Spray Delivery to Nursery Trees by Air Curtain and Axial Fan Orchard Sprayers[1]

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Abstract

Two types of air-assist sprayers were used to treat, from one side only, a single row of hedge-pruned, red maple (*Acer rubrum* L. 'Red Sunset') trees in a commercial Ohio nursery. A traditional orchard type sprayer and a prototype air curtain sprayer using crossflow fans and hydraulic nozzles were evaluated for differences in canopy deposits, spray coverage, and downwind ground deposits. The air curtain sprayer produced more uniform deposits vertically but not higher mean deposits than the traditional orchard type sprayer. The air curtain sprayer also produced somewhat higher ground deposits downwind of the treatment area. There were no differences in spray coverage between sprayers despite differences in the droplet spectrum produced by each sprayer. Evidence from the coverage and ground target samples indicate that slower fans on the air curtain sprayer might be needed to reduce air speed to retain more spray within the tree canopy. As operated, neither of the sprayers can be expected to produce uniform spray deposits around the nursery stock if treatments are made from one side of the row only. Canopy and ground target deposits indicate that alternate row spraying will not necessarily produce uniform deposits across two tree rows as planted at the test site.

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

Species used in this study: *Acer rubrum* L. 'Red Sunset'.

Chemicals used in this study: blue food coloring (FD&C No. 1); Kocide 2000 (copper hydroxide).

Significance to the Nursery Industry

Effective pest management schemes require that pesticides be delivered in an efficacious manner to maximize their performance and in a manner that minimizes the impact on off-target organisms and other sensitive areas. Traditional orchard sprayers are typically used to make applications to shade trees and other tall crops. The research reported in this work compares the use of traditional, air-assist, orchard spraying techniques with an experimental tower sprayer using crossflow fans for treating a single-row of multistem, red maple trees. Tower spraying provided more uniform vertical spray distribution in tree canopies than the traditional sprayer that release all of the spray from closer to the ground. Air distribution is still important independent of the delivery methodology and if not adjusted for the canopy, can result in ineffective spray penetration or increased spray drift. Because of the significant shading effect of a canopy, treatments down each side of a row are necessary to produce the most uniform deposits to achieve the desired biological efficacy. Concentrating on better targeting of the tree canopy may also reduce overall drift.

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Introduction

Nursery crops are highly desirable commodities for both commercial and residential landscapes. Most recent figures estimate that U.S. nursery production is valued at $8.9 billion (5). Commercial nurseries grow many plant varieties that can create a number of different kinds of pest management problems. Most nurseries can tolerate very little pest damage since cosmetic appearance of stock is strongly related to marketability. Any additional plant stress caused by pest problems may also add to the stress already caused by moving and transplanting the crops. The relatively rapid rotation of stock, compared to orchards and vineyards, creates a situation where there are many different sizes and species of stock in close proximity to each other. The variety of different crops and crop management techniques creates some unique planting systems. It is generally desirable for nurseries to be located near urban areas since many of the sales are retail and made direct to consumers. However, even larger nurseries that rely primarily on wholesale sales are finding themselves nearer urban populations than ever before. This close proximity to populated areas puts pressure on operators to minimize the real and perceived impact of their application practices on the surrounding areas.

Nursery tree stock usually does not exceed 5 m (16.4 ft) in height. The taller trees are relatively narrow. The desire of nursery managers to maximize use of their land also contributes to pest management pressure since many of plantings are closely spaced. These practices increase the difficulty of trying to treat the crop using conventional pesticide application equipment.

While most application research related to tree type canopies has been concentrated in apple and citrus orchard systems, much of this knowledge may be applied to nursery crop systems. Most useful information relates to the air delivery system and the orientation of the delivery system to the canopy. Randall (9) showed that more uniform spray distribution was provided when higher air volume to air speed ratios were used. He wrote that one of the most important considerations was that air velocity in the densest part of a canopy should provide some leaf deflection. Slower travel speeds were also reported by Randall to produce more uniform spray distribution. Slower travel speeds reduce deflection of the airjet and help maintain the integrity of the jet across greater distances. Salyani et al. (10) showed that in a 15 m/s (49.2 ft/s) air stream, 400 μm droplets were deposited most efficiently on citrus leaves compared to larger and smaller size droplets. However, most axial fan sprayers used in orchards, vineyards, and nurseries are configured and operated to produce smaller droplets and, therefore, may not require as high air speeds. Bayat et al. (1) showed that a conventional axial flow fan sprayer provided better spray coverage characteristics throughout a citrus canopy than a higher volume tower type sprayer with separate outlets directed at the bottom and top parts of the trees. While this may go against conventional thinking, the authors speculated that the better results provided by the traditional type of orchard sprayer was achieved because this sprayer had a higher air volume to air speed ratio. Bayat et al. (1) also pointed out that the better directed and higher volume treatment provided by the handgun application achieved better control of the California red scale than any of the air assist sprayers. Doruchowski et al. (4) showed that outlet airjet speed significantly affected foliar spray deposits as well as sedimentation and airborne spray losses.

Several researchers have investigated the effect of the nozzle position on spray distribution. Travis (12) showed that relative distribution of nozzle output on the sprayer manifold can affect distribution uniformity. Taller trees treated with conventional axial flow fan sprayers, for example, required higher flow rates from nozzles in the upper part of the nozzle manifold than smaller trees. Derksen and Gray (3) showed that elevating the fan and nozzle manifold on a conventional axial flow fan sprayer and directing spray along the canopy with additional duct work around the fan outlet could improve the uniformity of the vertical distribution of spray material in semi-dwarf apple trees.

The results of some of the previously cited work indicated that the distribution of spray along the nozzle manifold can significantly affect spray distribution in the tree canopy. There are several examples of work evaluating this factor. For example, Furness and Val Pinczewski (7) evaluated spray deposits produced by multi-outlet sprayers with the outlets vertically distributed along the tree height. They found that the multi-outlet sprayer provided less variable sprayer coverage than the conventional type of orchard sprayer despite using over 10 times lower spray volumes. In addition, directing the outlets to provide converging spray streams gave greater and less variable droplet densities than an arrangement that provided diverging spray streams. Van Ee and Ledebuhr (14) pointed out the advantages of using an air curtain type of sprayer with the spray uniformly distributed along the vertical profile of a cherry canopy. The air curtain sprayer with crossflow fans produced more uniform deposits than the higher volume, conventional orchard sprayer used as a comparison. Steinke et al. (11) also showed that a sprayer utilizing crossflow fans and directing spray horizontally along the entire vertical profile of the tree canopy provides higher spray deposits than traditional, axial flow fan sprayers. 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 (6, 8, 13).

Since the nursery industry desires to reduce the number of passes through blocks and to treat trees from one side only, the objective of this experiment was to compare the near-row fate of spray applications for conventional and prototype spray equipment using canopy spray deposits, spray coverage, and ground deposits as indicators of performance.

Materials and Methods

The air curtain sprayer (CF) used three, hydraulically driven, crossflow fans (87 cm × 18 cm, or 34 in × 7 in, outlets) (BEI, Grand Haven, MI) with the airflow directed parallel to the ground. These fans were stacked 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, and 10.5 ft) above the ground. Five, D4-25 nozzles (Spraying Systems Co., Wheaton, IL) were mounted on a pipe centered within each crossflow fan and spaced 18 cm (7 in) on center. When operating at a fan speed of 1160 rpm, the air speed at the outlet was approximately 22 m/s (72.2 ft/s). The nozzles were operated at approximately 2000 kPa (290 psi) and the measured average flow rate was 2.46 liters/min (0.65 gal/min). All fans and nozzles on the CF sprayer were oriented toward the same side of the sprayer (L.H.S). A Durand Wayland 1500 (DW) sprayer represented the conventional orchard type of axial fan sprayer. The DW sprayer had nine nozzle positions on each manifold on each side of the sprayer but the topmost and lowest three positions were not used. The upper nozzle outlet used a D8-56 nozzle set and the remaining four outlets used D5-45 nozzles. Only the L.H.S. of the DW was operated during these experiments. The total output from the L.H.S. of the DW sprayer was measured to be 36.6 liters/min (9.7 gal/min) at a pressure of 2067 kPa (300 psi). The maximum measured outlet airspeed of the DW sprayer was 38 m/s (125 ft/s). Both sprayers were operated at a travel speed of approximately 6.4 km/h (4.0 mi/h). Each treatment was replicated three times and the order of the treatments was randomized. Both sprayers treated the trees from one side only (upwind).

Markers were added to the spray tanks to aid in deposit and coverage analysis. Blue food coloring (Werner Jenkinson Co., St. Louis, MO), which was used as a deposit tracer, was added to the spray tanks to provide a concentration of 1.44 mg/ml. In addition, a commercial fungicide, Kocide 2000 (Griffin Corp., Valdosta, GA), with an active ingredient of copper hydroxide, $Cu(OH)_2$, was added to the spray tanks at a rate of 1.19 mg/ml. The copper served as a marker for spray coverage measurements on artificial targets.

The field experiment was conducted in a commercial nursery in Lake County, OH. Figure 1 shows an overhead view of the experimental layout. One row of four-year-old red maple multistem trees, cv. 'Red Sunset', *Acer rubrum* L. was selected for use in these tests. These trees were selected as target plants because they provided some of the most dense tree canopies on the nursery site and there had been some difficulty controlling insect pests in them previously. Drive rows were spaced 3.6 m (12 ft) on center. Drive rows alternated with 2.7 m (9 ft) row spacings. Tree height and width was approximately 4 m (13.1 ft) and 3 m (9.8 ft) respectively. There were few gaps between trees. Tree growth and

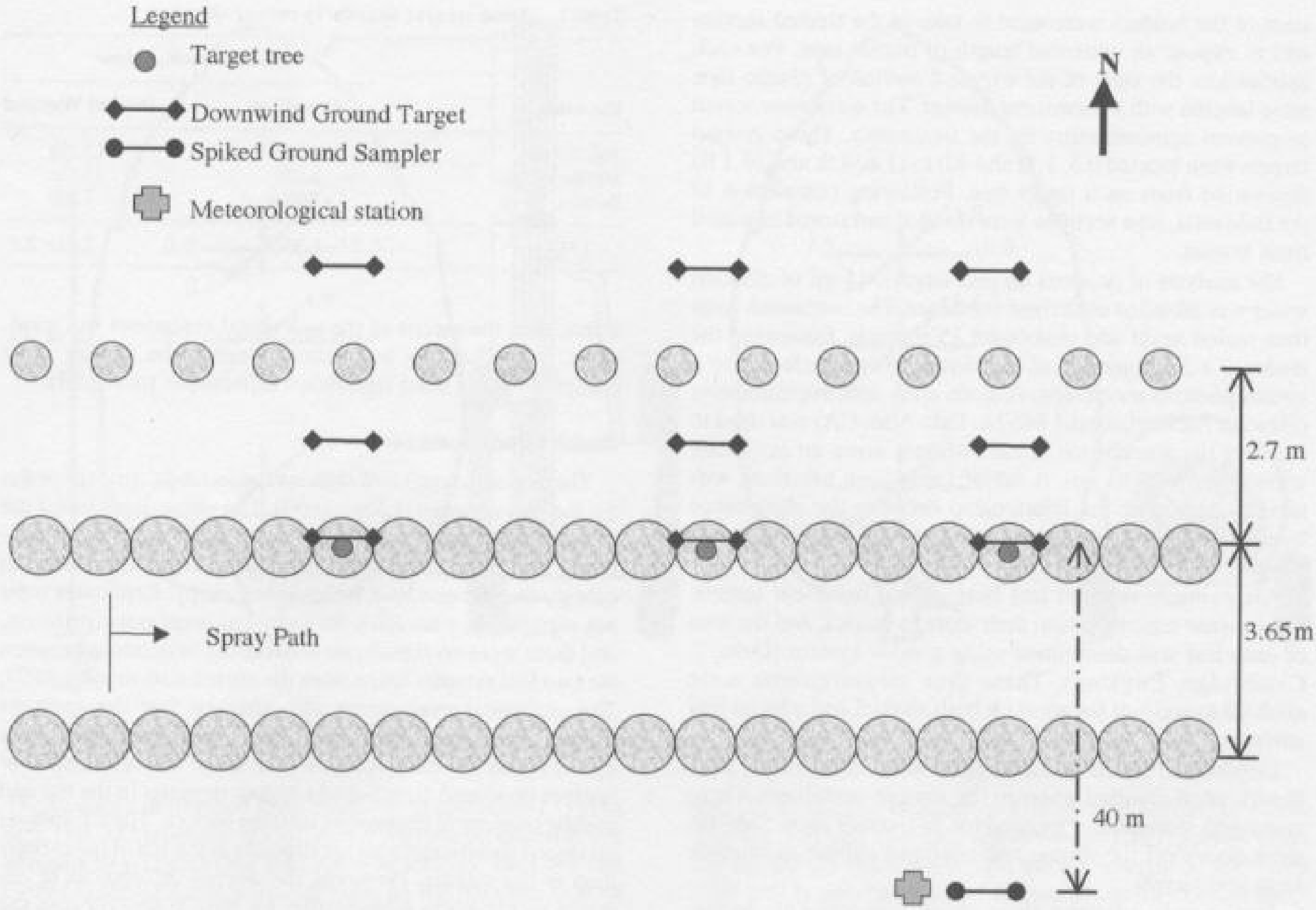


Fig. 1. Experimental site layout.

pruning had produced the densest canopy from the ground up to 2 m (6.6 ft). There was far less foliage above 2 m (6.6 ft) and most was concentrated near the center of the tree. Canopy deposits were measured in three different trees in this target row.

Untreated red maple leaves were used as the canopy spray collectors. These leaves were harvested from another row of red maple trees that was located over 100 m (328 ft) upwind of the test site. A pair of alligator clips, fastened end-to-end, was used to support leaves in the target areas. For each pair, one of the alligator clips was attached to a tree limb and the opposite was used to hold the leaves used as spray collectors. This fastening system permitted samples to be placed in nearly the same location for all runs. One alligator clip held the tip of each petiole of each leaf. This fastening technique permitted as much natural leaf movement as possible. Two leaf collectors were used in each section of the tree. The trees were divided into four quadrants around the canopy, with quadrant one being located on the far side of the tree from the drive row used by the sprayers and the other quadrants being numbered consecutively in a clockwise fashion as viewed from the top of the tree. Two leaf collectors were positioned within each quadrant. The leaf sample holders were all positioned approximately 1.0 m (3.3 ft) from the trunk. Collectors were also placed at three elevations in each quadrant (1.0, 2.0, and 2.5 m, or 3.3, 6.6, and 8.2 ft), respectively, above the ground).

Before any treatments were applied, untreated leaves were placed on the holders and then removed and placed in the rinse containers for storage before the return to the laboratory. These leaves were used to establish background levels of the tracer that could be found on the canopy naturally or due to our sampling procedure. After background leaves were collected, new untreated leaves were placed in the sample holders in the canopy in preparation for the first sprayer pass. Following treatment by one sprayer pass, these leaves were allowed to dry and then placed into sealed rinse bottles for storage. The same procedure was used for each subsequent sprayer pass.

Weather conditions were monitored 40 m (131 ft) upwind of the test side. Campbell Scientific (Logan, UT) temperature and relative humidity probes, and solar radiation sensors were used to monitor atmospheric conditions during each application. A Wind Sentry Set (R.M. Young, Traverse City, MI) was used to measure wind speed and direction 2.5 m (8.2 ft) above the ground. Light cross winds (≤3 m/s or 6.7 mi/h) were observed during all of the tests throughout the test period. Temperature and relative humidity through the period of testing ranged from 21.5 to 27.8C (71 to 82F) and from 54.1 to 75.7%, respectively.

Downwind ground deposits were collected on strips of plastic tape (243 cm × 5.1 cm) (96 in × 2 in) held in sheet metal holders. These holders were held 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 to expose an untreated length of plastic tape. For each 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. Three ground targets were located 0.5, 1.5, and 4.0 m (1.6, 4.9, and 13.1 ft) downwind from each target tree. Following completion of the field tests, tape sections were divided and stored in sealed rinse bottles.

For analysis of deposits on leaf targets, 15 ml of distilled water was added to each rinse container. The containers were then sealed again and shaken for 15 seconds. Following the shaking, a 5 ml sample of the rinsate was transferred to a spectrophotometer cuvette. A diode array spectrophotometer (Hewlett Packard, model 8452A, Palo Alto, CA) was used to measure the absorbance of each sample using an excitation wavelength of 630 nm. A set of calibration solutions was used to determine the relationship between the absorbance by the sample and the concentration of food coloring in each sample.

After rinsate samples had been drawn from leaf targets, 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 abaxial and adaxial leaf surfaces.

Deposits on plastic ground targets were recovered by adding 45 ml of distilled water to the sample containers. These containers were shaken by hand for 30 seconds each. Samples were drawn off the rinsate and analyzed similar to samples from leaf targets.

Inert sample collectors (inert stubs), composed of conductive/sticky tabs fastened onto aluminum specimen mounts, (Ted Pella, Redding, CA) for electron beam analysis (EBA), were also placed at 1.0, 2.0 and 2.5 m (3.3, 6.6, and 8.2 ft) elevations in 4 quadrants within each tree canopy adjacent to leaf sample holders. Deposits on the surface of these stubs could be used to assess spray coverage. EBA is a combination of scanning electron microscopy (SEM), energy dispersive x-ray analyzer (EDXA) and digital image analysis. The EBA permitted resolution to 70 Å, direct morphological, and chemical analysis of deposits. A Hitachi Model S-500 SEM, (Hitachi Instruments, Inc., San Jose, CA) equipped with a Voyager III EDXA with digital image analysis (Noran Inc, Middleton, WI) was used in the experiment. Secondary electron imaging and backscattered electron imaging were used to identify directly and quantify spray residue, both morphologically and chemically. The inert stubs were collected after each replicate from each sprayer. Tank mix was characterized with EBA for $Cu(OH)_2$ and blue food dye morphology and spectra for future identification. Specimens were examined at a magnification of 200X with EBA at 20kV and 15 mm working distance. Data were recorded as percent coverage based on the average of three rasters or images per stub. Droplet size and morphology was measured with EBA at the top level opposite the sprayer path.

The data collected was analyzed using SAS (SAS Institute, Inc., Cary, NC) to calculate the analysis of variance based on a general linear model for a completely randomized block which consisted of the sprayers and number of passes. The source of replication within each experimental block was the trees. Within each block, three elevations and four quadrants at each elevation created a split block design. Significant differences in the means of the individual elevations and quadrants, as well as the interaction between the factors, were compared using least significant differences ($\alpha = 0.05$).

Table 1. Mean sprayer deposits by canopy elevation.

Elevation	Mean deposit, µg/cm²	
	CrossFlow	Durand Wayland
Top, 2.5 m	7.70a	13.28a
Middle, 2.0 m	6.12b	11.72a
Bottom, 1.0 m	7.05ab	7.80b
LSD	1.39	2.32

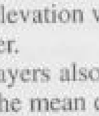
Results and Discussion

There were significant differences in mean spray deposits for the two sprayers (LSD = 0.90). The mean deposits for the CF and DW sprayer were 6.96 and 10.89 µg/cm², respectively. Other significant effects included elevation within the canopy and the quadrant around the canopy. Replicates were not significant, trees used for sampling were not significant, and there were no significant differences in deposits between the two leaf samples taken from the same locations ($P > 0.05$). The statistical evaluations also showed that the sprayers treated elevations differently. Table 1 shows mean deposits by elevation for each sprayer. The more conventional DW sprayer produced significantly higher deposits in the top and middle sections of the canopy than the bottom. The CF sprayer produced significantly higher deposits in the top of the canopy than in the middle. However, the overall differences in deposits by elevation were smaller for the CF sprayer than the DW sprayer.

The sprayers also treated quadrants around the trees differently. The mean deposits by quadrant location are shown in Table 2. Quadrant 3 was near the sprayer drive row and Quadrant 1 was the far side of the tree. Quadrants 2 and 4 were in the row. There were similar differences in mean deposits between the near and far sides of the canopies for both sprayers (approximately four times). The differences in how the sprayers treated quadrants appears to have been related to deposits in quadrants 2 and 4 within the row. There were significant differences in how the CF sprayer treated quadrants 2 and 4 but this was not the case for the DW sprayer. There were smaller differences in deposits between sprayers within the row (quadrants 2 and 4) than on the near and far sides of the canopy.

Figure 2 shows the mean canopy deposits by sprayer for each elevation and quadrant. The sprayers treated elevations and quadrants differently ($P > 0.05$). As expected, the highest deposits occurred in the quadrant closest to each sprayer.

Table 2. Mean sprayer deposits by quadrant around tree.



Quadrant	Mean deposit, µg/cm²	
	CrossFlow	Durand Wayland
Far side, 1	2.49d	4.58c
In row, 2	6.32c	10.41b
Near side, 3	10.83a	19.19a
In row, 4	8.19b	9.37b
LSD	1.61	2.67

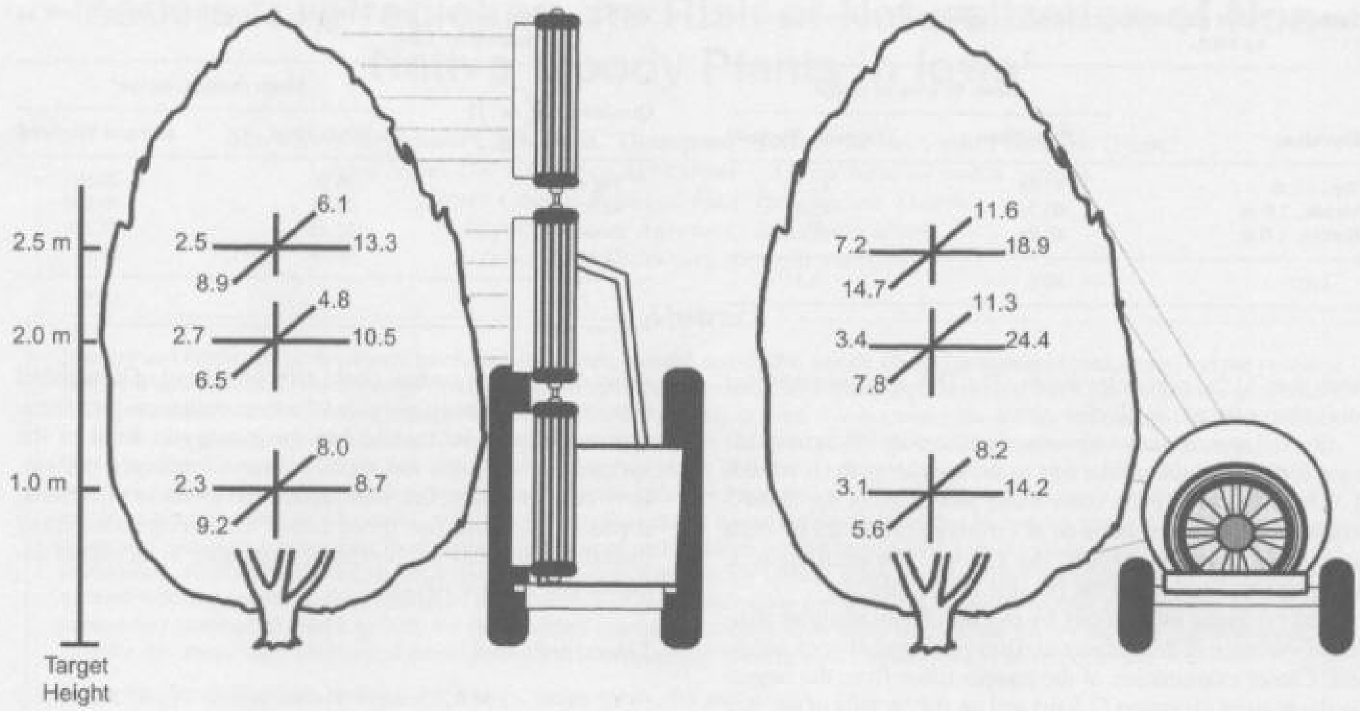


Fig. 2. Means spray deposits (µg/cm²) for CF and DW sprayers by elevation and quadrant.

The sprayers performed most similarly in elevation 1 (1.0 m or 3.3 ft). At higher elevations, the CF sprayer produced lower deposits in all quadrants than the DW sprayer. Derksen and Gray (3) showed that a second pass, on the opposite side of the tree row, would improve the uniformity of the horizontal distribution of spray deposits. However, this does not take into account any possible effect of alternate row spraying on spray distribution as desired by the managers of the nursery site where these tests were conducted.

Overall, target trees had no influence on ground target deposits. There were no significant differences in ground target deposits between sprayers. Statistical analysis showed that there were differences in how the sprayers treated ground targets. Table 3 shows the mean deposits on the ground targets for each sprayer. The DW sprayer produced significantly higher deposits on the middle target, 1.5 m (4.9 ft) from the spray row than on the other targets. However, for the ground targets treated by the CF sprayer, deposits increased with distance from the treatment row even though there was no significant difference in deposits between the 1.5 m (4.9 ft) and the 4.0 m (13.1 ft) targets.

One explanation for the differences in trends in ground deposits with downwind distance may have to do with the size of droplets produced by the two sprayers. The reported droplet volume median diameter (VMD) sizes for the D8-56 and D5-45 nozzles used on the DW sprayer at 2067 kPa (300 psi) are 390 and 160 µm, respectively. The reported VMD for the D4-25 nozzles used on the CF sprayer at 2000 kPa (290 psi) is approximately 140 µm. Since the droplet spectrum produced by the CF sprayer is smaller than that produced by the DW sprayer, there is potential for greater downwind ground deposits for the CF sprayer. The type of airflow produced by each sprayer may have also contributed to differences in downwind ground deposits by distance from the spray row. The airflow generated by the CF sprayer tends to maintain its integrity longer than the airjet produced by the axial flow fan on the DW sprayer. It is possible that the CF sprayer blew more spray through the canopy and carried spray further beyond the spray row than the DW sprayer. The delivery characteristics of the CF air curtain sprayer would reduce mean canopy deposits as well as increase downwind, off-target deposits. The results of Salyani et al. (10) would seem to support these hypotheses where 400 µm diameter droplets were deposited on citrus leaves more efficiently than other sizes in a 15 m/s (49.2 ft/s) air stream. Smaller droplets would probably be deposited more efficiently in lower velocity air streams.

Table 3. Mean ground target deposits by sprayer.

Ground target	Mean deposit, µg/cm²	
	CrossFlow	Durand Wayland
0.5 m	3.01b	3.39b
1.5 m	4.46a	5.05a
4.0 m	4.73a	2.37c
LSD	0.95	0.85

For the spray coverage analysis, the percent area of coverage from each of the three rasters or images from each stub was averaged to provide a mean for each sample site. Statistical analysis of the coverage data showed that there was no significant difference between sprayers. The overall mean percent areas of coverage across all targets for the CF and DW sprayers were 52.6 and 47.5%, respectively (LSD = 7.3). Independently, elevation had no significant effect on coverage but the quadrant was a significant effect on measured coverage. In addition, there no significant sprayer × elevation or sprayer × quadrant interactions.

The mean percent area coverage by canopy elevation for each sprayer treatment is shown in Table 4. The CF sprayer produced significantly higher coverage in the middle canopy

Table 4. Mean percent area coverage by canopy elevation as measured by EBA.

Elevation	Mean % area coverage	
	CrossFlow	Durand Wayland
Top, 2.5 m	47.8b	47.5a
Middle, 2.0 m	60.2a	45.4a
Bottom, 1.0 m	49.8b	49.6a
LSD	10.1	9.1

Table 5. Mean percent area coverage by quadrant around tree as measured by EBA.

Quadrant 2 1 × 3 4	Mean deposit, µg/cm²	
	CrossFlow	Durand Wayland
Far side, 1	36.9b	39.6b
In row, 2	55.9a	49.7ab
Near side, 3	57.4a	47.3ab
In row, 4	60.2a	53.6a
LSD	11.6	10.5

area than at the other elevations. The DW sprayer provided uniform coverage at all elevations.

Overall, percent coverage was significantly lower in quadrant 1, opposite side of the tree to the sprayer path ($\alpha = 0.05$, LSD = 7.8), than in the other quadrants (2, 3, or 4). Table 5 shows the mean percent area of coverage produced by each sprayer by quadrant around the canopy. For each sprayer, coverage was lowest in the far side of the tree.

The coverage evaluations by electron beam analysis indicated variation in droplet size and morphology between sprayers. Closer examination of the images taken from the targets in the highest elevation (2.5 m) and on the far side of the tree from the sprayer path (quadrant 1) showed that the droplet deposits produced by the DW sprayer were uniformly round with residue patterns ranging from 250 to 450 µm in diameter. Most of those deposits produced by the CF sprayer had a distinctively oval shape, perhaps indicating a streaking or smearing of the droplets across the surface of the target. These deposits ranged from 80–140 µm in width to 300–600 µm in length. Circular shaped deposits produced by the CF sprayer were relatively small and ranged from 40–180 µm in diameter. This sticky surface is intended to minimize movement of material striking the surface. These observations, while not analyzed statistically, lend support for the theory that the droplets produced by the CF sprayer were moving relatively fast, compared to those produced by the DW sprayer. This hypothesis could help explain differences between deposits on the ground targets between sprayers. Reduced fan speeds may actually be beneficial to both types of sprayers. Cross (2) showed that reducing fan speed on a conventional axial fan sprayer by 40% in a planting of smaller apple trees (<2 m) would better direct spray at the tree canopy. Since some of the spray stream is deflected over a mature tree canopy, reducing fan speed may keep more material within the canopy. Steinke et al. (11) also showed that reducing the rotational speed of fans similar to those used on the CF sprayer in this study, did not significantly reduce canopy deposits.

In summary, spraying relatively dense, four-year-old red maples from one side only with the sprayer configurations used in this experiment will not provide uniform distribution of product across the canopy. It is not clear from these results that alternate row spraying will significantly improve the uniformity of the product as desired by the manager of this commercial nursery. However, biological evaluations should be conducted to determine the levels of deposit necessary to provide the desired pest control. More uniform delivery of spray material along the canopy profile, as provided by the CF sprayer, can significantly improve the uniformity of the vertical distribution of product but not necessarily the horizontal distribution. Near-row ground targets showed that perhaps the air delivery system and the configuration of the spray distribution system could affect the level of downwind deposits. This study provides further evidence that these sprayers should be matched to the canopy in front of the sprayer. Slowing the fan speed on the CF sprayer, particularly of the topmost fan, will reduce the levels of downwind deposits. Slowing fan speed could also keep more spray material in the canopy, potentially resulting in increased deposits and spray coverage.

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