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DRIFT LOSSES FROM CITRUS SPRAY APPLICATIONS

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Abstract. **Two ground sprayers (high- and low-volume) and 2 aerial applicators (fixed- and rotary-wing aircraft) were used to quantify spray drift from typical citrus applications. Spray solutions, containing a fluorescent tracer dye, were applied to 4 tree rows on the edge of an orange grove in Martin County, Florida. Fallout and airborne drift deposits were measured at several locations downwind of the applications. All 4 types of spray equipment produced measurable amounts of off-target deposits (drift) as far as 195 m (640 ft) from the edge of the grove. More than 70% of the deposits originated from applications made to the last 2 rows. The fixed-wing aircraft and low-volume ground sprayer had the highest and lowest mean fallout deposits, respectively. However, the latter produced the maximum amount of airborne deposits. Minimum drift deposits were generated by the high-volume ground application. Nonetheless, the ratio of maximum/minimum mean deposits did not exceed 2.6/1 in the experiment.**

Florida citrus often requires several spray applications per year. Although ground sprayers have been predominant spray equipment (Whitney et al., 1978), both ground and aerial sprayers are currently used in citrus applications. However, the freezes of the 1980's have caused much of the new citrus plantings to be located in the east coast and south Florida where grove size and terrain are favorable for aerial applications. While the latter has shown comparable pest control results to ground applications (Bullock et al., 1977), it has been considered a prime source of spray drift and environmental contamination in agricultural applications. With rapid expansion of urban developments in Florida and proximity of residential areas to agricultural farms and groves, drift losses of agrochemicals have become more critical than ever. Shortage of drift data for Florida applications has developed conflicting perceptions about the safety of pesticide use in citrus operations.

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Therefore, a field experiment was conducted to collect spray drift data for typical ground and aerial sprays in Florida citrus applications. This paper is a concise version of an earlier report (Salyani and Cromwell, 1992) and provides drift information for commonly practiced spray applications.

Yates et al. (1966) found that as air stability (atmospheric stability ratio) increased, drift deposit from aerial application increased and the increase was more noticeable at farther sample locations. Ware et al. (1969) compared drifts of a mist blower ground sprayer and an aerial application. The ground sprayer showed about twice the fallout drift deposit as aircraft (on alfalfa, at 800 m downwind), and as much as 6 times more airborne insecticide (on air scrubbers, at 50 and 100 m). Bode and Md-Zain (1987) compared 4 atomizers and 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 volume median diameters (VMD) of droplets; but relative span and percent of droplets smaller than 220 µm were also important factors. Riley and Wiesner (1990) quantified drift from an air-assisted sprayer in an apple orchard. They reported that spray applications to the 5 rows closest to the downwind edge of the orchard cumulatively made up more than 99% of off-target deposits on the ground.

The objectives of the experiment were to: (a) quantify spray drift from typical ground and aerial applications in Florida citrus groves and (b) determine the contribution of spraying each tree row to the total drift under commonly practiced operational and meteorological conditions.

Materials and Methods

Test site and drift targets. The test was conducted in an orange grove south of Fort Pierce, Florida. The trees were 3.7-4.3 m (12-14 ft) high, set at 6.1 × 7.6 m (20 × 25 ft), with the rows oriented in the north-south direction. An irrigation canal extended along the northern side of the grove and the other 3 sides were surrounded by a cattle pasture. Only the last 4 tree rows at the west side of the grove were sprayed (Fig. 1). Having 66 trees per row, the total sprayed area was about 1.23 ha (3 acres). Downwind spray drift was sampled on 3 lines (N, C, and S) 140 m (460 ft) apart and perpendicular to the line of application (travel direction of the equipment (Fig. 2)). Sample stations (target locations) were at 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. Drift targets consisted of mylar plastic sheet and cellulose filter paper. Mylar targets (46 × 31 cm), stapled onto backing boards, were positioned horizontally on the ground for fallout deposit measurement. High-volume air samplers, positioned at 113 cm above ground, were used for airborne drift assessment. The air samplers used cellulose filter paper, with 8.9 cm exposed diameter and 0.5 m³/min air flow rate. Pairs of mylar targets (3-4 m apart)

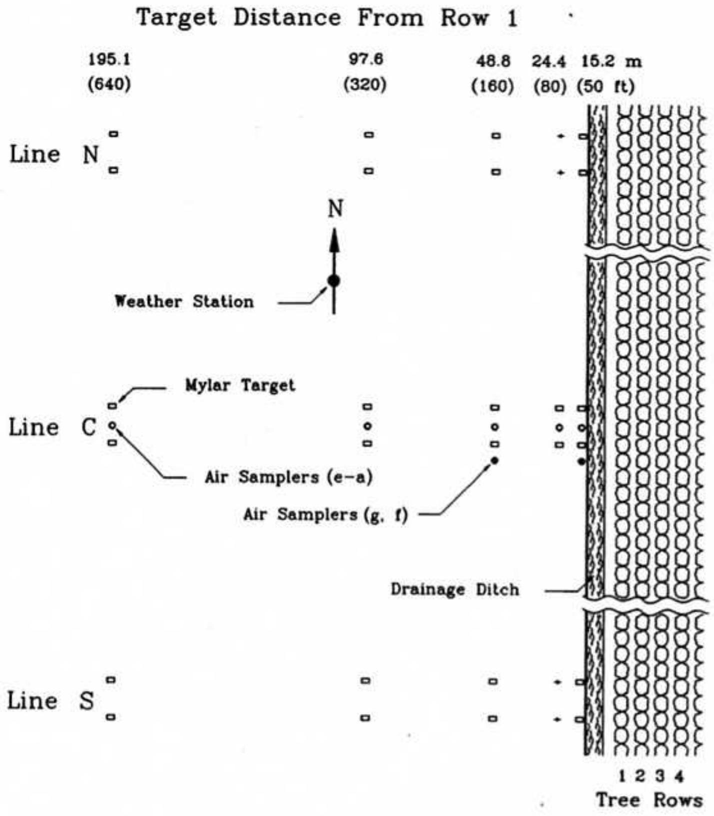

Figure 1. Schematic view of the test site and target locations.

Table 1. Spray equipment and application parameters.

Spray equipment	Atomizer type	No. of nozs.	Drop VMD µm	Spray rate liter/min	Spray press. kPa	Ground speed km/hr	Applic. rate liter/ha
Aircraft:							
Fixed-wing (FW) (Snow Air, AT-401)	Rotary (Micronair AU3000)	8	264	613	345	193	125
Helicopter (HE) (Hiller, UH 12E)	Disc/core (SS, D6-45/down	67	341	227	276	56	159
Ground sprayer:							
High-volume (GH) (Southwind 836 SS)	Disc/core (FMC, 5/3, 6/3, 7/3)	20	—[z]	168	1103[y]	2.6	5083
Low-volume (GL) (Southwind 836 SS)	Disc/core (FMC, 3/2, 3/3)	20	—	38	1103	4.4	674

[z] FMC 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.

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

were placed at all sample locations (except at 24.4 m on lines N and S). Air samplers were used on line C between mylar target pairs (a-e). Two additional air samplers (f, g) were placed at 15.2 and 48.8 m sample locations to determine drift contribution from each row application.

Spray treatments. The 4 tree rows were sprayed with spray solutions containing a fluorescent tracer dye (BASO Red NB 546) using both aerial and ground sprayers. The spray equipment (treatments) consisted of a fixed-wing aircraft (FW), a helicopter (HE), and a PTO-driven ground sprayer which was used as a high-volume (GH) and low-volume (GL) sprayer. More detailed information about the equipment and corresponding application parameters are shown in Table 1.

The ground sprayers (GH or GL) started with one-sided spraying the west side of the row 1 (1W) then sprayed middles of rows 1 and 2 (1E+2W), 2 and 3 (2E+3W), 3 and 4 (3E+4W), and finally one-sided spraying the east side of row 4 (4E) for each replication (Fig. 2). The aerial sprayers (FW and HE) had a swath width of 15.2 m (50 ft) and sprayed 2 rows in 1 pass (Fig. 2). The FW made 4 passes over each pair of rows to complete 1 replication. The HE had a smaller tank size; therefore, it made 2 passes over each pair of rows for each replication. The reason for multiple passes of aerial equipment was to generate drift clouds for longer periods of time and obtain more representative samples; however, the total amount of the discharged dye was kept the same as ground applications. Each machine sprayed 3 replications; however, due to a problem with nozzle pressure adjustments, 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 filters (a-e, Fig. 1) were uncovered before the start of each 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 aerial equipment. The collection and renewal of the filter papers were continued until a replication was completed. The pairs of mylar targets (at each 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. Details of the fluorometry, including a procedure for cor-

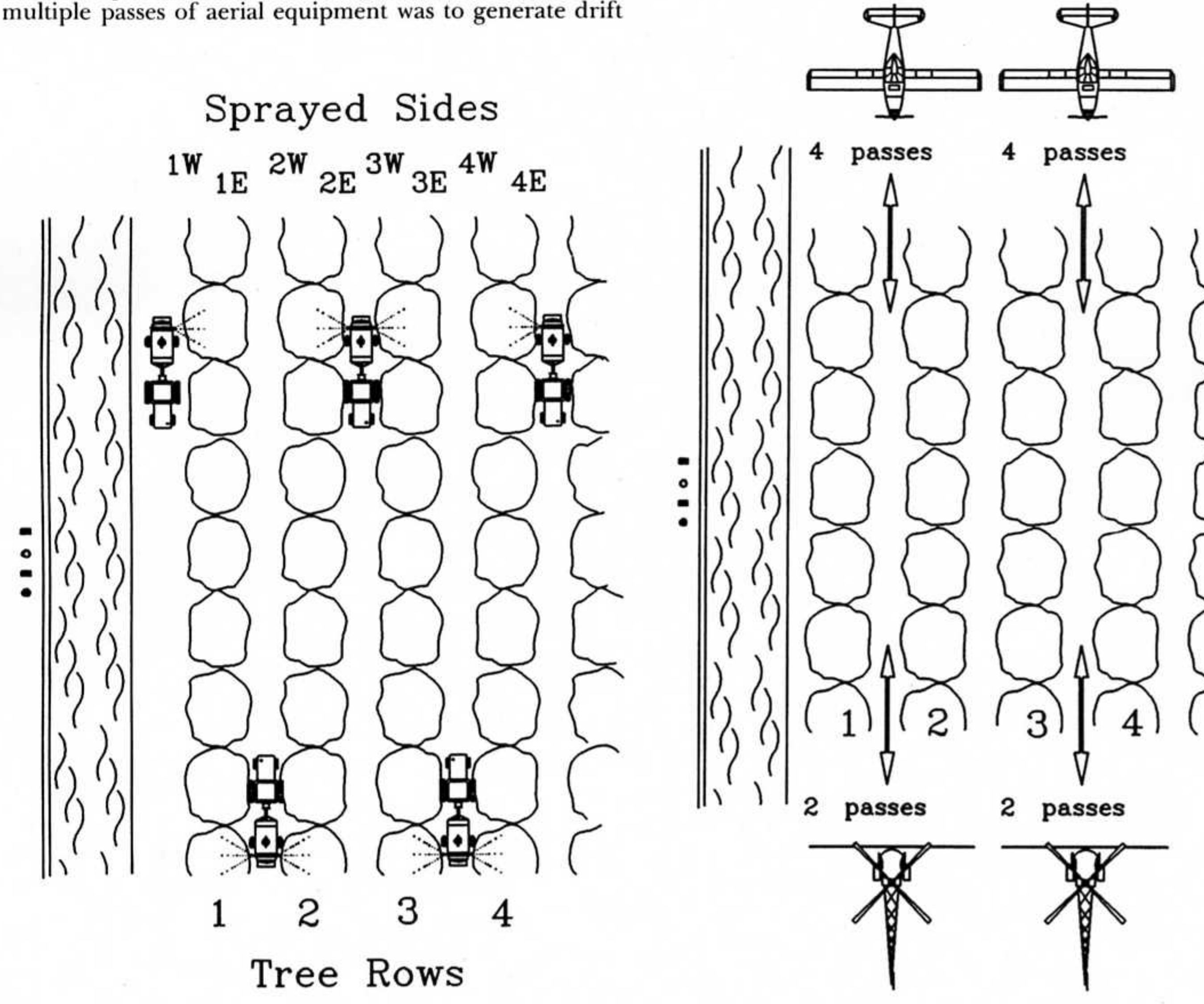

Figure 2. Directions of equipment travel in ground and aerial applications.

recting the deposits for fluorescence degradation (due to sunlight exposure), are given in the original paper (Salyani and Cromwell, 1992). Weather data including air temperature, relative humidity, wind velocity, wind direction, and atmospheric stability ratio are shown in Table 2.

Data analyses. The data from all equipment were normalized to a tracer application rate of 1,000 g/ha (10,000 ng/cm^2) and corrected for difference in wind directions. Several SAS procedures (SAS, 1985) were used to analyze the data and make comparisons between equipment, targets, and sample locations. The significance of effects were expressed at the 95% confidence level. More detailed information is provided in Salyani and Cromwell (1992).

Results and Discussion

Drift deposits. Table 3 shows fallout and airborne drift deposits at downwind sampling stations. 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 precisely 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 not be entirely legitimate. 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.

Apart from meteorological effects, both target distance downwind and spray equipment had significant effects on depositions. The amount of drift deposits decreased as target distance downwind increased (Fig. 3). Both filter (airborne) and mylar (fallout) deposits at the first 3 downwind stations were significantly different; however, deposits at the 2 farthest stations were not different. The curves of Fig. 3 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. Mean fallout and airborne deposits of each equipment are shown in Fig. 4. The highest mean fallout deposit on mylar targets (160.2 ng/cm^2) resulted from fixed-wing aircraft applications. Mean fallout deposits of the helicopter, high-volume ground sprayer, and low-volume ground sprayer were significantly less than FW's (85.6, 79.6, and 67.6, respectively) but not significantly different among themselves. 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 GL's and the GH had a significantly lowest deposit of 391.9 ng/cm^2.

Table 2. Weather conditions during the spray applications.

		Temp.			Wind[y]	Wind[x]	
Spray equip.	Rep.	Avg. °C	TD[z] °C	Rel. hum. %	vel. avg. m/sec	dir. avg. deg.	SR[w] °C/(m/sec)^2
FW	1	28.4	0.26	51	4.07	82	0.16 (S)
FW	2	26.7	0.39	56	3.65	97	0.29 (S)
FW	3	26.5	0.27	56	3.63	97	0.20 (S)
HE	1	27.0	0.52	53	2.51	78	0.82 (S)
HE	2	27.3	–0.04	56	4.41	103	–0.02 (N)
HE	3	27.0	0.43	56	4.33	95	0.23 (S)
GH	2	26.3	–2.01	68	5.09	129	–0.78 (U)
GH	3	28.7	–0.98	51	5.61	137	–0.37 (U)
GL	1	26.3	–2.06	59	2.55	132	–3.16 (U)
GL	2	29.5	–0.13	52	5.11	1.50	–0.05 (N)
GL	3	29.5	–0.02	52	4.53	152	–0.01 (N)

[z] Temperature difference $(T_2–T_1)$ recorded at 3.0 m (T_1) and 9.1 m (T_2).

[y] Average wind velocity (AWV) measured at 9.1 m; (m/sec) × 2.237 = (mph).

[x] Average wind direction measured clockwise from North ° 0°.

[w] Stability Ratio (SR) = 10 $(T_2–T_1)$ / $(AWV)^2$. Letters in parentheses refer to atmospheric conditions: stable (S), neutral (N), and unstable (U).

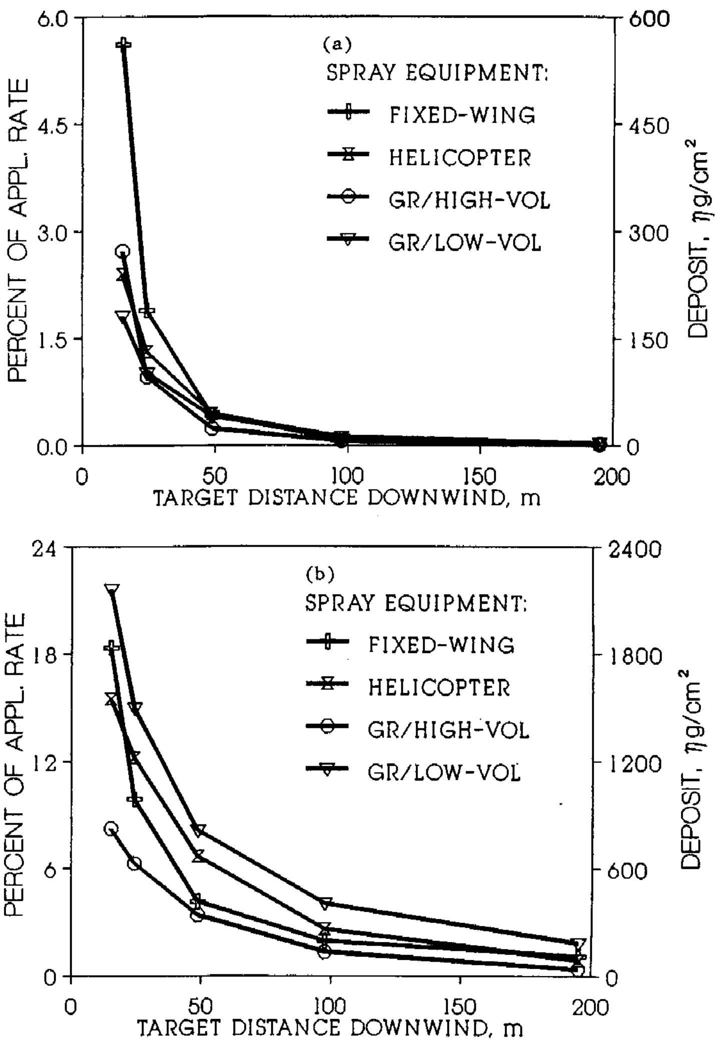

Figure 3. Off-target (drift) deposits in downwind sample stations: a) fallout, b) airborne.

The difference in the settling of the fallout and airborne deposits may be attributed primarily to the size and

Table 3. Fallout and airborne drift deposits for different equipment, ng/cm².

		Weather			Target distance downwind, m									
Spray[z] equip.	Rep.	AWV m/sec	AWD deg.	SR °C/(m/sec)²	5.2	24.4	48.8	97.6	195.1	15.2	24.4	48.8	97.6	195.1
FW	1	4.07	82	0.16 (S)	327	51	5	0.9	0.3	1235	708	235	56	10
	2	3.65	97	0.29 (S)	513	158	31	6.7	1.6	1593	822	355	179	106
	3	3.63	97	0.20 (S)	841	359	88	18.0	3.1	2670	1434	652	345	213
HE	1	2.51	78	0.82 (S)	251	100	21	3.4	0.4	1834	1772	997	300	48
	2	4.41	103	−0.02 (N)	200	134	52	13.2	2.2	1496	1165	669	308	113
	3	4.33	95	0.23 (S)	270	160	58	16.1	3.3	1316	727	335	174	102
GH	2	5.09	129	−0.78 (U)	191	92	28	7.1	1.6	519	499	314	122	29
	3	5.16	137	−0.37 (U)	354	99	18	4.3	1.3	1126	756	362	145	49
GL	1	2.55	132	−3.16 (U)	64	20	6	2.4	1.7	2029	1114	423	145	45
	2	5.11	150	−0.05 (N)	308	141	42	11.8	3.1	2363	1710	934	439	177
	3	4.53	152	−0.01 (N)	172	144	73	22.4	4.2	2095	1665	1080	626	325

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

[y] See Table 2 for complete weather data. AWV = average wind velocity, AWD = average wind direction, and SR = stability ratio. Atmospheric conditions: stable (S), neutral (N), and unstable (U).

size range of spray droplets (Akesson and Yates, 1981). The data suggest 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. (1969) who measured as much as 6 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 (Fig. 4) did not exceed 2.4 and 2.6 for fallout and airborne deposits, respectively. A 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.

Fig. 4 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 in aerial applications) revealed that a greater percentage of the airborne drift originated from spray applications to the tree rows closest to the outside of the grove (downwind of the spray application). Fig. 5 shows drift contributions of rows 1+2 and 3+4 in aerial applications. At the 15.2 m sample station, 84.5% of the fixed-wing drift deposits (including some swath displacement) and 79.4% of the helicopter's originated from rows 1+2. When rows 3+4 were sprayed, most of the displaced swath was appar-

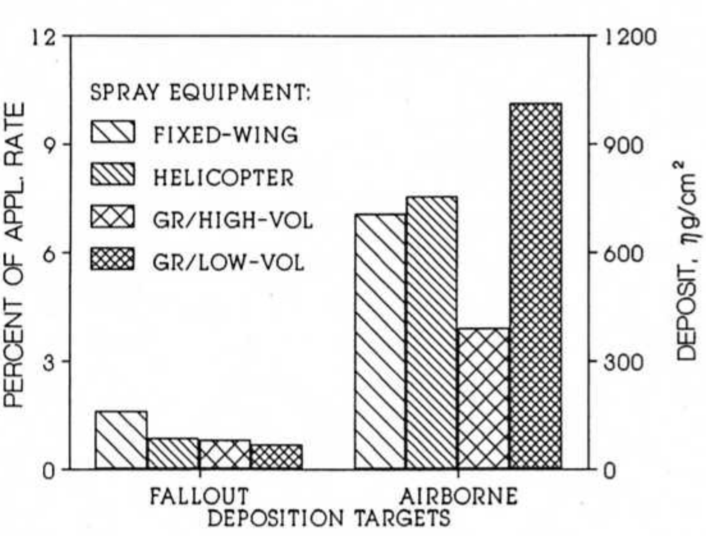

Figure 4. Mean fallout and airborne deposits from 4 equipment.

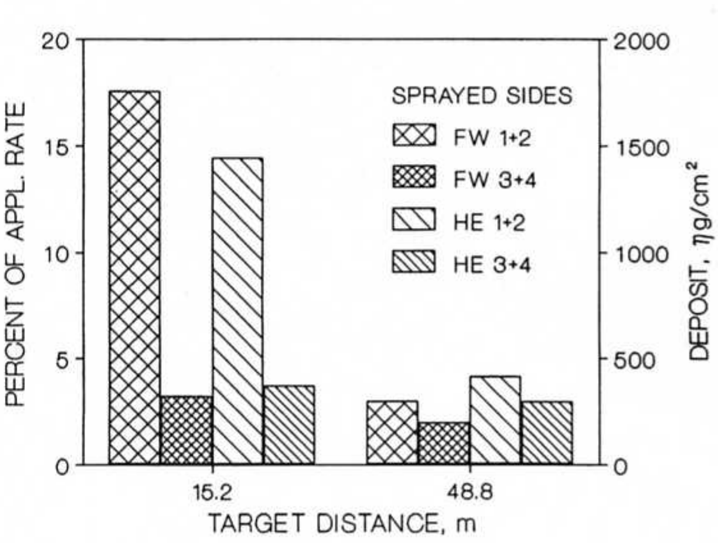

Figure 5. Airborne drift deposits resulting from spraying pairs of tree rows with the fixed-wing (FW) and helicopter (HE) sprayers.