sprayer and it did not look at the effect of multiple passes on either side of the target row.

A number of scientists have reported drift measurements in orchard crops (6, 8, 10, 16) with the objective of providing information that may be helpful in reducing off-target losses. However, sometimes what is considered spray drift in one application situation is actually considered desirable spray movement in another situation. Multiple-row cropping systems or alternate-row spraying techniques require spray to be delivered beyond the sprayed row adjacent to the sprayer drive row. The objective of our work was to evaluate the effects of sprayer type, fan orientation, application volume, and ground speed on foliar spray deposits and spray coverage across multiple target rows.

Materials and Methods

The six, single pass treatments, and their operating parameters are shown in Table 1. All treatments were made with only the left-hand-side (LHS) of the sprayers operating. Second passes of the standard cross-flow treatment (CFA2) and the standard air blast treatment (AFB2) were made between Rows 2 and 3 using the LHS of the sprayers only. All treatments were replicated three times. The order of treatments was randomized except for the second pass treatments CFA2 and AFB2. The second passes of each of these treatments followed the first pass of each CFA and AFB respectively.

The experimental tangential airflow or cross-flow sprayer (CF) used three, hydraulically driven, cross-flow fans (0.87 m × 0.18 m (34 in × 7 in) outlets) (BEI, Grand Haven, MI) with the airflow directed laterally or parallel to the ground (Fig. 1a). These fans were mounted one above the other on a vertical support structure. The fans were spaced 29 cm (11.4 in) apart vertically. The centers of each were approximately 0.84, 2.1, and 3.2 m (2.7, 6.9, 10.5 ft) above the ground. Five nozzles were mounted on a manifold centered within each cross-flow fan and spaced 18 cm (7 in) on center (Fig. 1b). A

Table 1. Treatments used in nursery test comparing cross-flow (CF) and axial-flow (AF) tree sprayers.

Treatment	Sprayer	Nozzle[z] Disc/Core No.	Total nozzle output[y] (L/min)	Ground speed (km/h)	Air outlet speed (m/s)	Air stream orientation
CFA	Cross-flow	15, SS D3-25	36.6	6.4	22	Lateral[x]
CFC	Cross-flow	15, SS D3-25	36.6	6.4	22	Converging[w]
CFD	Cross-flow	15, SS D3-25	36.6	6.4	15	Lateral
CFE	Cross-flow	15, SS D2-25	18.8	6.4	22	Lateral
AFB	Axial-flow[v]	4, SS D5-45 + 1, SS D8-56	36.6	6.4	38	Radial
AFF	Axial-flow	5, SS D5-45	22.9	4.0	38	Radial

[z]Spraying Systems ceramic disc-cores on CF sprayer and hardened stainless steel and brass disc-cores respectively on the AF sprayer.

[y]Measured flow rate at operating pressure for one side (left) of sprayer only.

[x]Air stream for all three fans directed parallel to ground.

[w]Top fan only tilted down 30 degrees from vertical.

[v]A Durand Wayland 1500, conventional orchard type, air blast, axial-flow fan sprayer was used.

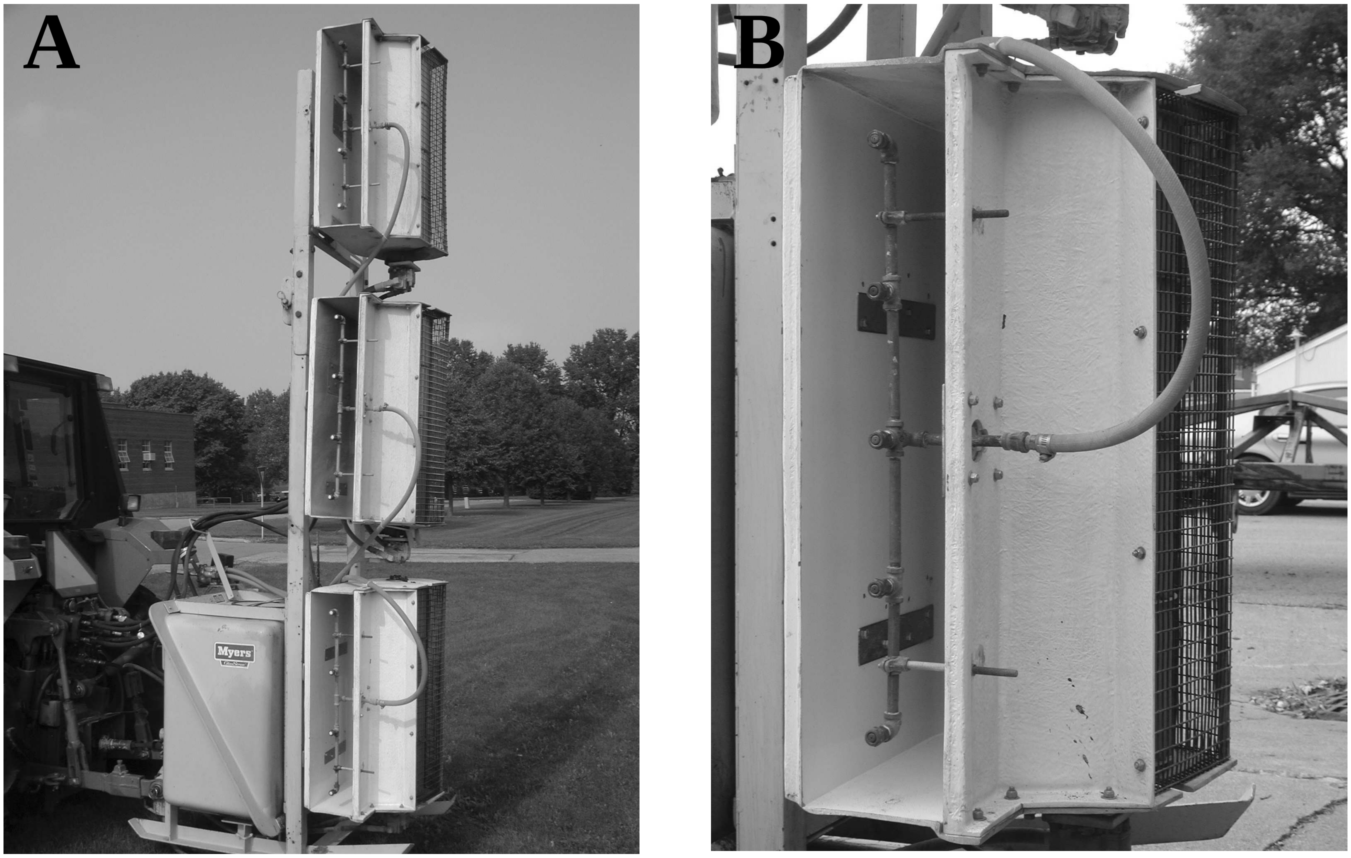

Fig. 1. Experimental, three fan, cross-flow (CF) sprayer used in nursery trials: A) CF sprayer with all fans oriented to produce horizontal air-flow and B) single CF fan assembly with five nozzles positioned at the fan outlet.

Durand Wayland 1500 sprayer represented the conventional orchard type of air blast or axial-flow (AF) sprayer. The DW sprayer had nine nozzle positions on each manifold on each side of the sprayer but the top most and lowest three positions were not used.

The test site was located in a commercial nursery in Lake County, OH. Fig. 2 shows an illustration of the test site. All applications were made to the same area and set of trees. The target area consisted of three rows of trees with 74 trees in each row. Rows 1 and 3 consisted of four year old, multi-stem, red maple trees, *Acer rubrum* ‘Franksred’ red maple trees. The multi-stem red maples had developed a relatively dense canopy and could be considered a relatively difficult crop to treat because of the size and density of the canopy. The trees in Rows 1 and 3 were 3.0 to 3.2 m (9.8 to 10.5 ft) high and spaced 1.5 m (4.9 ft) on center within the rows. The canopies were approximately 2.0 m (6.6 ft) wide and were relatively close to the ground. There was very little open space between trees. Above 2.5 m (8.2 ft), these trees consisted mainly of a couple of vertical limbs. Row 2 consisted of four year old, Turkish filbert trees, *Corylus colurna* L. These trees were also approximately 3.0 to 3.2 m (9.8 to 10.5 ft) tall and spaced 1.5 m (4.9 ft) on center within the rows. The canopies were approximately 0.7 m (2.3 ft) wide and were trimmed so that the bottoms of the canopies were approximately 1.5 m (4.9 ft) above the ground. The Turkish filbert trees were planted so that these tree trunks were directly across from the center between two red maple trees in Row 1.

As shown in Fig. 2, three different sampling lines were extended across Rows 1 to 3. The sampling lines started with trees 23, 34, and 37 in Row 1. Trees along these lines were similarly sized and shaped and had similar neighboring trees on either side of them. Drive rows on the south side of Row 1 and between Rows 2 and 3 were 3.65 m (12 ft) wide. The distance between non-drive rows such as between Rows 1 and 2 was 2.74 m (9 ft).

Fig. 3 shows the relative positions of the sampling sites in each row. In the Row 1, red maples, seven sites were selected across three quadrants around the tree and three elevations vertically through the canopy. Tree sampling sites were identified at both 1.0 and 2.0 m (3.3 and 6.6 ft) elevations with Quadrant 1 being the side closest to the first pass of the sprayers and Quadrant 3 being the side on the far side of the tree from the sprayers. Only one sampling location was made at the 3.0 m (9.8 ft) elevation in Row 1 because of the lack of canopy in that area. This location was considered to be within Quadrant 2 of the trees. Otherwise, two sampling heights (1.0 and 2.0 m (3.3 and 6.6 ft)) and three quadrants were used as sampling points around trees in Row 1.

As the Row 2 Turkish filbert canopies were trimmed up 1.5 m (4.9 ft) above the ground, no sampling was performed at the 1.0 m (3.3 ft) height. Four sampling sites within Row 2 were used including the near side to the first pass of the sprayer (Quadrant 1) and the far side of the tree relative to the first pass of the sprayer (Quadrant 3). Sampling sites in Row 2 were placed at 2.0 and 3.0 m (6.6 and 9.8 ft) heights.

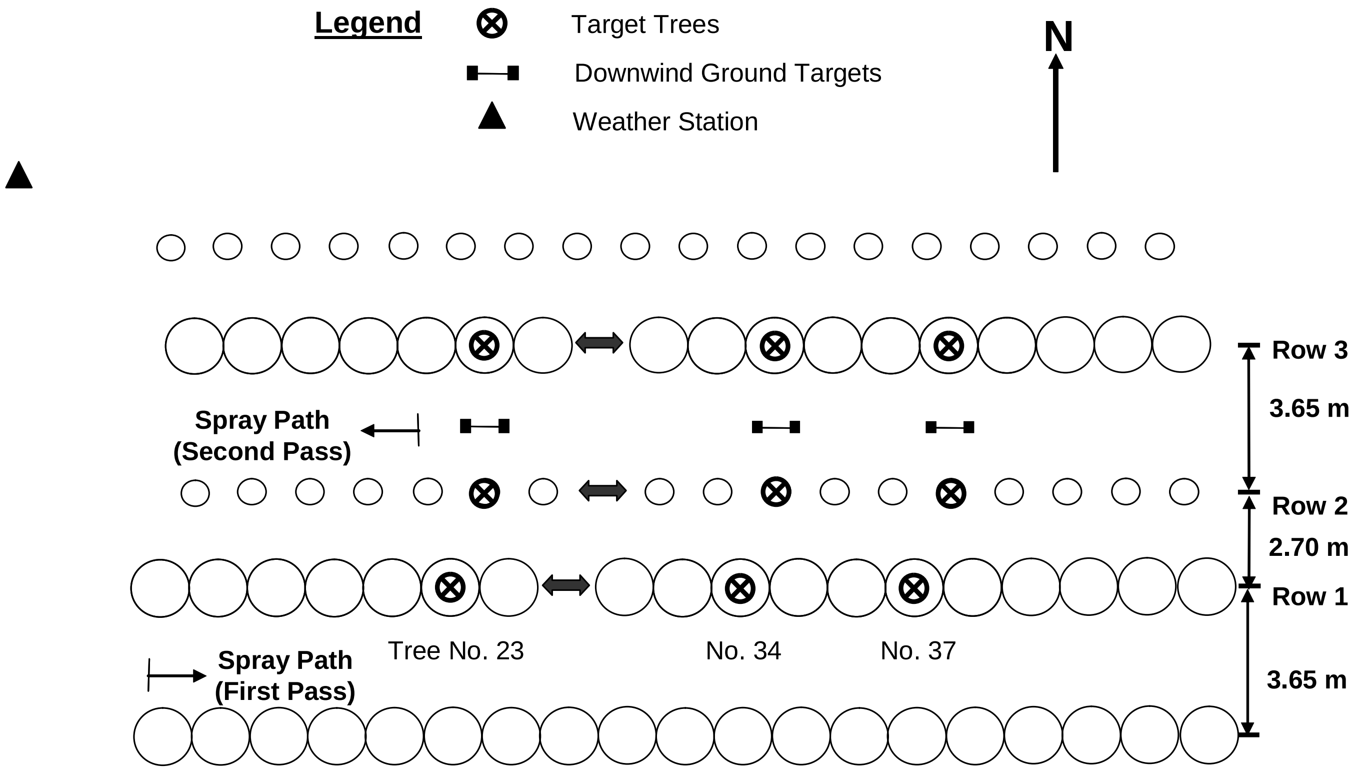

Fig. 2. **Overhead illustration of experimental nursery test site used in evaluation of cross-flow (CF) and axial-fan (AF) sprayers.**

Three sampling sites were designated in the Row 3 red maples. Targets were placed at 1.0 and 2.0 m (3.3 and 6.6 ft) heights in the near side of the tree row relative to the first pass of the sprayer (Quadrant 1). One additional target site was located at the 3.0 m (9.8 ft) height in the top of the tree. In Rows 1 and 3, targets at the 1.0 and 2.0 m (3.3 and 6.6 ft) elevations were located approximately 70 cm (2.3 ft) from the center of the trees. In Row 2, targets at both elevations were located approximately 25 cm (0.8 ft) from the tree centers.

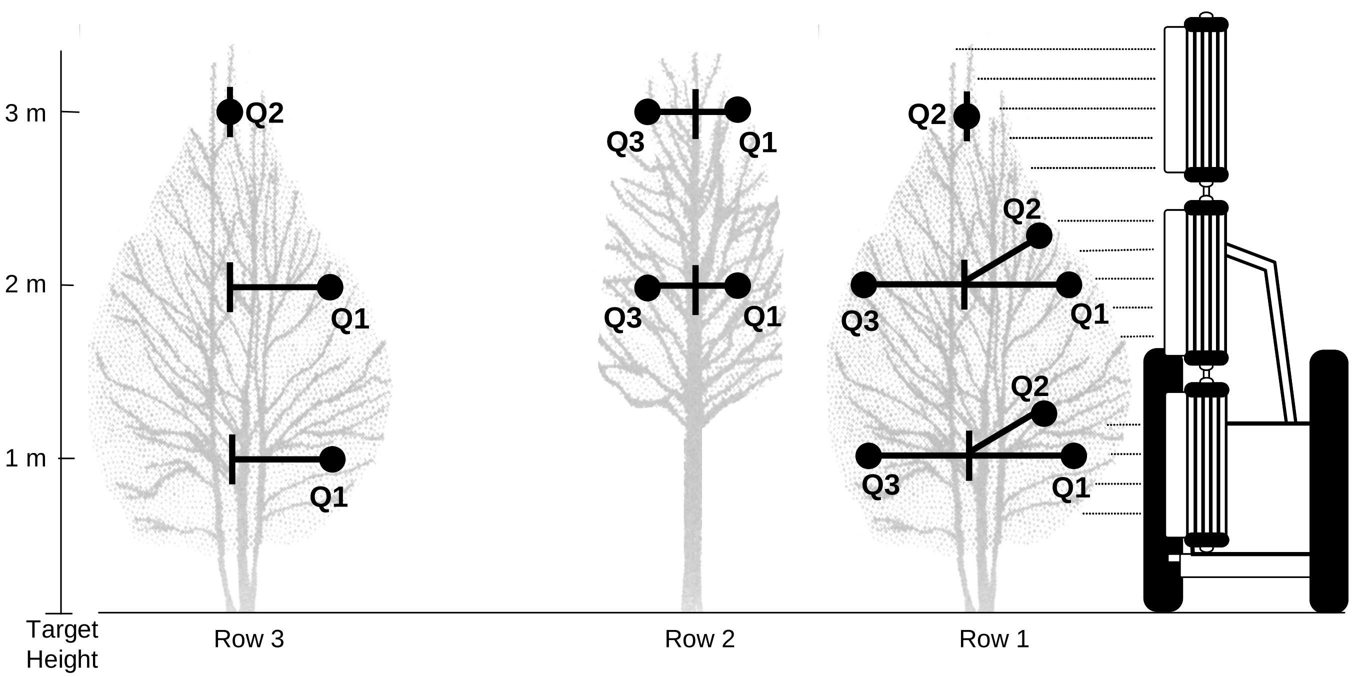

Fig. 3. **Illustration of canopy sampling sites at nursery test site used in evaluation of cross-flow (CF) and axial-fan (AF) sprayers.**

Blue food coloring (FD&C 1, Warner-Jenkinson Co., St. Louis, MO), was used as the deposit tracer. Dye was added to the spray tanks to provide a concentration of 2.0 mg/ml for all of the higher application rate treatments. A tank concentration of 4.0 mg/ml was used for the reduced application rate treatment, CFE, to ensure an equivalent amount of dye was applied to the test site.

Foliar deposit targets consisted of untreated red maple leaves harvested from a location over 100 m (328 ft) north and east of the spray site. The untreated samples were not harvested more than 30 minutes before being used for targets to ensure that leaves had not started to wilt significantly. Leaves were held in the target location using a pair of electrical connectors. These connectors were soldered together so that one clamp could be used to hold a sample leaf and the second connector was used to hold the first connector and leaf on a small tree limb. This fastening system permitted samples to be placed in nearly the same location for all runs. The electrical connectors held the tips of the petioles of each leaf. This fastening technique permitted as much natural leaf movement as possible.

As a check of background levels of material on the leaves, fresh, untreated leaves were placed at each sampling site before any treatments were applied. The CF sprayer was driven through the test site with the fans operating. Following one pass of the CF sprayer, the background level check leaves were removed from the target holders and placed individually in collection bottles. Treated leaves were allowed to dry and then were placed individually in collection bottles and capped. New, untreated leaves were placed on the target holders before each treatment.

In cases where the second pass of these treatments was expected (CFA2 or AFB2), two leaves were placed in each sample location. One leaf was sampled following the first pass (CFA or AFB) and the second leaf sampled following the second pass between Rows 2 and 3. The same sampling location was used for all treatments that involved a single pass beside Row 1.

Ground deposits were collected on strips of plastic tape (2.4 m × 5.1 cm (8 ft × 2 in)) held in sheet metal holders. These targets were located along the same spray lines as the trees used for foliar deposit evaluations and centered between Rows 2 and 3. These holders were positioned approximately 6 cm (2.4 in) above the ground. After each spray run, reels on the ends of the holders were used to take-in the treated section and expose an untreated length of plastic tape. For each single-pass application, the ends of the exposed section of plastic tape were labeled with a permanent marker. The reels were sealed to prevent contamination by the treatments. Following completion of the field tests, tape sections were divided and stored in sealed rinse bottles.

Meteorological measurements for each test are shown in Table 2. Campbell Scientific (Logan, UT) temperature probes, relative humidity probes, and solar radiation sensors were used to monitor atmospheric conditions during each application. A R.M. Young (Traverse City, MI) Wind Sentry Set was used to measure wind speed and direction 2.5 m (8.2 ft) above the ground. Meteorological measurements were made outside of the test site in an open area north and west of the test site. Even though the tests were conducted over two different days, winds remained primarily from the north. The first or single-pass spray delivery was generally against the wind.

The food coloring was recovered from leaves by adding 15 mL of distilled water to each sample bottle. The containers were then sealed again and shaken for 15 seconds. Next, a 5 mL sample of the rinsate was transferred to a spectrom-

Table 2. Meteorological conditions for two test days in Madison, OH for cross-flow (CF) and axial-fan (AF), tree sprayer, operational parameter tests.

Treatment	Rep	Day	Time	Wind speed (m/s)	Wind direction (0°–North)	Temp. (C)	Relative humidity (%)
CFA	1	1[z]	1148	2.0	338	20.1	45
CFA	2	1	1414	1.8	307	21.4	41
CFA	3	2[y]	1030	1.2	2	17.6	58
CFC	1	1	1110	1.9	350	20.4	47
CFC	2	1	1454	1.4	263	21.0	39
CFC	3	1	1559	1.6	301	21.0	40
CFD	1	1	1350	2.1	310	21.0	41
CFD	2	1	1709	1.9	332	21.2	40
CFD	3	2	1117	1.5	28	18.6	53
CFE	1	2	1330	2.6	10	19.3	54
CFE	2	2	1416	3.5	296	18.9	54
CFE	3	2	1445	3.0	304	18.9	55
CFA2	1	1	1208	1.8	25	20.5	44
CFA2	2	1	1429	0.3	53	21.2	42
CFA2	3	2	1051	1.5	346	19.1	57
AFB	1	1	1301	2.5	360	20.4	43
AFB	2	1	1518	2.1	317	21.0	40
AFB	3	1	1625	0.8	310	21.5	40
AFF	1	2	1154	1.9	346	17.5	54
AFF	2	2	1351	2.1	36	19.7	54
AFF	3	2	1510	1.2	328	17.7	57
AFB2	1	1	1324	1.7	279	20.9	42
AFB2	2	1	1537	2.1	358	21.0	42
AFB2	3	1	1645	1.6	297	21.5	37

[z]Day 1 — Sept. 10, 1998.

[y]Day 2 — Sept. 22, 1998.

eter cuvette. A single beam, scanning UV/VIS spectrometer (Lambda 10, Perkin-Elmer, Norwalk, CT) was used to measure the absorbance of the rinsate from each sample using an excitation wavelength of 629.7 nm. A set of calibration solutions was used to determine the relationship between absorbance by the sample and the concentration of food coloring in each sample.

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, England). These area measurements were doubled to account for areas on both upper- and underside leaf surfaces.

Deposits on plastic ground targets were recovered by adding 45 mL of distilled water to the sample bottles. These containers were shaken by hand for 30 seconds each and the tapes were unwound and rewound in the bottles. Samples of the rinsate were drawn out of the bottles and analyzed in the same manner as the leaf targets.

Spray coverage evaluations were made using 2.6 cm × 2.6 cm (1 in × 1 in) pieces of water sensitive paper (WSP) (Spraying Systems Co., Wheaton, IL, USA, developed by Ciba-Geigy, Basle, Switzerland). The WSP targets were stapled onto leaves near the sampling site used for the foliar deposit measurements. Care was taken in placing and removing the staples so that the same leaf could be used throughout the entire test. Coverage evaluations were also replicated three times. The WSP was placed in one sampling tree line (n = 37 trees) compared to three for the deposit measurements. No WSP targets were placed in Row 1 because it was assumed that these targets would receive good coverage. The same person rated all papers during two different rating periods that were separated by approximately 10 days. The final coverage rating for each target was calculated as the mean of the ratings for the two different periods. The papers were separated into 11 different ratings categories, from 0–10 with 0 being no detectable drops and 10 being saturated or completely covered. Statistical evaluation showed that there were no interactions with time.

The deposit data were analyzed using PROC MIXED from SAS (SAS Institute, Inc., Cary, NC) to calculate the analysis of variance based on a general linear model for a complete randomized block which consisted of the sprayers and number of passes. The source of replication within each experimental block was the trees. Canopy data for treatment Rows 1, 2, and 3 were analyzed separately. Within each block, elevations and quadrants at each elevation created a split block design. Coverage data were analyzed similarly by rows using the mean ratings for two rating times. Separate evaluation of coverage data by rating time was performed to detect differences in coverage ratings due to the time factor. Homogeneity of variance tests on the data using a Levene's test indicated that the data did not need any transformations. Mean separations were compared and reported using Least Significant Differences (alpha = 0.05). Duncan's multiple range test, Duncan-Waller, and differences of least square means produced the same comparison of mean separation as the LSD test.

Results and Discussion

Canopy deposits. There were differences in Row 1 deposits between treatments. There were also differences in deposits found at different elevations and quadrants around the trees in Row 1. Mean canopy deposits and T-groupings for each row are shown in Table 3. Conventional AF treatment produced the highest deposits in Row 1 following a single-pass of the sprayers on one side of the row. The slower fan speed treatment for the cross-flow sprayer (CFD) produced the highest deposits in Row 1 for any of the CF treatments. The CFD deposits were not different from the reduced application rate treatment (CFE) in Row 1. Overall, the 3.0 m elevation (Elev. 3) received the highest deposits. There were no differences between deposits found at the 1.0 m and the 2.0 m elevation target sites. The side of Row 1 closest to the sprayers (Quad. 1) received the highest deposits overall. The target sites on the far side of the Row 1 relative to the first pass of the sprayer (Quad. 3) received lower deposits than all other sections of the tree.

Overall, deposits in Row 2 varied from the same as, to half as much, compared to those measured in Row 1 for the CF treatments. However, deposits in Row 2 from the AF treatments decreased by more than a factor of 10. For Row 2 evaluations, there were differences between treatments. Target elevation was significant and there was a elevation and treatment interaction. The target quadrant or side, relative to the position of the sprayer, was also significant. The side of the tree closest to the sprayer (Quad. 1) received higher deposits than the far side (Quad. 3). The AF single pass treatment also had the lowest deposits in Row 2.

Mean deposits found for Row 3 generally decreased more compared to the Row 2 deposits for the CF treatments than the AF treatments. However, AF treatments had very low deposits in Row 2. The standard CF treatment (CFA) had the highest overall deposits in Row 3 but deposits were not different from the CF converging fan treatment (CFC).

A single-pass of the sprayers resulted in quite varied deposits across canopy profiles. Table 4 shows the variation in spray deposits across Row 2 broken down by target location. Despite target locations being only 50 cm (1.6 ft) apart across the filbert canopy, deposits on the far side of the tree (Quad. 3) were lower than deposits on the side closer to the sprayer (Quad. 1). Table 4 also shows the effect of the converging

Table 3. Foliar spray deposition on red maple and filbert leaves using cross-flow and axial-flow fan sprayers.

Treatment	Row 1 deposit (μg/cm²)	Row 2 deposit (μg/cm²)	Row 3 deposit (μg/cm²)	Ground deposit (μg/cm²)
CFA[z]	0.2048c[y]	0.1846ab	0.0866a	0.2463a
CFC	0.1881c	0.1485bc	0.0670ab	0.2297ab
CFD	0.2505b	0.1239c	0.0247c	0.1581abc
CFE	0.2269bc	0.2369a	0.0363bc	0.2120ab
AFB	0.3547a	0.0209d	0.0088c	0.0874c
AFF	0.3202a	0.0179d	0.0103c	0.1245bc

[z]CFA = cross-flow sprayer, 36.6 L/min nozzle output and application along one side of Row 1 only; CFC = cross-flow sprayer, fans orientated to converge in Row 1 canopy, 36.6 L/min nozzle output and application along one side of Row 1 only; CFD = cross-flow sprayer, reduced fan speed, 36.6 L/min nozzle output and application along one side of Row 1 only; CFE = cross-flow sprayer, 18.8 L/min nozzle output and application along one side of Row 1 only; AFB = axial-flow fan sprayer, 36.6 L/min nozzle output, 6.4 km/h travel speed and application along one side of Row 1 only; AFF = axial-flow fan sprayer, 22.9 L/min nozzle output, 4.0 km/h travel speed and application along one side of Row 1 only.

[y]Means in the same column followed by the same letter are not significantly different ($p < 0.05$; LSD test).

Table 4. **Mean deposits in Row 2 (Turkish filbert, *Corylus colurna* L) by height and side in relation to sprayer.**

Treatment	Elevation, 2.0 m		Elevation, 3.0 m	
	Quadrant 1[z] ($\mu g/cm^2$)	Quadrant 3 ($\mu g/cm^2$)	Quadrant 1 ($\mu g/cm^2$)	Quadrant 3 ($\mu g/cm^2$)
CFA[y]	0.2509ab[x]	0.0703ab	0.3200ab	0.1064b
CFC	0.3897a	0.0618ab	0.0857cd	0.0567bc
CFD	0.2006b	0.0482bc	0.1898bc	0.0571bc
CFE	0.2346b	0.0996a	0.4149a	0.1720a
AWB	0.0151c	0.0134cd	0.0413cd	0.0142c
AWF	0.0533c	0.0051d	0.0096d	0.0035c

[z]Quadrant 1 = side of tree closest to sprayer drive row; Quadrant 3 = side of tree farthest from sprayer drive row.

[y]CFA = cross-flow sprayer, 36.6 L/min nozzle output and application along one side of Row 1 only; CFC = cross-flow sprayer, fans orientated to converge in Row 1 canopy, 36.6 L/min nozzle output and application along one side of Row 1 only; CFD = cross-flow sprayer, reduced fan speed, 36.6 L/min nozzle output and application along one side of Row 1 only; CFE = cross-flow sprayer, 18.8 L/min nozzle output and application along one side of Row 1 only; AFB = axial-flow fan sprayer, 36.6 L/min nozzle output, 6.4 km/h travel speed and application along one side of Row 1 only; AFF = axial-flow fan sprayer, 22.9 L/min nozzle output, 4.0 km/h travel speed and application along one side of Row 1 only.

[x]Means within columns followed by the same letter are not significantly different based on protected differences of least squares means ($p < 0.05$). Significant Treatment F-tests were first obtained for each Elevation-Quadrant combination ($p = 0.0019$, $p = 0.0045$, $p = 0.001$, and $p = 0.0006$, respectively).

fan configuration. Tilting the top fan of the CF sprayer (CFC) produced much lower deposits higher in the tree (3.0 m (9.8 ft)) compared to the normal configuration of the sprayer (CFA). As shown in Table 3 however, the converging fan treatment did not significantly reduce deposits measured in Row 3.

The second passes of the CF and AF treatments reduced the variation in canopy deposits between these treatments. The second passes of the CF and AF treatments (CFA2, AFB2) produced higher mean deposits in Row 1 compared to the first pass of either treatment (CFA, AFB). The second pass of the AF treatment (AFB2) produced higher mean deposits in Row 1 than the second pass of the CF treatment (CFA2) (0.4531 vs 0.3522 $\mu g/cm^2$); however, there were no differences in deposits between these treatments in the overall mean deposits in Row 2 (0.3625 vs. 0.3652 $\mu g/cm^2$).

Ground deposits. Analysis of deposits found on ground targets between Rows 2 and 3 showed that there were differences between treatments. There were no differences between the three targets in any one treatment. Mean deposits and T-groupings for the ground targets are shown in Table 3. The CF sprayer produced higher ground deposits than any conventional AF treatment. There were no differences between any of the CF treatments but the slower fan CF treatment (CFD) did produce the lowest deposits among the CF treatments. While there were no differences between the AF treatments, slowing travel speed (AFF) seemed to produce slightly higher deposits on the ground targets.

The CFA and CFC treatments produced ground deposits between Rows 2 and 3 that were higher than deposits in the Row 1 canopy. In most cases, the CF ground deposits were also higher than those found in the Row 2 canopies. The converging fan configuration (CFC) did not result in any greater ground deposits found between Rows 2 and 3 even though the CFC treatment produced relatively high deposits in Row 3 (Table 3). The AF treatments produced higher ground deposits than those found on Row 2 leaves. Ground deposits between Rows 2 and 3 were also much greater than those found in Row 3 for all treatments.

Canopy coverage ratings. Table 5 shows the mean coverage ratings and T-groupings for Rows 2 and 3 following a single pass of the sprayer. Row 2 split-plot model evaluations of ratings showed that sprayer treatment and sampling location (elevation and quadrant) were significant factors. Coverage at 2.0 m (6.6 ft) was greater than coverage at the highest elevation (3.0 m (9.8 ft)). Two-way interactions including sprayer ×quadrant and elevation × quadrant were significant ($p > 0.05$). No differences were found between CF treatments. The mean rating for the standard CF treatment (CFA) was greater than for the standard conventional treatment (AFB). The AFF and AFB treatments tended to produce lower coverage ratings than the CF treatments except on the far side of Row 2 (Quad. 3). The AF treatments produced higher mean coverage ratings on the far side of Row 2 (Quad. 3) than on the near side of the row (Quad. 1).

Sprayer treatment and elevation were significant factors for overall Row 3 coverage ratings. The amount of coverage decreased by elevation in the row with the lowest coverage found at the 3.0 m (9.8 ft) elevation for all treatments.

It should be noted that the differences in mean coverage ratings observed in Row 2 do not necessarily correlate with the differences in spray deposits measured in Row 2. In all cases, the differences in coverage ratings appear smaller than the differences in spray deposit. However, the trends were similar with the CFE and CFA treatments producing relatively high coverage ratings and high spray deposits. The AFB and AFF treatments produced the lowest coverage ratings as well as the lowest spray deposits. Similar trends were observed in Row 3 where the CFA treatment produced the highest coverage rating and the highest spray deposits. However, one difference was found where the CFE treatment produced relatively high coverage ratings (despite producing

Table 5. **Mean coverage ratings (scale: 0 = lowest, 10 = highest) within tree canopies as assessed on water sensitive paper targets.**

Treatment	Row 2 coverage[z]	Row 3 coverage
CFA[y]	6.3ab [x]	5.8a
CFC	4.9abc	5.2a
CFD	4.8abc	1.5b
CFE	6.8a	1.2b
AFF	4.0bc	2.1b
AFB	2.7c	1.4b

[z]Row 2 = Turkish filbert; Row 3 = Multi-stem, red maple.

[y]CFA = cross-flow sprayer, 36.6 L/min nozzle output and application along one side of Row 1 only; CFC = cross-flow sprayer, fans orientated to converge in Row 1 canopy, 36.6 L/min nozzle output and application along one side of Row 1 only; CFD = cross-flow sprayer, reduced fan speed, 36.6 L/min nozzle output and application along one side of Row 1 only; CFE = cross-flow sprayer, 18.8 L/min nozzle output and application along one side of Row 1 only; AFB = axial-flow fan sprayer, 36.6 L/min nozzle output, 6.4 km/h travel speed and application along one side of Row 1 only; AFF = axial-flow fan sprayer, 22.9 L/min nozzle output, 4.0 km/h travel speed and application along one side of Row 1 only

[x]Means in the same column followed by the same letter are not significantly different ($p < 0.05$; LSD test).

fewer spray droplets at the reduced application rate) and low deposit measurements (compared to CFA). In addition, the differences in coverage ratings for the CFA treatment between Rows 2 and 3 are relatively small. This is not reflected in the deposit measurements where the Row 3 mean deposits are less than half of those measured in Row 2.

For the equipment and production systems tested in these experiments, the differences in application parameters evaluated produced differences in deposit characteristics and coverage across the treatment area. A single-pass operation results in decreases in deposits across a canopy and successive tree rows. Variations across canopies and treatment area are smaller for the cross-flow type of sprayer compared to the conventional air blast sprayer. If the goal is to spray across wide areas and to possibly use alternate row techniques using the same type of production system tested in this experiment, the cross-flow sprayer will provide results that are more satisfactory. A second sprayer pass down an adjacent drive row significantly improves the uniformity of deposits across the primary spray rows and reduces differences between the cross-flow and air blast sprayer.

For the ground speeds evaluated in these canopies, it does not appear that reducing ground speed increases spray penetration across successive rows when using a conventional air blast sprayer. Reduced rate application with a cross-flow fan type of sprayer does not decrease sprayer performance with the first two rows and would result in a significant increase in field capacity of the spraying operation. However, the reduced rate application (without changing the droplet spectrum) does appear to affect spray delivery into the third row and may be less effective than the standard cross-flow treatment if alternate row spraying techniques were used. Reducing cross-flow fan speed helps keep more material in the first row near the sprayer but reduces deposits and coverage in additional rows. Tilting the top fan section of a cross-flow fan sprayer and producing converging air/spray streams does not appear to offer any advantages over the standard cross-flow fan configuration. Other fan configurations, such as one that would help keep spray down in the canopy without delivering spray, may help reduce drift over the canopy. Biological evaluations will be important in further understanding how these equipment parameters will affect pest management.

Literature Cited

1. Cross, J.V., P.J. Walklate, R.A. Murray, and G.M. Richardson. 2001. Spray deposits and losses in different sized apple trees from an axial fan orchard sprayer: 1. Effects of spray liquid flow rate. Crop Protection 20:13–20.

2. Cross, J.V., P.J. Walklate, R.A. Murray, and G.M. Richardson. 2001. Spray deposits and losses in different sized apple trees from an axial fan orchard sprayer: 2. Effects of spray quality. Crop Protection 20:333–343.

3. Cross, J.V., P.J. Walklate, R.A. Murray, and G.M. Richardson. 2003. Spray deposits and losses in different sized apple trees from an axial fan orchard sprayer: 3. Effects of air volumetric flow rate. Crop Protection 22:381–394.

4. Derksen, R.C. and R.L. Gray. 1995. Deposition and air speed patterns of air-carrier apple orchard sprayers. Trans. of the ASAE 38:5–11.

5. Derksen, R.C., Krause, C.R., R.D. Fox, and R.D. Brazee. 2004. Spray delivery to nursery trees by air curtain and axial fan orchard sprayers. J. Environ. Hort. 22:17–22.

6. Doruchowski, G., R. Holownicki, and A. Godyn. 1996. Air jet setting effect on spray deposit within apple tree canopy and loss of spray in orchard. AgEng96, The European Conference on Agricultural Engineering, Madrid, Spain. Paper No. 96A-139.

7. Floriculture and Nursery Crops Situation and Outlook Yearbook. 2004. Martha Evans, Ed. Market and Trade Economics Division, Economic Research Service, U.S. Department of Agriculture, FLO-2004.

8. Fox, R.D., D.L. Reichard, C.R. Krause, R.D. Brazee, S.A. Svensson, and F.R. Hall. 1993. Effect of sprayer type on downwind deposits from spraying orchards. ASAE Paper No. 931078. St. Joseph, MI: ASAE

9. Furness, G.O. and W. Val Pinczewski. 1985. A comparison of the spray distribution obtained from sprayers with converging and diverging airjets with low volume air assisted spraying on citrus and grapevines. J. Agric. Eng. Res. 32:291–310.

10. Ganzelmeier, H. 1993. Drift of plant protection products in field crops, vineyards, orchards, and hops. International Symposium on Pesticide Application. Strasbourg, France. 1:125–132.

11. Herrington, P.J., H.R. Mapother, and A. Stringer. 1981. Spray retention and distribution on apple trees. Pesticide Sc. 12:515–520.

12. McFadden-Smith, W., K. Ker, and G. Walker. 1993. Evaluation of vineyard sprayers for coverage and drift. ASAE Paper No. 931079. St. Joseph, MI: ASAE.

13. Miller, D.R., E.W. Huddleston, J.B. Ross, and W.E. Steinke. 2003. Airblast spray partitioning in a mature pecan orchard. Trans. of the ASAE 46:1495–1501.

14. Raisigl, U., H. Felber, W. Siefried, and C. Krebs. 1991. Comparison of different mistblowers and volume rates for orchard spraying. British Crop Protection Council Monograph No. 46, pp. 185–197.

15. Randall, J.M. 1971. The relationships between air volume and pressure on spray distribution in fruit trees. J. Agric. Eng. Res. 16:1–31.

16. Riley, C.M. and C.J. Wiesner. 1990. Off target pesticide losses resulting from the use of an air-assisted orchard sprayer. Pesticide Formulations and Application Systems: 10th Volume, ASTM STP 1078, L.E. Bode, J.L. Hazen, and D.G. Chasin, Eds., American Society for Testing and Materials, Philadelphia, PA.

17. Salyani, M. 2000. Optimization of deposition efficacy for airblast sprayers. Transactions of the ASAE 43:247–253.

18. Steinke, W.E., B.W. Wilson, and F.G. Zalom. 1992. Drift measurements in dormant orchard spraying. ASAE Paper No. 921083. St. Joseph, MI: ASAE.

19. Van De Werken, J. 1991. The development of an unmanned air assisted tunnel sprayer for orchards. British Crop Protection Council Monograph No. 46, pp. 211–217.

20. Van Ee, G.R. and R.L. Ledebuhr. 1988. Performance evaluation of the ‘air-curtain’ orchard spraying concept. International Conference on Agricultural Engineering, Paris, France, Paper No. 88–043.