Evaluation of Tunnel Sprayer Systems for Dwarf Fruit Trees

D. L. Peterson, H. W. Hogmire

Abstract. *Two types of spray systems were tested in a tunnel sprayer with different configurations and operating parameters. Two pairs of opposing cross-flow fans yielded the most uniform deposition on the target trees and least deposition on the downwind tree row; but results of two sets of three opposing Proptec® fans were improved over previous tests. Deposition to the downwind row did not appear to be a serious problem; but 14 to 37% of the spray material was deposited onto the ground within the tunnel sprayer. Spray deposition at 8 km/h (5 mile/h) was as effective as it was at 4.8 km/h (3 mile/h).* **Keywords.** *Sprayer systems, Fruit trees, Tunnel, Drift.*

Improving sprayer application efficiency and reducing pesticide drift is important to the orchard industry. Peterson and Hogmire (1994) reviewed recent developments in air-blast and tunnel orchard sprayers. An Ontario apple grower (Andy Spanjers, 1995) has developed a self-propelled tunnel sprayer that yields effective control when applying 375 L/ha (40 gal/acre) at 12.8 km/h (8 mile/h). A New York state apple grower (Oakes, 1995) developed a trailing tunnel sprayer for his dwarf apple orchards. He utilized opposing pairs of cross-flow fans with conventional hydraulic nozzles and had effective control when applying 470 L/ha (50 gal/acre) at 8 km/h (5 mile/h). Peterson and Hogmire (1994) described a tunnel sprayer they developed for dwarf fruit trees. They showed that two pairs of cross-flow fans on opposite sides of the tunnel, with hydraulic nozzles, yielded the highest average deposition with the most uniformity of any configuration tested. They also showed that two pairs of Proptec® fans (located above and below the tree canopy) resulted in less spray deposition and uniformity than the cross-flow fans. They concluded that most configurations of the tunnel sprayer showed improved application efficiency and significant drift reduction potential over a commercial air-blast sprayer.

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Objectives

The objective of this research was to evaluate our tunnel sprayer with both the cross-flow and Proptec fans at two horizontal outlet orientations, two ground speeds, and two applications rates. Evaluation factors were deposition within the target tree row, deposition on the ground in the area traversed by the tunnel, and deposition on the first downwind tree row adjacent to the target tree row. The tunnel sprayer was also compared to a conventional air-blast sprayer using the same evaluation factors.

Materials and Methods

Test Sprayers

The tunnel sprayer was the same unit as previously reported (Peterson and Hogmire, 1994). Two types of air-assisted spray delivery systems were utilized. The first type used Proptec fan units (BEI, Inc., South Haven, Mich.). Each unit had a 440 mm (17.5 in.) diameter, five-blade axial fan with an integral controlled droplet atomizer (CDA). The Proptec fan units were driven at 4500 rpm and produced turbulent airflow. The CDA produced droplets in the 75 to 100 micron range (VanEe et al., 1985). Schematic of the Proptec fan configuration in the tunnel sprayer is shown in figure 1. We felt that three Proptec units positioned along each side of the tree would be more

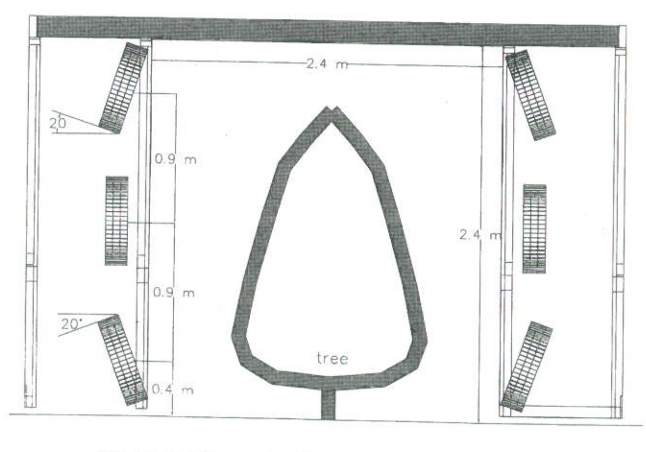

Figure 1–Schematic of setup of Proptec fan units.

effective than the "above and below" placement in previous tests.

The second main spray delivery system used Curtec® (BEI, Inc.) cross-flow fans. Each cross-flow fan had a 280 mm (11 in.) diameter rotor and a 180 × 900 mm (7 × 35 in.) rectangular outlet. The cross-flow fans were driven at 900 rpm and produced less turbulent airflow than the Proptec fan units. Spray atomization at the cross-flow fan outlet was accomplished with four hollow cone nozzles equally spaced along the center-line of the outlet. To keep a fairly constant droplet size distribution with varying application rates and travel speeds, the following hollow cone hydraulic nozzles (Spraying Systems Co., Wheaton, Ill.) were used: 1) D1-13 at 490 kPa (70 psi), $D_{v.5}$ = 140 µm, for 187 L/ha (20 gal/acre) and 4.8 km/h (3 mile/h); 2) D2-13 at 1050 kPa (150 psi), $D_{v.5}$ = 140 µm, for 187 L/ha (20 gal/acre) and 8 km/h (5 mile/h); and 3) D4-25 at 1330 kPa (190 psi), $D_{v.5}$ = 160 µm, for 700 L/ha (75 gal/acre) and 8 km/h (5 mile/h). Schematic for the cross-flow fan configuration in the tunnel sprayer is shown in figure 2. The only difference in the cross-flow fan setup over previous tests was the two lowest fan's outlets were vertical, instead of angled up 6°. This change was made to insure adequate coverage in the lower part of the tree.

An FMC (Jonesboro, Ark.) Economist air-blast sprayer was used to represent a typical commercial orchard sprayer. The top two nozzles were shut off, and the next five nozzles (FMC C3400-268 disc, C462-10 whirl) were operated at 950 kPa (135 psi). The axial flow fan was operated at 2400 rpm.

Test Setup

A series of four sets of tests were conducted to determine the best configurations and operating characteristics for effective spray deposition while minimizing off-target spray. Information gained during a test helped determine the setups for the next test. For the tunnel sprayer, major factors studied were: 1) travel speed of 4.8 km/h (3 mile/h) versus 8 km/h (5 mile/h); 2) fan outlet orientation with respect to travel direction of either one side angled 7.5° forward and the opposite side angled 7.5° backward, or both sides angles 15° backward; and 3) application rate of 187 L/ha (20 gal/acre) versus 700 L/ha (75 gal/acre).

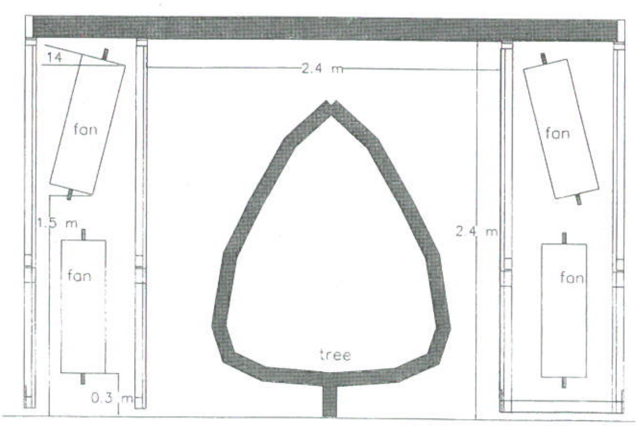

Figure 2–Schematic of setup for cross-flow fan units.

In all the tests, winds were very calm and only during tests 3 and 4 did the wind occasionally gust to 4 km/h (2.4 mile/h).

Deposition Measurements

Either 'York' (three tests) or 'Delicious' (one test) apple trees planted on M-9 rootstock and spaced 1.8 × 3.6 m (6 × 12 ft) were used to evaluate the sprayers. Tree canopies were 2.4 m (8 ft) high and ranged in width from 2 to 2.4 m (6.5 to 8 ft). Two water soluble food dyes (FD&C no. 1 Blue and FD&C no. 6 Yellow, Warner Jenkinson, St. Louis, Mo.) were used to quantify spray deposition on samples (Hayden et al., 1990). Dyes were mixed at the rates of 6.6 g/L and 1.76 g/L for the 187 L/ha (20 gal/acre) and 700 L/ha (75 gal/acre) application rate, respectively. Two areas within the tree canopy were evaluated for deposition. Since spray was delivered from both sides of the tree, leaves were randomly sampled from the outer 0.5 m (20 in.) (periphery) of the canopy on both sides of the tree and then from the remaining center canopy. All leaf samples were from 0.7 to 1.7 m (28 to 66 in.) above the ground. Treatments were applied to 15 adjacent trees in a row, that had comparable tree rows on either side. Since two dyes were used, two treatments were applied to each tree group. Five trees in each 15 tree group were randomly selected as replications. Before treatment, each replication had the top surface of 20 randomly selected leaves and the bottom surface of 20 randomly selected leaves, in both the periphery and center regions, covered with cellophane tape (80 leaves/tree). After treatments were applied and spray had dried (30 to 60 min), each 20-leaf sample was collected into labeled brown paper bags. In the laboratory, tape was removed from the leaves and a 2.54 cm (1 in.) diameter disc was cut from the center of each leaf with a leaf punch. The leaf discs were placed in a 60 mL capped plastic jar with 50 mL of distilled water. Each jar was then rotated for 15 min on a conveyor belt on a portable fruit sizer to remove the dyes. Leaf discs were carefully removed. Solution absorbance for each dye was measured using a spectrophotometer (Spectronic 20, Bausch & Lomb, Rochester, N.Y.). Dye deposits were quantified using a linear regression equation and expressed as $\mu g/cm^2$ of leaf area. To measure deposit on the downwind tree row, 20-leaf samples were randomly taken from the outer 0.5 m (20 in.) of the canopy on each side of the tree, on the tree across from the sampled treatment tree. To measure deposit on the ground in the area traversed by the tunnel, two petri dishes [95 mm (3.75 in.) diameter] were placed on the ground (one in tree line and one at drip edge) under each tree replication. After treatments, dyes were dissolved in distilled water and analyzed as discussed above. SAS (SAS Institute Inc., Cary, N.C.) was used to analyze the data. The coefficient of variation (CV) was calculated for each treatment and used as a measure of deposition uniformity, since it is a relative measure of variation among treatments. The lower the CV, the more uniform the deposition between locations within the tree, and top and bottom of leaf surfaces.

RESULTS AND DISCUSSION

Dye deposit results on target trees, downwind trees, and on the ground in the area traversed by the tunnel are summarized in table 1 and figures 3, 4, and 5, respectively.

In test 1, the arrangement of three Proptec units on each side gave greater deposition (1.71 mg/cm^2 versus 0.5 to 1.3 mg/cm^2) with less variation among deposits (86.4 versus 75 to 120 CV) than in previous Proptec tests with the "above and below" arrangement (Peterson and Hogmire, 1994). Deposition on the leaves from the two cross-flow fan arrangements at 4.8 km/h (3 mile/h) tended to be slightly less than the Proptec treatment, but with slightly better uniformity. The angle of outlet orientation did not affect leaf deposition, but it was observed that more dye was deposited on the insides of the tunnel with the 7.5° forward and the opposite side angled 7.5° backward orientation, than when all cross-flow fans were angled backward 15°. The highest and most uniform deposition of all four of test 1 treatments occurred with the cross-flow fans angled backward 15° at a ground travel speed of 8 km/h (5 mile/h). This improved coverage with increased ground speed disagrees with results from conventional air-blast sprayers (Randall, 1971), but agrees with improved tunnel sprayer effectiveness at higher speed reported by Derksen (1995). In all four treatments, deposition on the downwind trees did not appear to be a significant problem. Ground deposits in the area traversed by the tunnel accounted for 14 to 38% of the dye sprayed in the orchard (calculated by dividing the product of the average ground deposit rate and the area traversed by the tunnel per hectare by amount of dye applied per hectare).

Test 2 showed that increased ground speed maintained leaf deposition on the target trees with both the Proptec and cross-flow fan units. Leaf deposition and uniformity of coverage was very good for all treatments, and there were no significant differences. The Proptec treatments had significantly more deposition on the downwind tree row than the cross-flow fan treatments, but less than 5% when compared to deposits on the target trees. Ground deposits were not recorded for this test.

Test 3 showed that application rates [187 or 700 L/ha (20 or 75 gal/acre)] with the cross-flow fans resulted in no significant difference in deposition on target trees, on the downwind trees, on the ground in the area traversed by the tunnel, and very little difference in uniformity. Even the higher application did not produce runoff from the trees. The Proptec setup resulted in less deposition and less uniform coverage than the cross-flow fan configurations, and Proptec results from tests 1 and 2. Trees had a very light fruit crop and excessive vegetative growth, which may have reduced the Proptec fans ability to effectively penetrate the canopy. This Proptec test also had significantly more deposition on the downwind tree row, but less deposition on the ground in the area traversed by the tunnel than the cross-flow fan configurations. The commercial air-blast sprayer had the poorest deposition, least uniformity, and most deposition on the downwind tree row of any of the treatments. This result was the same as previous year tests where most of the deposition was in the periphery of the tree on the bottom of the leaves. The commercial air-blast sprayer did result in a lower level of ground deposition than the tunnel sprayer with the cross-flow fan configuration. This was expected since the airstream of the commercial air-blast sprayer is away from the ground.

Table 1. Sprayer evaluation results

Treatments	Deposit* Target Trees	CV	Deposit† Downwind Trees	Ground Deposit‡ Tunnel Area	
§ ‖ # ** ††	(μg/cm^2)	(%)	(μg/cm^2)	(μg/cm^2)	(% Applied)
1 P A M L	1.71ab	86.4	0.00a	2.74c	(14)
1 C A M L	0.95c	69.4	0.08a	3.40bc	(18)
1 C B M L	1.09bc	76.0	0.14a	4.76b	(26)
1 C B E L	2.28a	46.0	0.00a	7.00a	(38)
2 P A M L	2.59a	36.1	0.13a		
2 P A E L	2.66a	32.9	0.13a		
2 C B M L	2.76a	42.2	0.04b		
2 C B E L	2.94a	48.5	0.04b		
3 P A E L	1.26bc	114.7	0.33a	2.64b	(14)
3 C B E L	1.90ab	60.8	0.04b	5.69a	(31)
3 C B E H	2.18a	42.6	0.05b	6.70a	(36)
3 F D S H	0.55c	174.0	0.40a	1.65b	(9)
4 P A E L	0.97b	107.5	0.04b	2.58bc	(14)
4 P B E L	1.47b	71.1	0.00b	3.64b	(20)
4 C B E L	2.46a	65.2	0.07b	8.13a	(44)
4 F D S H	0.78b	99.0	0.21a	1.91c	(10)

* Dye deposition on trees within tunnel. Mean separation within test group by Duncan's multiple range test, P = 0.05, df = 76.

† Dye deposition on trees in downwind row. Mean separation within test group by Duncan's multiple range test, P = 0.05, df = 36.

‡ Dye deposition on the ground in the area traversed by the tunnel. Mean separation within test group by Duncan's multiple range test, P = 0.05, df = 36.

§ Test date 1 = 6/15/94, 2 = 7/12/94, 3 = 8/09/94, 4 = 8/31/94.

‖ Sprayer type; P = Proptec, C = cross-flow, F = FMC.

\# Sprayer outlet horizontal orientation; A = One side 7.5° forward, opposite side 7.5° backward, B = both sides 15° backward, D = standard fan setup for FMC sprayer.

** Ground speed; S = 3.5 km/h (2.1 mph), M = 4.8 km/h (3 mph), F = 8.0 km/h (5 mph).

†† Application rate; L = 187 L/ha (20 gal/acre), H = 700 L/ha (75 gal/acre).

Again, in the fourth test, the cross-flow fan configuration gave the highest deposition and most uniform coverage of any of the treatments. Although not significant, orienting all Proptec fans backward 15° seemed to improve deposition and uniformity over having one side 7.5° forward and the other side 7.5° backward. With the 15° backward orientation, less dye was deposited on the sides of the tunnel, but more on the ground in the area traversed by the tunnel than with the 7.5° forward and 7.5° backward orientation. The commercial air-blast sprayer yielded the lowest deposition on target trees with the most deposition on the downwind trees. Ground deposits were similar to earlier tests.

In all four tests series, the tunnel sprayer with the cross-flow fans and a ground speed of 8 km/h (5 mile/h) gave the most uniform coverage, highest dye deposition on the target trees, and lowest deposition on the downwind tree row of any treatment. Application rate and horizontal fan orientation did not appear to be significant factors in application effectiveness. Observation of the spray pattern of the cross-flow fans (no tree in tunnel) showed good mixing action in the center of the tunnel and slight downward movement of the air stream. This downward

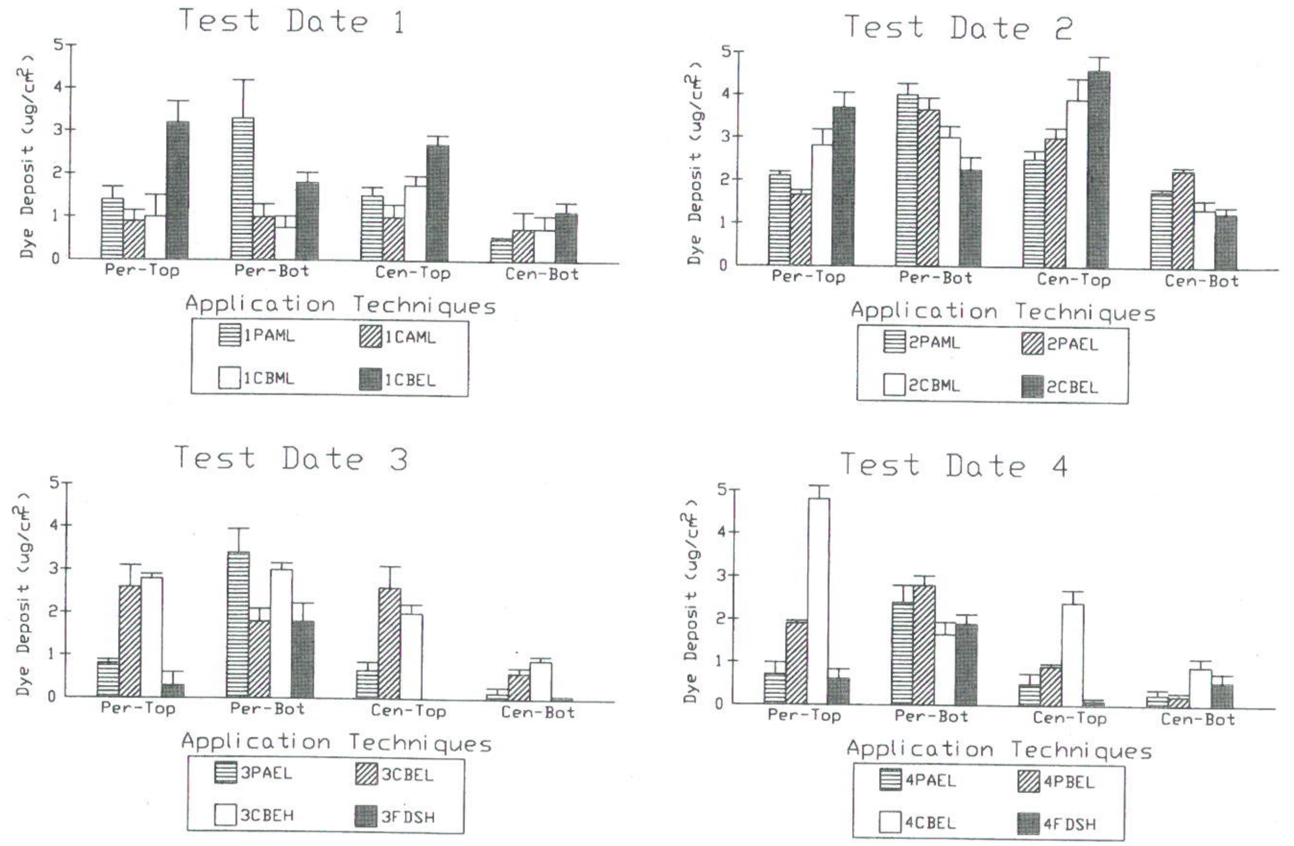

Figure 3–Average dye deposition on target trees (Per = periphery of tree, Cen = center of tree, Top = top of leaf, Bot = bottom of leaf, standard error bars shown).

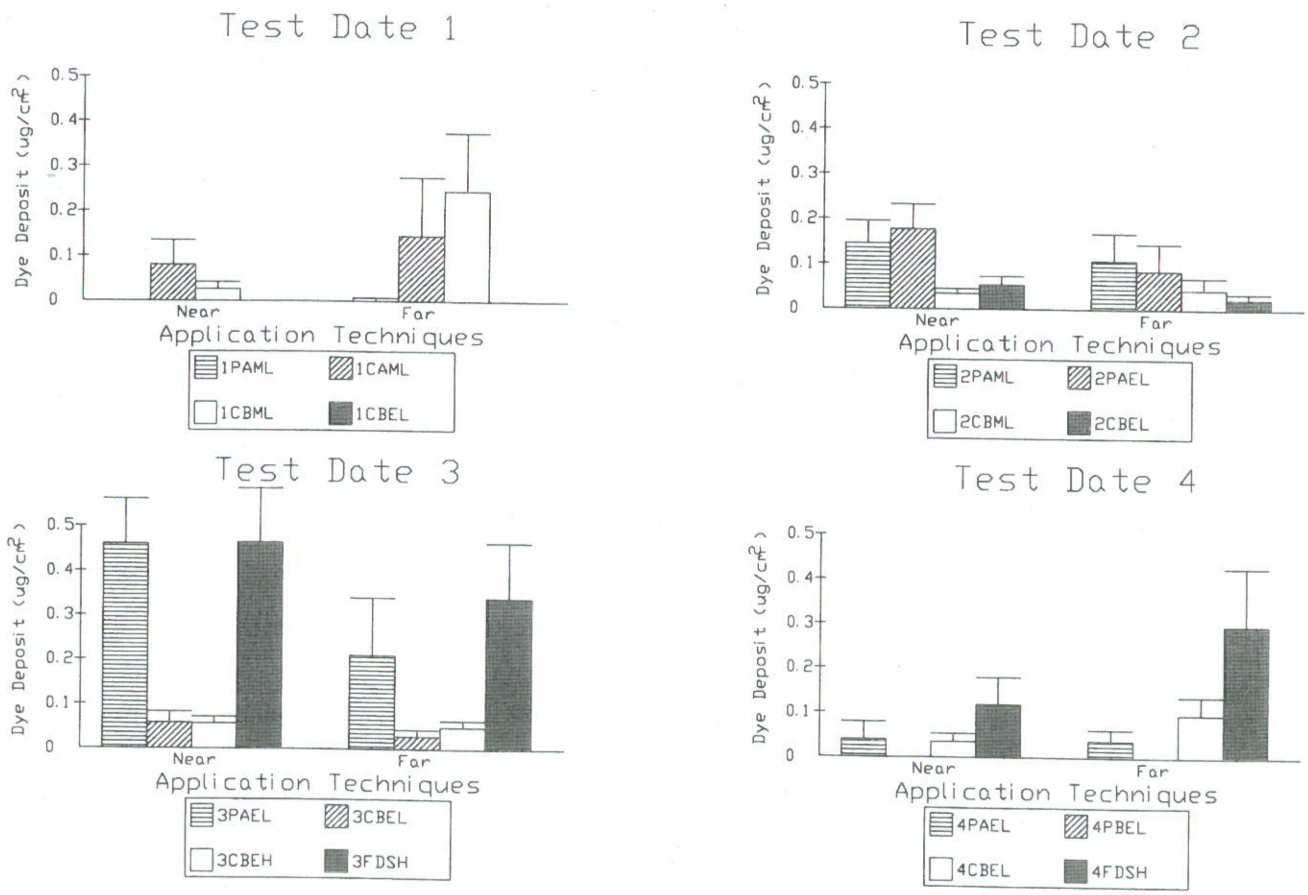

Figure 4–Average deposition on downwind tree row (Near = side next to sprayed row, Far = opposite side of downwind trees, standard error bars shown).

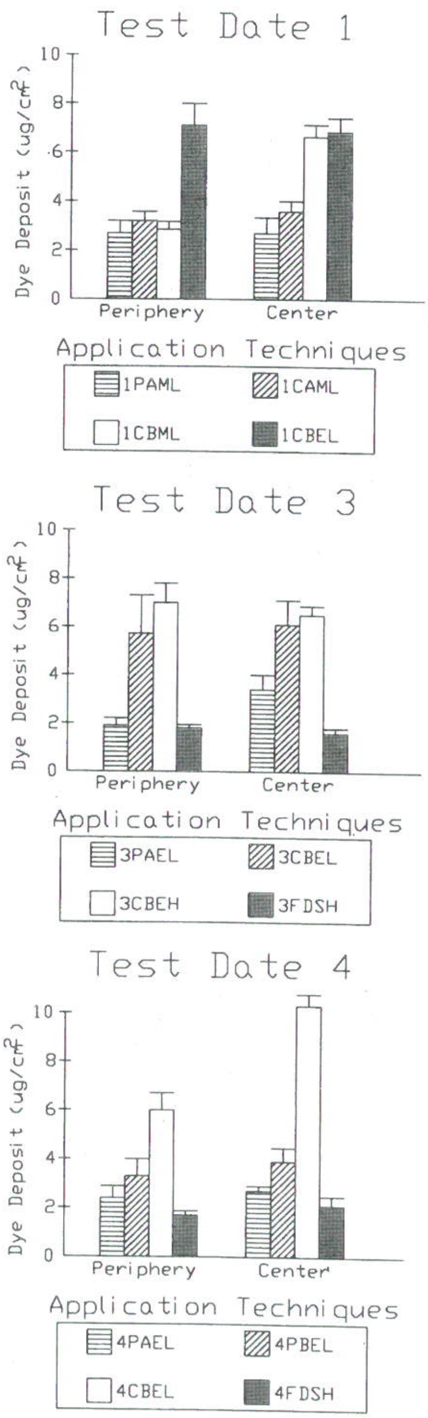

Figure 5–Average dye deposition on ground in the area traversed by the tunnel (Periphery = periphery of tree, Center = center of tree).

movement may be responsible for the highest ground deposition in the area traversed by the tunnel of any of the treatments. This high ground deposition would indicate that a below-tree recovery system might be beneficial in reducing off-target material. Angling the lower cross-flow fans upward might also reduce ground deposits.

CONCLUSIONS

Field tests to date have resulted in the following conclusions.

Two pairs of cross-flow fans on opposite sides of the tunnel sprayer, angled backward 15°, and operated with a ground speed of 8 km/h (5 mile/h) resulted in consistently good deposition and uniformity of coverage, with minimal deposition on the downwind tree row.

Proptec fans configured three to a side resulted in greater and more uniform deposition than pairs of Proptec fans configured above and below the tree canopy, but were not as effective as the best cross-flow fan configuration.

Operating the tunnel sprayer with either Proptec or cross-flow fan configurations at 8 km/h (5 mile/h) resulted in deposition and uniformity of coverage as good as or better than operating the same configurations at 4.8 km/h (3 mile/h).

Fan outlet orientation with respect to travel direction of either one side angled 7.5° forward and the opposite side angled 7.5° backward, or both side angles 15° backward did not significantly affect deposition, uniformity, or ground deposits with either the Proptec or cross-flow fan configurations. However, when both sides were angled backward 15°, there appeared to be less spray deposits on the inside walls of the tunnel.

For the two application rates tested with the tunnel sprayer with the cross-flow fans, there was no significant differences in deposition on target trees, on the downwind trees, on the ground in the area traversed by the tunnel, and very little difference in uniformity.

Substantial spray deposits on the ground within the tunnel's boundary would indicate that either an below-tree recovery system would be beneficial in reducing off-target material or repositioning of lower spray components is warranted.

The commercial air-blast sprayer yielded less deposition, less uniformity, and more deposition on downwind tree row when compared to the best configuration of the tunnel sprayer with either the Proptec or cross-flow fans.

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