SPRAY DRIFT FROM GROUND AND AERIAL APPLICATIONS

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ABSTRACT

A field test was conducted to quantify spray drift from typical spray applications of citrus in Florida. Spray equipment included both fixed-wing and rotary-wing aircraft and high- and low-volume airblast ground sprayers. Spray solutions containing a fluorescent tracer dye were applied to the four tree rows, closest to the downwind edge of an orange grove, under commonly practiced operational conditions. Mylar targets as well as air samplers were used to sample spray fallout and airborne drift at several locations downwind of spray applications. All applications resulted in measurable drift up to 195 m downwind and more than 70% of drift deposits (including swath displacement) originated from sprays applied to the last two rows of the trees closest to the drift line. Averaged over all distances and replications, the highest and lowest drift fallout were from the fixed-wing and low-volume ground sprayer (2.4:1), but, the highest and lowest airborne drift were from low-volume and high-volume ground sprayers (2.6:1), respectively. **KEYWORDS.** Sprayers, Drift, Pesticides.

INTRODUCTION

Numerous reports show that in virtually all pesticide applications, a fraction of released material drifts from the target site and settles on non-target objects downwind of the application. In 1975, the U.S. Environmental Protection Agency (EPA) estimated that 10-60% of applied chemicals drift 300 m or more from target area (Silbergeld, 1985). These materials contaminate air, soil, water, and food resources and may result in adverse effects to humans, animals, and plants. Therefore, pesticide drift has raised world-wide concern about the safety of all agrochemical applications and many researchers have conducted laboratory and field experiments to find ways and means of minimizing drift losses from all pesticidal applications.

With rapid expansion of urban developments in Florida and proximity of residential areas to agricultural farms and groves, the off-target drift of agrochemicals has become more critical than ever. Shortage of drift data for Florida applications (Cromwell et al., 1990) have developed conflicting perceptions about the safety of pesticide applications. Therefore, a field experiment was conducted to collect spray drift data for typical aerial and ground applications in Florida citrus groves and determine the drift contribution of spraying each tree row under commonly practiced operational and meteorological conditions.

LITERATURE REVIEW

Spray drift is a complex problem. It is dependent on equipment design and application parameters (Ware et al., 1969; Stewart and Gratkowski, 1976; Smith et al., 1981), spray physical properties and formulation (Goering and Butler, 1975; Bouse and Merkle, 1975; Yates et al., 1976), and meteorological conditions (Yates et al., 1966; Threadgill and Smith, 1975; Picot et al., 1986). Spray equipment, including aerial and ground sprayers, are equipped with various designs of nozzles or atomizers which, depending on operational variables, may produce different spectrum of spray droplets. Relatively large droplets (> 100 μm) tend to settle near the target area and may result in swath displacement (from the cross swath wind). But, smaller droplets (< 100 μm) become airborne and may be carried by wind for many miles before sedimenting to earth or contacting a target (Akesson and Yates, 1981).

Yates et al. (1966), evaluating drift residues from aerial applications, found that as atmospheric stability ratio (SR) increased, drift deposit increased and the increase was more noticeable at farther sample stations. Ware et al. (1969) compared drifts of an aerial application and a mist blower ground sprayer. The latter showed nearly twice the aircraft drift fallout on alfalfa (at 800 m downwind) and as much as six times more airborne insecticide (at 50 and 100 m) collected in ethylene glycol air scrubbers. Göhlich (1983), spraying sloping vineyards with aerial and ground equipment, observed more drift from an air-blower ground sprayer than spray gun and helicopter and higher wind velocities resulted in greater amounts of drift. Bode and Mohammad Zain (1987) made drift comparisons from four atomizers using soybean oil and water as spray carriers. They observed more drift from low-volume applicators than conventional nozzles. Semmes et al. (1990) measured drift of aerially applied sprays under high temperature and high humidity conditions. They concluded that downwind deposits could be correlated with $D_{V.5}$; but relative span and percent of droplets < 220 μm were also important factors. Riley and Wiesner (1990) quantified drift from an

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air-assisted sprayer in an apple orchard and reported that spray applications to the five rows closest to the downwind edge of the orchard made up more than 99% of drift deposits on the ground.

Several computer simulation and mathematical models have been developed to predict the movement of spray droplets and potential of spray applications for drift. The Forest Service Cramer-Barry-Grim (FSCBG) Model for aerial applications is useful in planning spray operations, calculating pesticide dosage, estimating spray drift, and developing spray prescription (Barry and Ekblad, 1983). Picot et al. (1986), using a Lagrangian Model, concluded that drift is minimized when stability conditions are near neutral and where the aircraft have a high vortex descent rate. Miller (1980) developed the "stirred settling from a volume source" model for a systematic approach to data analysis. Thompson and Ley (1982) applied a modified model of atmospheric diffusion to the drift simulation of evaporating and sedimenting spray droplets. Smith et al. (1981) developed a "drift index" as a function of nozzle height and methodological variables. They found that horizontal wind velocity had more effect on the drift index than any other variables they evaluated. Threadgill and Smith (1975) developed an equation to predict drift potential from a ground application and found the stability ratio and droplet size to be the two most important parameters for drift prediction. Akesson and Gibbs (1990) developed a program (PARIS) that can aid the user to define the application constants and determine the airborne and fallout drift losses that would result from different modes of spray atomization.

Various sampling techniques and tracer materials have been used in drift studies. Yates et al. (1974) used mylar plastic sheets for drift fallout assessment. They found a nearly straight-line (second degree polynomial) correlation between the log values of the residues on mylar sheets and corresponding log values of pesticide residues on green alfalfa. Yates et al. (1976) also used air samplers to measure airborne concentration of the fine drift particles. Deposit per unit area of the air sampler filters were several times that of mylar targets. Goering et al. (1977) found that the size of a flat mylar target did not significantly affect the quantity of spray deposit per unit area when the target surface was not elevated above the surrounding surface. Riley and Wiesner (1990) used wire arrays and "Rotorod" samplers to assess the spray drift flux. They found that drifting spray cloud extended above the 11 m sampling height.

The objectives of this research were to:

- Quantify spray drift from typical aerial and ground applications in Florida citrus groves;
- Determine the contribution of spraying each tree row to the total drift under commonly practiced operational and meteorological conditions.

EXPERIMENTAL PROCEDURE

TEST SITE AND DRIFT TARGETS

The test was carried out in an orange grove (49 ha) in southeast Florida, south of Fort Pierce. The trees were 3.7-4.3 m high, set at 6.1 m within and 7.6 m between the rows, in north-south direction. An irrigation canal extended along the northern side of the grove and the other three sides were surrounded by a cattle pasture. Only the last four tree rows at the west side of the grove were used for spray application. Having 66 trees/row (402 m long), the sprayed area was about 1.23 ha. The west side pasture was used to lay out drift targets downwind of the spray application (fig. 1). The sample lines N, C, and S were 140 m apart and perpendicular to the line of application (travel direction of the spray equipment). Sample stations (target locations) were 15.2, 24.4, 48.8, 97.6, and 195.1 m from the first tree-row line at the western edge of the grove.

Mylar plastic sheets (45.7 × 30.5 cm), centered and stapled onto backing boards (61.0 × 45.7 cm), were positioned horizontally on the ground for fallout drift deposit measurement. High volume air samplers (Staplex TFIA), positioned on a cross-arm at 113 cm above the ground,were used for airborne drift assessment. The samplers, containing cellulose paper filter (TFA41, with 8.9 cm exposed diameter), had an average air volume flow rate of 0.517 m^3/min. Pairs of mylar targets (3-4 m apart) were placed at all sample locations except at 24.4 m on lines N and S. However, due to shortage of air samplers, they were only used on line C at the five sample locations (a-e) between mylar target pairs. Two additional air samplers (f, g) were placed at the 15.2 and 48.8 m sample locations (line C) to determine drift contributions from each row application.

SPRAY EQUIPMENT

Spray solutions containing a Rhodamine free base fluorescent dye (BASO Red NB 546, BASF Corp.) as a tracer were applied to the four tree rows using both aerial and ground sprayers. Nozzle configuration and application parameters of each equipment are shown in Table 1. The fixed-wing aircraft (Snow Air Tractor Model AT-401) was equipped with a Pratt and Whitney R1340 engine. It used eight modified Micronair rotary atomizers (AU 3000 with rotor blades truncated to 8.9 cm) which generated droplets with VMD of about 264 μm (measured at the University of California, Davis, under wind tunnel simulation of application conditions and reported by Semmes et al., 1990). The rotary-wing aircraft (Hiller helicopter; Model UH 12E) was equipped with D6-45 disc/core nozzles that generated droplets with VMD of about 341 μm (data from Akesson and Yates (1988) extrapolated to 56 km/h air speed). A PTO-driven airblast sprayer (Southwind 836 SS) equipped with air oscillators was used with two different nozzle configurations as high- and low-volume ground sprayers. The air volume flow rate of the sprayer was reported to be 16.0 m^3/s (Whitney et al., 1986). The ceramic disc/core nozzles 3/2, 3/3, 5/3, 6/3, and 7/3 were reported to generate droplets with VMDs of 137, 203, 210, 219, and 232 μm (at 1380 kPa), respectively (FMC, 1982).

SPRAY APPLICATION

The fixed-wing aircraft (FW) and the helicopter (HE) applications were made with a swath spacing of 15.2 m; therefore, they sprayed two rows in one pass. The FW made four passes over middle of rows 1 and 2 and four passes over middle of rows 3 and 4 to complete one replication (rep.). The HE had a smaller spray tank size; therefore, it made two passes over each pair of rows to complete one replication. The high-volume (GH) and low-

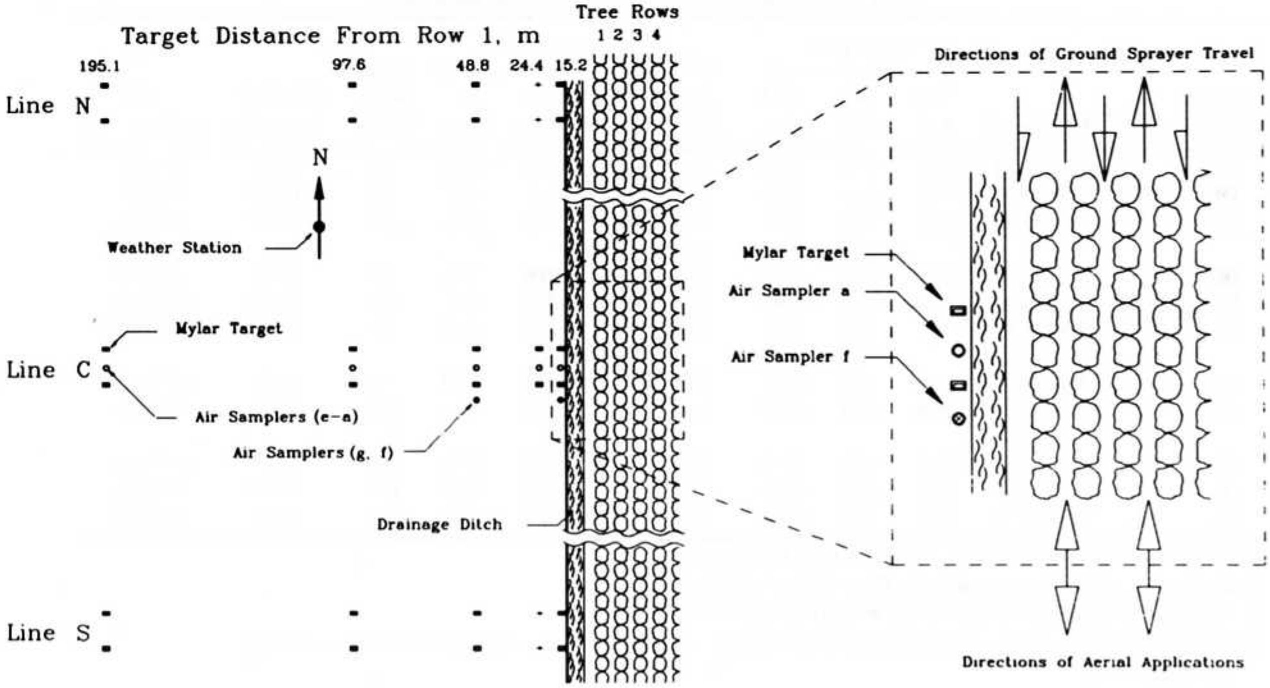

Figure 1–Schematic view of the test site and drift target locations.

volume (GL) ground sprayers started with one-sided spraying the west side of the row 1 (1W) then sprayed middles of rows 1 & 2 (1E & 2W), 2 & 3 (2E & 3W), 3 & 4 (3E & 4W), and finally one-sided spraying the east side of row 4 (4E) for each replication (fig. 1). Each machine sprayed three replications; however, due to a problem with nozzle pressure adjustment, the data pertinent to the GH/rep. 1 was deleted. One spray solution sample of each tank mix was collected before and one after each spray application to measure actual dye concentrations.

All mylar targets and air sampler filter papers (a-e) were uncovered before the start of each equipment treatment/replication and collected a few minutes after completion of the replication. However, filter papers of the air samplers (f) and (g) were collected after each pass of ground sprayers or after spraying each pair of rows with the aerial applicators. The collection and renewal of the filter papers were continued until a replication was completed. The pairs of mylar targets at each downwind sample location were gathered and placed face to face in a bag. The air sampler filter papers were collected individually and placed in Zip-Loc® plastic bags. The samples were stored in a dark place for later analysis.

TABLE 1. Spray equipment and application parameters

Spray Equipment	Nozzle No.	or Atomizer Type	Spray Rate (L / min)	Spray Press. (kPa)	Ground Speed (km / h)	Appl. Rate (L / ha)
Aircraft:						
Fixed-wing (FW)	8	Rotary (micronair)	613.2	345	193.1	125.0
Helicopter (HE)	67	Disc/core (S.S.)*	227.1	276	56.3	158.9
Ground Sprayer:						
High-volume (GH)	20	Disc/core (FMC)*	168.1	1103†	2.6	5083.3
Low-volume (GL)	20	Disc/core (FMC)*	37.9	1103	4.4	673.5

* Helicopter nozzles were D6-45 and oriented straight down. High-volume and low-volume ground sprayers had 10 ceramic disc/core nozzles on each side and were arranged from top to bottom as follows (disc no./no. of core holes): High-volume: 6/3, 6/3, 7/3, 7/3, 7/3, 7/3, 6/3, 5/3, 5/3, 5/3. Low volume: 3/2, 3/2, 3/3, 3/3, 3/3, 3/2, 3/2, 3/2, 3/2, 3/2.

† The pressure for one-sided spraying (1W and 4E) was 1207 kPa.

WEATHER CONDITIONS

Weather data including air temperature, wind velocity, and wind direction were recorded at the test site (fig. 1) by a Campbell Scientific weather station (with Model CR-10 datalogger). Additional data including relative humidity and solar radiation was obtained from a neighboring weather station (about 16 km from the site). Temperature readings at 3.0 m (T_1, ° C) and 9.1 m (T_2, ° C) and average wind velocity (U, m/s) were used to calculate the stability ratio ($SR = 10\,(T_2 - T_1)/\,U^2$). Solar radiation data and sunlight exposure time were used to estimate the degradation of the dye deposit fluorescence. A summary of weather conditions during the spray applications is shown in Table 2.

FLUOROMETRY

The amount of drift deposits on both mylar sheets and filter papers were determined by washing the samples with a 30% ethyl alcohol-deionized water solution and measuring the tracer dye concentration with a Turner Model 111 fluorometer. Removal of drift deposits from filter papers involved: (a) pouring 50 mL alcohol solution in the plastic bags and soaking the samples for at least 5 min, (b) shaking the bags for 1 min (30 strokes), taking two 5 mL samples in fluorometer cuvettes, and (c) reading the fluorescence with the fluorometer. The removal of mylar deposits was more involved and required making a special arrangement. Briefly, two pieces of PVC pipe (with different diameters) were used to make two concentric cylinders. With the ends of each cylinder closed, the gap between them (annulus: 510 mm long, 2.4 mm thick, and 75.4 mm avg. diameter) was used as a container to wash

TABLE 2. Weather conditions during the spray applications

			Temperature				Wind Velocity					
Spray Equip.	Rep.	Time Period	Max (°C)	Min (°C)	TD* (°C)	Rel. Hum. (%)	Max (m / s)	Min (m / s)	U† (m / s)	Wind Dir.‡ (Deg.)	Solar Rad. (MJ / m²-h)	SR§ (° C / (m / s)²)
FW	1	16:18-16:30	28.9	27.8	0.26	51	4.87	3.22	4.07	82	1.967	0.16(S)
FW	2	17:10-17:21	27.2	26.1	0.39	56	4.25	2.86	3.65	97	0.670	0.29(S)
FW	3	17:50-18:01	27.2	25.8	0.27	56	4.65	2.59	3.63	97	0.670	0.20(S)
HE	1	17:12-17:23	27.8	26.3	0.52	53	3.17	2.06	2.51	78	0.753	0.82(S)
HE	2	15:30-15:40	27.7	26.9	-0.04	56	6.35	2.86	4.41	103	1.340	-0.02 (N)
HE	3	15:50-16:00	27.7	26.3	0.43	56	5.05	3.22	4.33	95	1.298	0.23(S)
GH	2	9:47-12:16	27.3	25.3	-2.01	68	7.24	3.26	5.09	129	2.177	-0.78 (U)
GH	3	12:49-14:40	29.8	27.5	-0.98	51	7.15	3.31	5.16	137	2.512	-0.37 (U)
GL	1	11:22-12:12	27.4	25.1	-2.06	59	4.42	0.63	2.55	132	2.043	-3.16 (U)
GL	2	15:23-16:13	30.7	28.3	-0.13	52	7.15	3.58	5.11	150	1.884	-0.05 (N)
GL	3	16:41-17:25	30.7	28.2	-0.02	52	6.75	3.31	4.53	152	1.231	-0.01 (N)

* Temperature recorded at 3.0 m (T_1) and 9.1 m (T_2). TD = $T_2 - T_1$.

† U = Average wind velocity measured at 9.1 m. (m / s) × 2.237 = (mph).

‡ Wind direction measured clockwise with wind from North = 0°.

§ Stability ratio (SR) = $10\,(T_2 - T_1) / U^2$. Letters in parentheses refer to atmospheric conditions: stable (S), neutral (N), and unstable (U).

the mylar targets. The procedure involved: (a) pouring 100 mL alcohol solution in the outer cylinder, (b) separating a mylar sheet from its backing board, (c) wrapping the mylar sheet around the inner cylinder and placing inside the outer cylinder, (d) capping the cylinder and tumbling, rolling, and inverting the assembly for 2 min, and (e) pouring out the wash liquid and taking two 5 mL samples in the fluorometer cuvettes. The above procedures resulted in tracer dye recoveries of 99.7 ± 0.5 and 95.9 ± 0.9% (mean ± S.D., N = 4) from filter and mylar targets, respectively, using 1,328.8 ng dye/sample. Details of the fluorometry procedure, light sources, and filters of the fluorometer are given in Salyani and Whitney (1988).

FLUORESCENT TRACER DEGRADATION

A side test was conducted to estimate the decay rate of the fluorescent deposits under solar radiation. Briefly, 100 pieces of mylar sheet and filter paper (13.5 cm² each) were sprayed uniformly with a 308 ppm fluorescent dye solution and dried in the dark. The sprayed pieces were positioned horizontally in the sunlight and four pieces of mylar and four pieces of filter paper were collected after 0, 7, 10, 20, 30, 40, 60, 80, 120, and 180 min. Simultaneously, solar radiation was recorded by a pyranometer and micrologger. After fluorometry of the samples, the following equations were established for dye degradation:

$$PD_f = 100 \times EXP\,(-0.0823 \times Rad.);\ (R^2 = 0.89^{**})\quad (1)$$

$$PD_m = 100 \times EXP\,(-0.1295 \times Rad.);\ (R^2 = 0.75^{**})\quad (2)$$

where

PD_f = percent fluorescence of filter paper deposits
PD_m = percent fluorescence of mylar sheet deposits
Rad = solar radiation (MJ/m²)
** = highly significant effect ($p < 0.01$)

Considering the orientation of the targets with respect to solar position (Duffie and Beckman, 1974), fractions of total deposit on a target and exposure time of each fraction to sunlight, and intensity of radiation, the equations above were used to adjust the deposits for fluorescence degradation.

DATA ANALYSIS

Samples of tank mixes and number of passes of each equipment were used to correct the deposits to an equivalent amount of the tracer dye per hectare. The data were then normalized to tracer application rate of 1,000 g/ha (10,000 ng/cm²). Also, cosines of the angles of deviation between the sample line (90° to spray swath) and mean wind direction were used to correct the data for wind direction deviation (ASAE Standard S387.1, 1983). Wind directions were also used to determine if spray drift clouds of any pass or application missed any of the sampling stations. The data of any station that missed the drift cloud were eliminated from the analysis.

A second-degree polynomial regression was fitted to data of each replication to relate the mylar and filter deposits to distance downwind of spray application.

The general form of the regression was

$$\log Y = b_0 + b_1\,(\log X) + b_2\,(\log X)^2 \qquad (3)$$

where

Y = drift deposit as percent of calibrated application rate
X = target distance downwind (m)
b_r = regression coefficients

Several SAS procedures (SAS, 1985) were used to analyze the data and make comparisons. The significance of difference between deposits of two mylar targets in a sampling station was examined by T-test statistics. The variance of deposits from different equipment were analyzed by the General Linear Model (GLM) procedure. Deposit means of the equipment were compared by Duncan's Multiple Range Test. The correlation between mylar (fallout) and filter (airborne) deposits were established with the Pearson correlation coefficient. The significance of effects were expressed at the 95% confidence level.

RESULTS AND DISCUSSION

FLUORESCENCE DEGRADATION

Fluorescence degradation of standard samples under sunlight revealed that there was a slower decay of fluorescent deposits on filter paper (eq. 1) than on mylar targets (eq. 2). This might be explained by porosity of the paper and absorption of the dye by the filter fibers. Mylar targets had smooth surface and their deposits were more susceptible to radiation decay. Among drift targets, those of the high volume ground sprayer had the longest exposure times; therefore, fluorescence on some targets reached as low as 86.9 and 63.7% on filter and mylar targets, respectively. Aerial application deposits had minimal exposure and fluorescence did not decrease beyond 97.8% (filter) and 93.5% (mylar). Low-volume ground sprayer deposits had intermediate degradation. Goering and Butler (1974) measured as much as 71% loss in Rhodamine-B fluorescence and 68% loss in Brilliant Sulfo Flavine fluorescence during a 28 min exposure of mylar target deposits to sunlight.

DRIFT DEPOSITS

Table 3 shows regression coefficients corresponding to mylar (fallout) and filter (airborne) drift deposits for each replication. The regression equations provide estimates of the mean drift deposition under the specified application and weather conditions (Tables 1 and 2). Table 4 shows the deposits at sampling stations downwind of the spray application. There was substantial variation in deposits comparing different replications of each spray equipment application. These variations may be due to momentary changes in wind velocity, wind direction, and atmospheric turbulence which are not reflected exactly in the tabulated summary of weather conditions. The same argument may be true in comparison of deposits from different equipment. Since it is virtually impossible to obtain the same weather conditions in the field, comparison of the drift results from different equipment or different replications may be objectionable. Therefore, the regression equations and deposit data are technically valid for only certain weather conditions. Generally speaking, higher stability ratios and more stable conditions tend to increase deposits at farther sampling stations (Yates et al. 1966). Considering this fact, it can be said that aerial applications were carried out under more drift-prone weather conditions; however, it is not possible to normalize the data for a uniform weather condition.

TABLE 3. Regression coefficients for drift deposits*

Spray Equip.§	Rep.	Filter†			Mylar‡		
		b_0	b_1	b_2	b_0	b_1	b_2
FW	1	1.173	0.883	− 0.804	7.307	− 7.258	1.284
FW	2	3.495	− 2.389	0.382	4.125	− 3.209	0.274
FW	3	3.596	− 2.267	0.367	2.346	− 0.682	− 0.438
HE	1	− 1.113	3.782	− 1.499	1.717	− 0.395	− 0.606
HE	2	0.933	0.833	− 0.531	− 0.349	1.745	− 1.011
HE	3	3.085	− 1.999	0.286	0.640	0.621	− 0.674
GH	2	− 1.096	2.904	− 1.161	1.523	− 0.617	− 0.363
GH	3	1.354	0.250	− 0.427	4.700	− 4.180	0.569
GL	1	2.412	− 0.642	− 0.246	4.576	− 5.386	1.144
GL	2	1.590	0.248	− 0.364	2.228	− 1.296	− 0.146
GL	3	1.460	0.200	− 0.268	− 1.263	2.674	− 1.189

* Where $\log Y = b_0 + b_1 (\log X) + b_2 (\log X)^2$
Y = drift deposit as percent of calibrated applicaiton rate
X = target distance downwind (m)

† Coefficients for airborne drift on air sampler filter papers ($R^2 > 0.98$*; except HE / rep. 1 with $R^2 = 0.92$ ns).

‡ Coefficients for fallout drift on mylar sheets ($R^2 > 0.88$*).

§ Spray equipment: FW = fixed-wing aircraft, HE = helicopter, GH = high-volume ground sprayer, and GL = low-volume ground sprayer.

Apart from meteorological effects, both spray equipment and target distance downwind had significant effects on depositions. The highest mean fallout deposit on mylar targets (160.2 ng/cm^2) resulted from fixed-wing (FW) aircraft applications (all replications were made during stable conditions). Mean fallout deposits of the helicopter (HE), high-volume ground sprayer (GH), and low-volume ground sprayer (GL) were significantly less than FW (85.6, 79.6, and 67.6, respectively) but not significantly different among themselves (see Table 2 for the corresponding weather conditions). On the other hand, the highest airborne drift (1011.2 ng/cm^2) resulted from the GL applications. Those of the HE and FW (757.0 and 707.5) were significantly less than the GLs and the GH (with all replications made during unstable conditions) had a significantly lowest deposit of 391.9 ng/cm^2.

The amount of drift deposits decreased as target distance downwind increased. Mean filter (airborne) and mylar (fallout) drift deposits of each equipment and their corresponding regression lines are shown in figure 2. Both filter and mylar deposits at the first three downwind stations were significantly different; however, deposits at the two farthest stations were not different. Deposit data in Table 4 and drift curves of figure 2 show that a high portion of drifted material settled close to the grove. When the data of the 15.2 m sample stations (which included some swath displacement) were excluded from the analysis, there was no difference in the mean fallout deposits from different equipment, but the effect of equipment on airborne deposits remained significant. Even when both the 15.2 m and 24.4 m data were excluded, the order of equipment for airborne deposits did not change. The GL and GH retained their highest and lowest airborne deposits, respectively.

TABLE 4. Drift data for different equipment* (ng/cm²)

Sp. Eq.‡	Rep.	Weather† WV (m / s)	WD (deg.)	SR	Target Distance Downwind (m) 15.2	24.4	48.8	97.6	195.1	15.2	24.4	48.8	97.6	195.1
					Fallout Drift					Airborne Drift				
FW	1	4.07	82	0.16(S)	326.7	50.9	5.1	0.9	0.3	1234.7	707.5	234.9	55.7	9.5
	2	3.65	97	0.29(S)	512.9	158.1	30.7	6.7	1.6	1592.8	822.4	354.6	179.3	106.4
	3	3.63	97	0.20(S)	841.0	359.4	88.0	18.0	3.1	2670.4	1433.8	651.6	345.2	213.1
HE	1	2.51	78	0.82(S)	251.2	100.3	20.9	3.4	0.4	1834.3	1772.3	996.7	299.9	48.3
	2	4.41	103	−0.02 (N)	199.5	133.5	51.8	13.2	2.2	1496.1	1164.8	668.6	307.5	113.3
	3	4.33	95	0.23(S)	269.5	159.8	58.4	16.1	3.3	1316.2	726.8	334.6	173.6	101.5
GH	2	5.09	129	−0.78 (U)	191.2	92.2	27.7	7.1	1.6	518.5	498.9	313.9	121.7	29.1
	3	5.16	137	−0.37 (U)	354.0	98.7	18.3	4.3	1.3	1126.0	755.8	361.5	144.7	48.5
GL	1	2.55	132	−3.16 (U)	63.6	20.2	5.5	2.4	1.7	2028.7	1114.4	422.6	144.6	44.7
	2	5.11	150	−0.05 (N)	308.4	140.6	41.9	11.8	3.1	2363.0	1710.0	934.3	438.6	176.8
	3	4.53	152	−0.01 (N)	172.3	143.8	72.7	22.4	4.2	2094.9	1664.6	1079.6	626.1	324.7

* Average drift deposits for FW, HE, GH, and GL, respectively, are: 160.2, 85.6, 79.9, and 67.6 ng / cm^2 (fallout deposit on mylar sheet) and 707.5, 757.0, 391.9, and 1011.2 ng / cm^2 (airborne deposit on filter paper).

† See Table 2 for complete weather data. WV = average wind velocity, WD = average wind direction, and SR = stability ratio. Atmospheric conditions: stable (S), neutral (N), and unstable (U).

‡ Spray equipment: FW = fixed-wing aircraft, HE = helicopter, GH = high-volume ground sprayer, and GL = low-volume ground sprayer.

The difference in the settling of the fallout and airborne deposits may be attributed primarily to the size and size range of spray droplets (Akesson and Yates, 1981). The data suggests that aerial applications did not produce as many drift-prone small droplets as did the low-volume ground sprayer. This is in agreement with Ware et al.

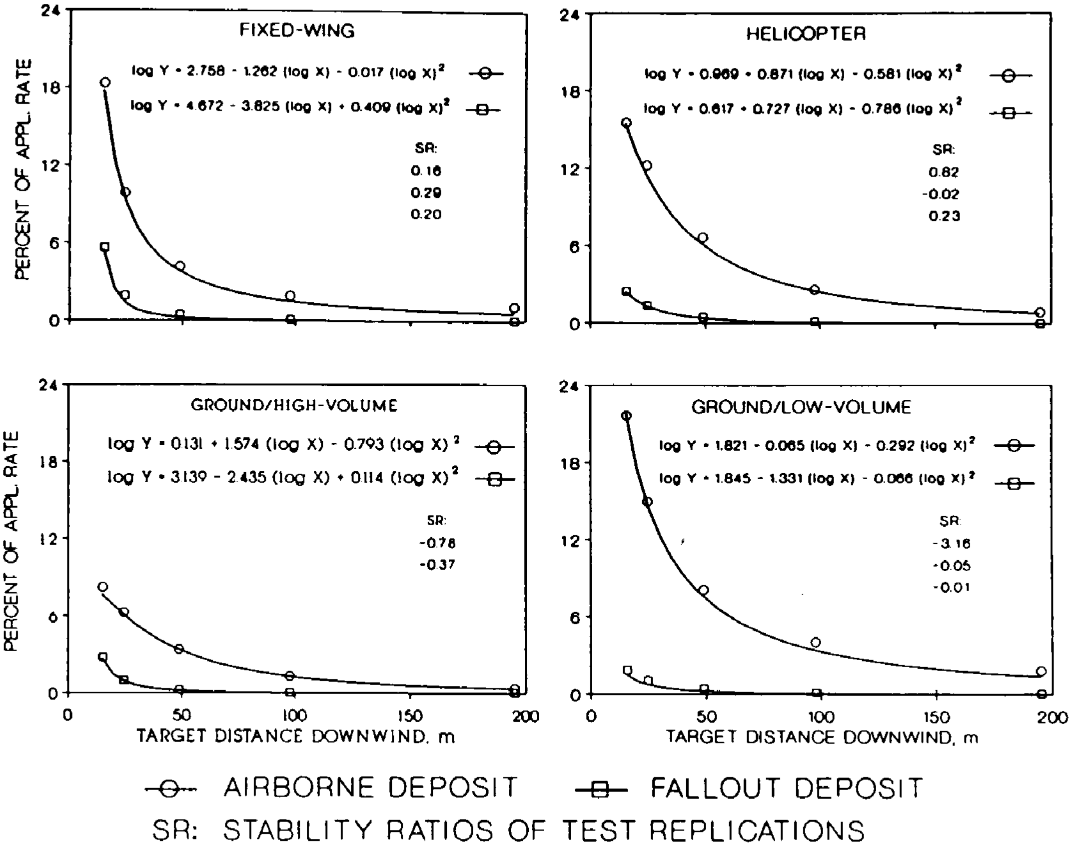

Figure 2–Mean drift deposits and regression lines for different equipment and under different microweather conditions.

(1969) who measured as much as six times more airborne deposits with an air carrier sprayer compared to an aerial application. The high-volume ground sprayer produced minimal deposits and appeared to be the least drift-prone among all the spray equipment in the test. However, the ratio of maximum/minimum mean deposits produced by different equipment did not exceed 2.4 and 2.6 for fallout and airborne deposits, respectively. The public perception that "aerial applications are the prime sources of drift" could not be verified here and all the equipment seemed to be capable of producing drift. The use of the same ground sprayer in both high- and low-volume applications indicated that droplet size (nozzle selection) is one factor that is related to spray drift. This is probably true with all types of sprayers and results could be different under different operational conditions. It should be noted that the test equipment were not necessarily used in their optimum application conditions; nevertheless, they represented typical Florida applications.

Figure 2 shows that the magnitude of airborne drift on filter papers is always higher than fallout deposits on mylar targets. Overall, filter paper captured 7.5 times more drift deposits than mylar targets. This is in agreement with the results of Yates et al. (1976) and Semmes et al. (1990) and could be attributed to the active suction of the drift cloud by the air samplers. However, there was a good correlation between mylar and filter deposits (Pearson Corr. Coeff. = 0.75, $p < 0.01$). The difference between deposits on pairs of mylar targets from the same sampling locations was not significant.

DRIFT FROM SPRAYING EACH TREE ROW

The collection of air sampler filter papers after spraying each tree row (or pair of rows) revealed that a great percentage of the airborne drift originated from spray applications to the last few tree rows (closest to the outside of the grove) downwind of the spray application. Figure 3 shows drift contributions of rows 1 & 2 and 3 & 4 from aerial applications. At the 15.2 m sample station, 84.5% of the fixed-wing (FW) drift deposits (including some swath displacement) and 79.4% of the helicopter's (HE) originated from rows 1 & 2. When rows 3 & 4 were sprayed, most of the displaced swath was apparently captured by the downwind rows 1 & 2; thereby, contributions of rows 3 & 4 became 15.5% (FW) and 20.6% (HE). However, smaller droplets could move to farther distances; and at the 48.8 m station, drift contributions of rows 1 & 2 were 60.1% (FW) and 58.4% (HE).

Figure 4 shows the drift data for ground applications. The columns corresponding to the row 1W represent drift deposits from spraying the west side of the row 1, where the spray clouds were directed against the wind direction. The columns of the 4E show deposits from spraying the east side of the row 4 where the spray clouds were discharged toward the sample stations. In two-sided spraying row middles (i.e., 1E & 2W, 2E & 3W, and 3E & 4W), one side of the sprayer discharged the spray cloud toward the sampling stations (W) and the other side in the opposite direction (E). Assuming that 60% of drift from rows 2E & 3W came from spraying the east side of the row 2 (2E), then cumulative deposits of the rows 1W, 1E & 2W, and 2E could provide an estimate of total drift from rows 1 & 2, comparable to that of rows 1 & 2 in aerial applications. At the 15.2 m sample station, 72.3% of the GH drift deposits (including some swath displacement) and 79.8% of the GL deposits originated from rows 1 & 2. However, at the 48.8 m station, 63.2% (GH) and 70.0% (GL) of the total drift could be attributed to the rows 1 & 2 applications. Deposits of rows 1 & 2, 2 & 3, and 3 & 4 show that, as the sprayer moved deeper inside the grove, the amount of drift out of the grove substantially decreased.

These data indicate that the last one or two rows of the grove, downwind of the spray applications, have the greatest contribution to off-target drift deposits (including swath displacement). This is in agreement with Riley and Wiesner (1990) who reported that more than 99% of drift deposits on the ground originated from an air-assisted ground spraying of the last five rows of an apple orchard. Therefore, it appears that treating the last few rows of a grove with less drift-prone equipment and weather conditions may be a feasible practice to minimize drift.

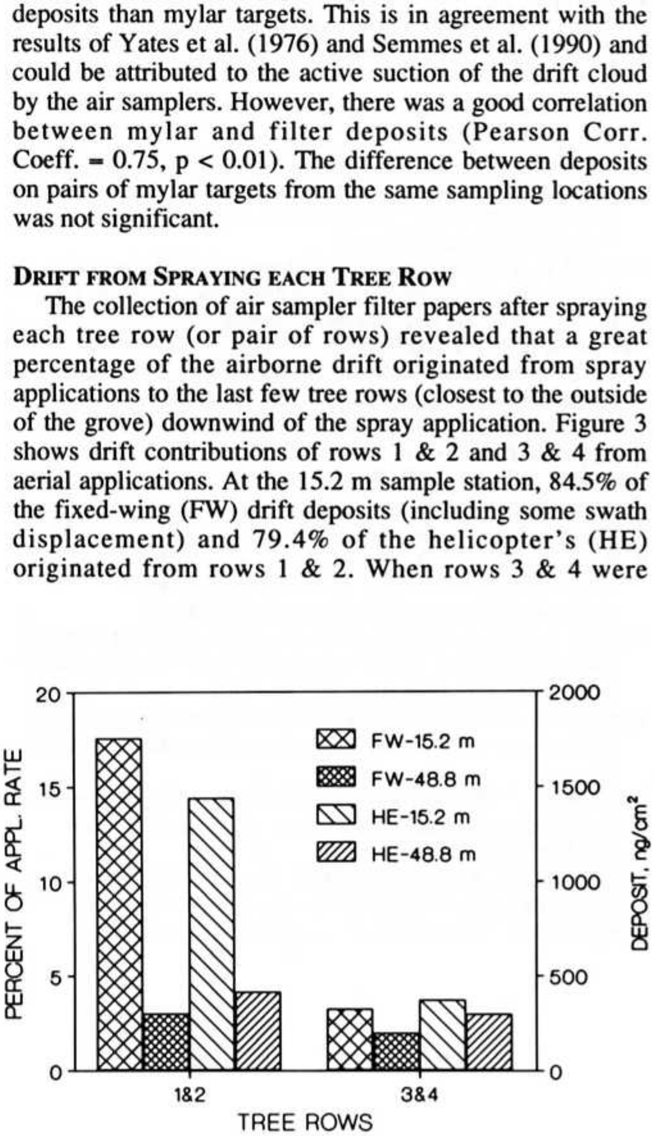

Figure 3–Airborne drift deposits resulting from spraying pairs of tree rows with fixed-wing (FW) and helicopter (HE) sprayers.

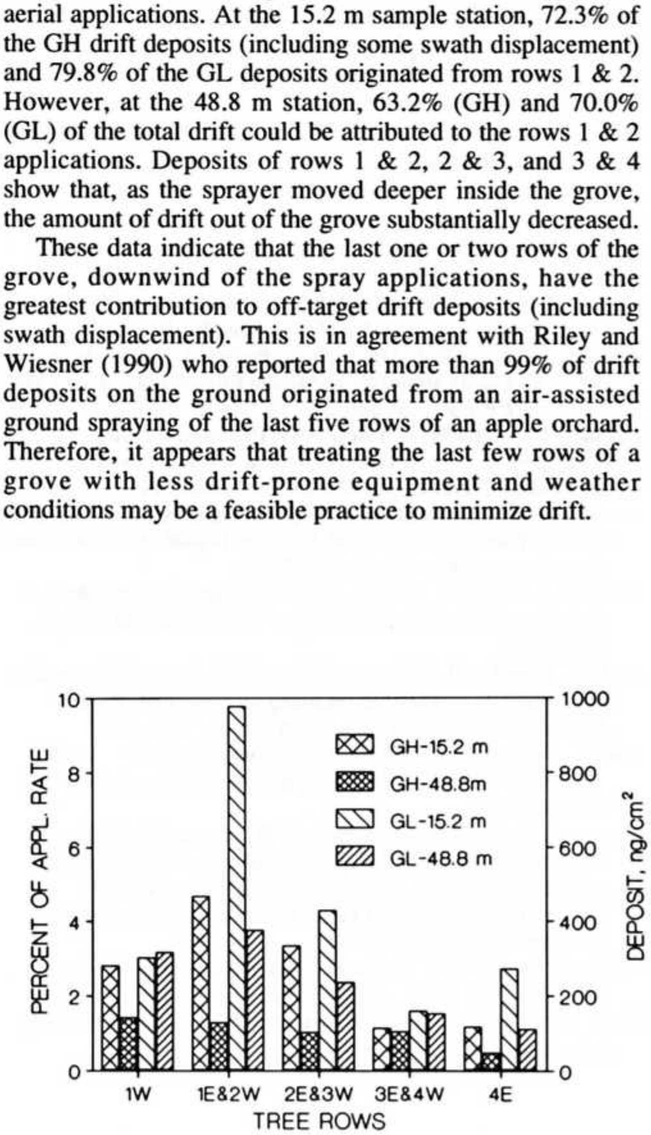

Figure 4–Airborne drift deposits resulting from spraying each tree row with high-volume (GH) and low-volume (GL) ground sprayers.