DEPOSITION CHARACTERISTICS OF TWO AIR-CARRIER SPRAYERS IN CITRUS TREES

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ABSTRACT

A copper-water spray was applied to one side of orange and grapefruit trees with a conventional air-carrier sprayer and an "Air Curtain" sprayer (with 4 cross-flow fans), both operating at 233 L/ha and 2.4 km/h. The conventional and "Air Curtain" sprayers delivered air volume flow rates of 25 and 14.8 m^3/s per side, respectively. Deposition of copper on the sampled leaves from the conventional sprayer was greater than that from the "Air Curtain" sprayer. The coefficient of variability of the deposits throughout the tree exceeded 100% for both sprayers.
KEYWORDS. Sprayers, Citrus trees.

INTRODUCTION

Improvement in the uniformity and efficiency of chemical deposition is frequently the goal of spray application research. Often a target pest may be localized or prefer certain areas on a plant, thus requiring precise pesticide deposition in these areas. This demands a great improvement in deposition efficiency. Increasing the density and depth of foliage usually increases the difficulty of achieving uniform deposition.

Florida citrus trees are commonly allowed to develop canopy diameters and heights exceeding 6 m at maturity and can develop relatively dense foliage, especially in the outer 1 m of the canopy shell. Pesticides are commonly applied by conventional air-carrier sprayers which normally consist of a single axial flow or centrifugal fan (near ground level) to generate the air volume flow rate necessary to carry spray droplets from nozzles into the tree canopy and provide for penetration of foliage and drop impaction.

During the 1980s, a different type of air-carrier sprayer, sometimes referred to as the "Air Curtain" sprayer (Van Ee et al., 1985; Van Ee and Ledebuhr, 1988), was introduced and researched in the U.S. The sprayer uses rotary atomizers to produce spray droplets which are carried to the target in an air stream generated by cross-flow fans. The principle of the cross-flow fan is well-known but was not widely used for air-carrier sprayers until about 1960 following development work in Germany and later in England (Sharp, 1980). In tree crop spraying with this concept, the air and spray are generally delivered parallel to the ground over a tree height of up to 6 m. Van Ee et al. (1985) have stated "The axial, turbine, and centrifugal fans used in current sprayers produce high speed, turbulent outputs. In comparison, the cross-flow or tangential fan produces a relatively non-turbulent 'straight stream' flow."

Previous reports (Van Ee et al., 1985; Van Ee and Ledebuhr, 1988) indicated the "Air Curtain" sprayer achieved uniform depositions on mylar targets throughout the canopies of mature Florida grapefruit trees when spraying from one side of the tree. The conventional air-carrier sprayer in their test was reported to provide less uniform deposition, even when spraying from the two opposing sides of the tree and at higher spray volume rates/ha. These results suggested that the "Air Curtain" sprayer, as compared to the conventional air-carrier sprayer, achieved uniform deposition at twice the field capacity and lower spray volume rates; and could apply chemicals more uniformly with a significant reduction in application costs.

In response to inquiries from Florida citrus growers about performance of the "Air Curtain" sprayer, a comparative field experiment was conducted. The objective of this experiment was to measure and compare the deposition characteristics of the "Air Curtain" sprayer and a conventional citrus air-carrier sprayer when each sprayed from one side of orange and grapefruit trees.

METHODS

The field experiment was conducted in an orange and grapefruit grove near Lake Alfred, FL, in April, 1989. Tree rows were north-south with a between-row spacing of 9.1 m for both orange and grapefruit trees. The in-row spacings, however, were 7.6 and 6.1 m for grapefruit and orange trees, respectively. The grapefruit trees had developed natural individual canopies 5.5 m high. Near ground level, the canopy cross-row diameter was 7.5 m and the canopies were touching in-row. The orange trees had sustained considerable freeze damage during the early to mid 1980s, and had developed relatively dense regrowth (foliage) in the center of the canopies. Their canopies were 4.7 m high and 6.2 m in diameter near ground level. The orange trees used in this experiment were standing as individual trees because of missing or very small adjacent trees in-row.

Two sprayers compared in this field experiment were a pto-powered CURTEC* sprayer (air curtain, hereafter

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*Trade and company names used are solely for providing specific information. Their mention does not constitute an endorsement over other products not mentioned.

called AC) and an engine-driven FMC Model 9100 sprayer (conventional air-carrier). The AC sprayer was single sided with four cross-flow fans and one rotary atomizer per fan. The average outlet velocity and air volume flow rate of each fan were 23 m/s and 3.7 m^3/s, respectively (Greiffendorf, 1990). The conventional sprayer was two-sided and its average outlet velocity and air volume flow rate per side were measured as 41 m/s and 25 m^3/s, respectively. For the experiment, each sprayer was calibrated to discharge a copper-water spray mixture (650 ppm elemental copper) at 8.6 L/min per side at a ground speed of 2.4 km/h. For sprayer outputs similar to those in this experiment, Van Ee and Ledebuhr (1988) reported the rotary atomizers on the AC sprayer produced droplets in the 75 to 100 μm range. On the conventional sprayer, the one side used for spraying was operated at 1100 kPa with FMC ceramic nozzles; four number 3 discs with 2-hole whirlplates in the top half of the air discharge and three number 2 1/2 discs with 1-hole whirlplates in the bottom half of the air discharge. The trees were sprayed from one side only, making the application equivalent to 233 L/ha. All trees were sprayed from the east side with the sprayer moving in a southerly direction.

Six trees (3 orange, 3 grapefruit) with uniform canopies were selected for sampling. Eighteen target positions (6 locations at 3 heights) were selected in each tree to characterize the deposition of the sprayers (fig. 1). The target heights for the orange and grapefruit trees were 1.2, 2.4, and 3.6 m, and 1.5, 3.0, and 4.5 m, respectively. Locations 1 through 4 were in a line perpendicular to the tree row with location 1 being near the outside of the canopy nearest the sprayer discharge, 2 and 4 were about 0.6 m inside the canopy, and 3 was in the tree center. Locations 5 and 6 were in the tree row line, about 0.6 m inside the canopy on the leading and trailing edge of the canopy (with respect to the direction of sprayer travel).

Shoots containing 5 to 10 leaves were used as spray deposit targets. The shoots were clipped from trees in the same grove, rinsed in a 0.05 N nitric acid solution and deionized water, then allowed to air dry. They were then taped to branches at the 18 designated positions in each tree prior to spraying and removed as soon as the deposit had dried.

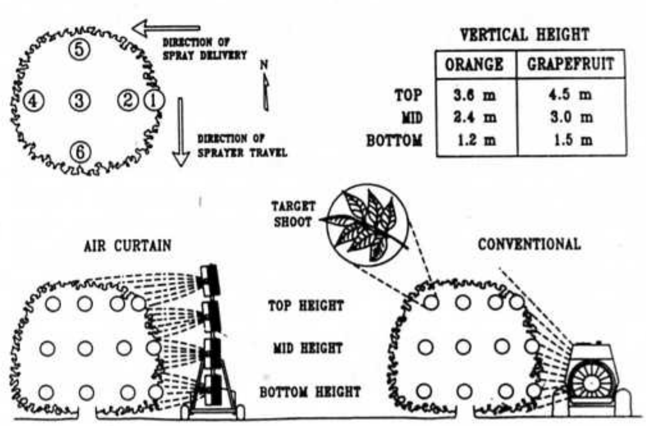

Figure 1–Schematics of trees showing the 18 target positions (6 locations at 3 heights) and the elevation profiles of the air curtain and conventional sprayers with respect to the tree canopy.

All 6 trees selected for this experiment were sprayed once in the morning and then again during the afternoon of the same day. In the morning, 2 orange trees and 1 grapefruit tree were sprayed by the conventional sprayer while 2 grapefruit trees and 1 orange tree were sprayed with the AC sprayer. In the afternoon, the spraying order was reversed.

Three to five leaves were removed at random from each target shoot by grabbing their petioles, placing in a clean, coded plastic bag, and refrigerating within 3 to 4 h. The copper was removed from the leaves in the bags (in the same order as they were collected from the trees) by placing 50 mL of 0.05 N nitric acid solution in each bag and vigorously shaking it. Copper was quantified with a Hach Model DR-100 colorimeter, after which the leaf surface areas were measured on a Delta-T type AMB area meter to determine the amount of copper deposited per unit area (Salyani and Whitney, 1988).

Limited weather data (wind direction and velocity) were obtained on site and temperatures from an official weather station 16 km from the site. In the morning, the winds averaged 8 km/h from the SSE, with dry bulb and dew point temperatures of 22 and 13° C, respectively. In the afternoon, the winds averaged 22 km/h from the SSW with dry bulb and dew point temperatures of 23 and 14° C, respectively.

Results and Discussion

Table 1 shows arithmetic means of the copper deposit, coefficients of variability (CV), and variances (V) of the several factors in the experiment. The difficulty of spraying the 18 target positions in each tree from one side of the tree resulted in CVs that ranged from 69 to 124%, and were comparable to earlier observations (Whitney et al., 1989). Smaller deposit values tended to have smaller variances than larger deposit values. According to Steel and Torrie (1960), when the variances are proportional to the squares of the treatment means, the logarithmic transformation equalizes the variances for the valid application of tests of significance in the analysis of variance. A "least-squares" linear regression analysis of log means ($\overline{x}$) listed in Table 1 and their log variances (V) gave the equation:

$$\log V = 0.31 + 1.84 \log (\overline{x}) \qquad (1)$$

with a coefficient of determination of 0.82. This regression analysis indicated the variances were closely related to the squares of the means and, thus, the analysis of variance was performed on log of the copper deposit values to stabilize variances (Table 2). Tests of significance are reported in terms of log values. It should be noted here that the analysis of variance of the raw data (without log transformation) resulted in similar F values as those in Table 2, except the main effects of tree type and sprayer type F values were greater using the raw data.

Table 3 shows the "least-squares" means (SAS, 1985) associated with tree type, sprayer type, height, and location. The least-squares means were adjusted relative to the arithmetic means to remove the time of day bias using the least-squares method of analysis. The adjustment (see footnote of Table 3) was required due to unequal replication of sprayers across tree types in the morning and afternoon.

TABLE 1. Means, coefficients of variability (CV), and variances (V) of copper deposits on leaves

	Tree Type		Time of Day		Sprayer Type		Height in Tree			Location in Tree					
	Orange	Grapefruit	AM	PM	AC*	Conv†	Bot	Middle	Top	1	2	3	4	5	6
Mean (ng/cm^2)	78	99	83	94	70 ‡	107 ‡	102	92	72	185	149	56	42	51	46
CV (%)	124	103	113	113	105	110	96	124	118	69	87	73	112	85	93
$V \times 10^{-2}$	94	104	88	113	54	139	96	130	72	163	168	17	22	19	18

* "Air Curtain" CURTEC.

† "Conventional" FMC Model 9100.

‡ The target mean leaf area and CV for the AC and Conv sprayer were 154 cm^2 and 20%, and 155 cm^2 and 21%, respectively.

From Tables 1 and 2, the mean copper deposit in the grapefruit trees was significantly higher than in the orange trees at the 0.06 level. Time of day was significant at the 0.09 level. The mean copper deposition of the conventional sprayer was significantly (P = 0.03) more than that of the AC sprayer. The effects of height and location in the tree were significant at < 0.01 level. Overall, deposits decreased with increasing height. Deposits were markedly reduced with increasing distance from the sprayer discharge inside the canopy. The average deposit at location 4 (farthest from sprayer) decreased to 23% of the deposit at location 1 (nearest to sprayer). Salyani and Whitney (1990) reported similar deposit relationships inside citrus tree canopies when spraying from one side. The height x location interaction was not significant.

The sprayer type x tree type interaction was significant at the 0.04 level while the sprayer type x location interaction was significant at the 0.06 level. The bottom of Table 3 shows the least-squares means associated with these interactions. Average deposits of the conventional sprayer were similar in both tree types while those of the AC sprayer were considerably different (less in the orange trees than in the grapefruit trees). The deposit of AC sprayer in the orange trees was significantly (0.01 level, not shown) less than that of conventional sprayer. In grapefruit trees, however, the deposits of the two sprayers were not significantly different. For all heights combined, the deposits of the conventional sprayer were numerically greater than those of the AC sprayer in 4 of the 6 locations in the grapefruit trees and in all 6 locations in the orange trees.

The sprayer type x height interaction was not significant (Table 2). However, the averages in right hand column of Table 3 show differences in sprayers with height within tree type. In the grapefruit trees, deposit means decreased with increasing height for the conventional sprayer more so than for the AC sprayer. In the orange trees, however, deposit means for the conventional sprayer were about the same for all 3 heights whereas the deposit mean of the AC sprayer at the midheight was considerably less than at the other heights. For the conventional sprayer at the top tree height, the grapefruit trees were apparently more difficult to spray than the orange trees and may have been due in part to the larger size of the grapefruit trees. For the AC sprayer, the lower deposition at the mid-height in the orange trees may have resulted because of the dense inner canopies of the orange trees. Also, the low values at most locations (particularly location l) at the mid-height (Table 3) suggest the spray from the rotary atomizers may not have completely merged to form a continuous, uniform pattern at the 2.4 m height (fig. 1).

The means in Table 3 show the deposition of both sprayers generally decreased at greater distances into the canopy. One exception to this was the conventional sprayer

TABLE 2. Analysis of variance for $\log_{10}$ of copper deposits

Source of Variation	df	MS	F	P
Tree type	1	1.611	6.42	0.064
Error (a)	4	0.251		
Time of day	1	0.718	6.11	0.090
Sprayer type	1	1.711	14.55	0.032
Sprayer type × tree type	1	1.396	11.87	0.041
Error (b)	3	0.118		
Height	2	0.456	5.23	0.006
Location	5	3.083	35.34	0.001
Height × location	10	0.104	1.19	0.302
Sprayer type × height	2	0.059	0.68	0.506
Sprayer type × location	5	0.188	2.15	0.061
Tree type × height	2	0.591	6.78	0.002
Tree type × location	5	0.236	2.71	0.022
Error (c)	173	0.087		

TABLE 3. Deposit means* (ng/cm^2) of tree type, sprayer type, height, and location

Tree type	Sprayer type	Location 1	2	3	4	5	6	Avg.
		Bottom height						
Orange	AC†	112	57	56	7	42	42	53
	Conv‡	266	179	58	22	56	50	105
Grapefruit	AC	185	157	89	78	67	37	102
	Conv	199	278	109	127	46	117	146
		Mid-height						
Orange	AC	57	44	31	12	20	19	30
	Conv	289	199	45	27	33	37	105
Grapefruit	AC	249	169	49	69	80	25	107
	Conv	166	371	65	29	57	62	125
		Top height						
Orange	AC	203	40	49	36	29	19	63
	Conv	301	169	58	34	38	57	109
Grapefruit	AC	114	55	29	30	116	31	63
	Conv	86	72	36	39	19	59	52
		All heights						
Orange	AC	124	47	45	18	30	27	49
	Conv	285	182	53	28	42	48	107
Grapefruit	AC	183	127	56	59	88	31	90
	Conv	150	241	70	65	41	79	108

* Deposit means were adjusted using the least-squares method of analysis. Arithmetic means can be obtained by subtracting a value of 2 from the Conv× orange and AC× grapefruit least-squares deposit means; adding a value of 2 to the Conv× grapefruit and AC × orange least-squares deposit means.

† "Air Curtain" CURTEC.

‡ "Conventional" FMC Model 9100.

in grapefruit trees at the two lower heights. The deposition at location 2 was substantially more than it was at location 1, nearest the sprayer discharge. This result may suggest that where the sprayer discharge is very near the canopy, the air volume and velocity of the conventional sprayer are too high to allow maximum deposition on outer canopy of the grapefruit trees. For the AC sprayer, this experiment did not confirm the uniform deposition throughout the grapefruit tree canopy when spraying from one side as reported by Van Ee and Ledebuhr (1988). Possible reasons for this may have been differences in foliage density, wind conditions, ground speed, spray application rate, and deposition measuring methodology.

The prevailing wind speeds during the test were not abnormally high for spray applications in the citrus industry. However, they may have affected the deposition performance of each sprayer differently because of the difference in proximity of the sprayer discharges to the tree canopies and their air volume flow rates and discharge velocities. The AC sprayer discharged spray at about a 3.5 m horizontal distance from the tree center, whereas the distance for the conventional airblast sprayer was approximately 3 m. These configurations put the discharge of the AC sprayer farther from the tree canopy, and with its smaller air volume flow rate and discharge velocity, wind could have disrupted its spray pattern more than the conventional sprayer. The design of the AC sprayer allowed the fan discharges to be pointed at the tree canopy, but did not allow the fan discharges to be configured near the profile of the tree canopy as did the earlier model of the AC sprayer (Van Ee et al., 1985).

The lower overall deposition on the orange tree targets was probably in part due to their inner canopies being denser than the grapefruit trees. For locations 2 through 6 (inside the tree canopies), the mean deposition was 52 ng/cm^2 in the orange trees and 85 ng/cm^2 in the grapefruit trees.

For these tests, tree types, and weather conditions, the deposition performance of the conventional sprayer was superior to and deposited about 52% more copper than the AC sprayer. The least-squares mean deposit of the conventional sprayer was essentially the same in both tree types while that of the AC sprayer was 41 ng/cm^2 less in the orange trees than the grapefruit trees, resulting in a significant sprayer type x tree type interaction. Overall, the CVs of the deposits were 105% and 110% for the AC and conventional sprayers, respectively.

It should be noted that these results are related to the citrus tree and weather conditions described herein, and could be different for other citrus tree and weather conditions.

Conclusions

Based on the citrus tree and weather conditions of these tests with both sprayers discharging 8.6 L/min per side at 2.4 km/h ground speed, and a conventional airblast sprayer discharging air at 25 m^3/s per side, the AC sprayer discharging air at 14.8 m^3/s per side, the following conclusions may be drawn:

1. The mean spray deposit of the AC (air curtain) sprayer was significantly less than that of the conventional sprayer in orange trees, but not significantly less in grapefruit trees.
2. The overall coefficients of variability of spray deposits in both citrus tree types were similar for both sprayer types.

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