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DEPOSITION OF SPRAY MATERIAL ON CITRUS FRUIT AND FOLIAGE BY AIR AND GROUND APPLICATION[1]

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Abstract. **Deposition of spray material containing a tracer dye was evaluated on leaf and fruit surfaces of citrus trees. Spray applications were made by a Bell UH1B Huey helicopter and a conventional PTO driven, trailered air carrier (air blast) ground sprayer in 1993; and in 1994 by a Bell UH1B Huey helicopter, and 3 ground sprayers, a PTO driven FMC 452 series air blast sprayer, a diesel engine driven FMC 937 CPD series air blast sprayer, and a Curtec Air Curtain sprayer. Spray volumes from helicopter and Curtec sprayers were 20% to 25% the volumes sprayed by the air blast sprayers. Water soluble dye, "Brilliant Blue" was washed from leaf and fruit surfaces (1993) or eluted from paper targets (1994) and the solutions analyzed for optical density in a spectrophotometer. The helicopter tended to deposit more spray material in the top canopy while the air blast sprayers favored the bottom and middle canopy and the Curtec sprayed uniformly over canopy heights. The dye tracer coupled with stick-on paper targets, provided a convenient means of assessing deposition to particular regions of the fruit or leaf surface. Surfaces of leaves and fruit oriented toward the sprayers tended to receive the preponderance of spray material, especially those closest to the spray outlet. Coverage was more uniform at greater distance from or out of the direct line of air source. It was concluded that greater turbulence was probably responsible for the more uniform spray coverage observed at increasing distance from the sprayers.**

The efficacy of protectant and contact pesticides is only as good as the uniformity of spray coverage achieved in application. Inconsistent application can leave fruit and leaf surfaces unprotected and subject to injury by pests and pathogens. Adequate coverage of the lower leaf surface is especially critical for control of greasy spot disease caused by the fungus *Mycosphaerella citri* Whiteside (Whiteside, 1972). Blemish-causing pests such as citrus rust mite and diseases such as melanose and scab require all surfaces to be covered to avoid grade-out.

Current technology for ground sprayers in Florida citrus employs a high volume, fan generated air carrier to force spray material through the tree canopy. Fixed wing or helicopter sprayers are also employed, although less commonly. Visual judgement, the usual method of evaluating deposition patterns, is rapid and adequate for discerning general patterns of spray coverage, but may not reveal subtler effects. Salyani and Whitney (1988) evaluated quantitative methodologies of assessing of spray deposition in citrus including the use of copper and fluorescent tracers and leaf or mylar targets. Targets were placed at different locations within the canopy and tracers were washed from the leafs and quantified with a colorimeter or fluorometer respectively. Area of the mylar targets was known and area of the leaves determined with an area meter so that results could be expressed in µ active ingredient/cm^2 surface area. The authors concluded that analysis of copper deposition on leaves was a convenient method that provided a realistic picture of spray distribution. The method was later refined to evaluate each leaf surface separately by taping the top surface for an initial wash, then removing the tape, washing it and the leaf separately to recover copper from the top surface (Whitney et al., 1989). However, citrus leaves may contain residues of copper which is commonly used in Florida citrus to control fungal disease, and deposition on fruit was not evaluated. We used a blue tracer dye (Carleton 1992) with spectral characteristics distinct from any spray materials normally applied to citrus, and employed stick-on paper targets in 1994 to evaluate deposition on particular regions of leaf and fruit surfaces sprayed by air and ground equipment.

Materials and Methods

1993 Trial Site. The trial was conducted in a 10 acre portion of a mature (10-year-old) producing commercial grove of 'Pineapple' sweet orange (Citrus sinensis, Osbeck) on Carrizo citrange (*C. sinensis* × *Poncirus trifoliata*) rootstock, planted on north-south oriented two-row beds with a tree spacing of 15 × 26 feet in row and between rows, respectively. Uniform test trees (3 for each of 4 replicates) were randomly chosen from seven contiguous interior rows. Canopy size was determined by canopy volume measurements to assure general tree size uniformity. Selected trees formed part of a hedge row and were not adjacent to smaller trees or unplanted tree spaces. Only trees from the interior of each row and in most cases not contiguous to other test trees were selected.

Spray Equipment & Mixtures. Aerial applications were made using a Vietnam era Bell UH1B Huey helicopter with no modifications except for the spray system. The spray boom extended 20 feet on either side of the helicopter with 46 nozzles on the right side and 47 on the left plus a 10 foot section under the belly with 24 nozzles. Nozzles were #D5-45 disc type operated at 60 psi. Spray application by ground was with a conventional PTO driven trailered air carrier (air blast) grove sprayer equipped with a 1,000 gallon tank and powered by a 70 horsepower tractor. Spray nozzles were arranged by size from top to bottom of the manifold in order

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as #3, #5, #5, #5, #4, #4, #4, #3, #3 mated with a 2-hole whirl plate. The pressure gauge reading during application was 160 psi. Trees in the north 5 acres were sprayed by a Huey helicopter traveling directly above the tree tops of alternate rows and trees in the south 5 acres were sprayed by a ground sprayer traveling every row.

The spray deposition tracer used was "Brilliant Blue" (FD&C #1 blue dye Warner-Jenkinson, 2526 Baldwin Street, St. Louis, Mo. 63106). Preliminary tests had determined that a dye concentration of 1200 ppm was sufficient to insure spectrometric detection of dye even when leaf or fruit coverage was minimal. Spray application rates simulated those in commercial practice of approximately 20 gal/acre for helicopter and 130 gal/acre for ground application. Spray concentrations were calculated based on output to give the same rate per acre of dye.

The helicopter tank had been pre-loaded by company employees at their site of operations with 79 gallons of water and 21 gallons of 435-66 citrus spray oil. At the grove site 2,783 grams of dye was pre-mixed with water and then added to the spray tank to provide material for 4.25 ac @ 654 g ai/ac. The helicopter sprayed it's designated area at 20 mph making four south to north passes over alternate rows. Each pass was timed and the actual mean spray rate/acre determined for comparison to the expected 23.5 gallons/acre. The residual mix was drained and a sample retained for later analysis.

The ground sprayer tank mix contained 250 gallons of water metered into the tank at SWFREC, 10 gallons of the same 435-66 citrus spray oil and 1,309 grams of pre-mixed dye to cover 2 ac at 654 g ai/ac. The ground sprayer speed was 1.5 mph. Each pass was timed and the actual spray rate/acre compared to the expected 130 gallons/acre. After application, the remaining mix was drained from the tank and a sample retained for later analysis.

Sample collection and processing. Leaf and fruit samples were collected into plastic zip-lock bags the day of spray application as soon as plant material was dry enough to prevent dye loss from handling. Each tree was represented by 48 leaf samples containing 3 leaves each and 12 fruit samples containing 2 fruit each. Leaves were selected at random from 4 canopy locations by azimuth (North, South, East, West), 3 heights above ground (high, medium, low) at each azimuth, and from 2 depths within the canopy (outer, inner) at each azimuth and height. Six leaves, three for upper surface coverage and three for lower surface coverage, were collected from each position. Two fruit were collected from each azimuth and height.

Leaves surface areas (cm^2) were determined using a Li-Cor LI-3000A portable area meter fitted with a LI-3050A belt conveyer (Li-Cor Inc., 4421 Superior Street, P.O. Box 4425, Lincoln NE, 68504-0425). After leaf area determinations, each leaf was sealed on one side with 3M Scotch brand transparent Premium Commercial Grade Box Sealing Tape (product # 3750), and excess tape cut from the leaf perimeter.

Dye deposit was washed from the untaped leaf surface using 10 ml distilled water for each 3-leaf sample. Wash solution was collected in a labeled vial, sealed and refrigerated. Surface area for the fruit was determined by calculation ($A=4*3.14r^2$) based on the mean diameter obtained by two perpendicular measurements with calipers. Fruit were washed in 20 ml distilled water using the same procedure as leaves. Vials containing washings from fruit were refrigerated until all fruit and leaves had been processed.

The optical density of contents of each vial at 629 nm was determined as a measurement of dye concentration using a Perkin Elmer Lambda 8 UV/VIS spectrophotometer linked to an IBM PC computer. Spray coverage of dye deposition in micrograms per square centimeter ($\mu g/cm^2$) of surface area for each leaf and fruit sample was determined.

Analysis was performed on the recovered helicopter and ground sprayer tank mixtures and from laboratory prepared similar or "mock" mixtures of the helicopter and ground sprayer tank mixes prepared in the exact proportions used in the field trial. These were then agitated and observed as they settled. Equal amounts of the recovered tank samples and the prepared "mock" samples were centrifuged. Samples of all four mixes were sent to Dr. George Snyder at the IFAS Research and Education Center, Belle Glade. Portions of each sample were put in test tubes containing chloroform and water. Mix components not in solution could also be identified with this procedure.

Data were subjected to statistical analysis using the SAS program (SAS Institute, 1988). Data was analyzed by the General Linear Models (GLM) procedure with means separation by least significant difference (LSD).

1994 Trial Site. The trial was conducted in four, 10 acre blocks of a mature, producing, commercial grove. Blocks 1 and 2 (Replicates 1 and 2, respectively) were 'Hamlin' sweet orange (Citrus sinensis, Osbeck) on Carrizo citrange (*C. sinensis* × *Poncirus trifoliata*) rootstock. Tree heights were about 18 feet. Blocks 3 and 4 (Replicates 3 and 4, respectively) were 'Duncan' grapefruit (*C. paradisi*, Macf.) on Carrizo citrange rootstock. The grove was planted in north-south oriented single row beds with tree spacing of 15 × 24 feet in row and between rows, respectively. Uniform test trees were randomly chosen from each section. Trees had been topped at 14 ft. Selected trees to be sprayed (plots) formed part of the hedge row and were not adjacent to smaller trees or unplanted tree spaces. Twelve trees per plot were sprayed by the ground sprayers, two of which were sample trees located near the center of the 12-tree plot. Helicopter-sprayed plots were 5-rows wide and 30 trees long in row. Spraying was done by ground rigs passing by each side of the trees in each plot, with both spray manifolds (left and right) spraying (with the exception of the Curtec which sprayed one side only). The helicopter flew above tree tops on rows 1, 3, and 5.

Spray equipment and mixtures. A Bell UH1B Huey helicopter was used again for aerial application. Three ground sprayers were also tested: a PTO driven FMC 452 series ground sprayer pulled by a 77 hp Ford 7710 tractor at 1900 RPM (540 RPM PTO speed), a Diesel engine driven FMC 937 CPD series ground sprayer pulled by a Ford 6610 tractor, and a Curtec Air Curtain ground sprayer equipped with a single-sided tower sprayer with 4 cross-flow fans and one rotary atomizer per fan. Each sprayer was calibrated using water on 29 Nov. 94 (Table 1). Tank mixtures for each sprayer used in the test were made at the test site in Turner Foods Highland Grove on 30 Nov.94 (Table 2).

Sample collection and processing. White microscope slide stickers (Shamrock Labels, Fisher Scientific #11-885) were used as targets to measure dye deposition. Targets were placed on out-

Table 1. Pre-test Sprayer Calibrations for speed, pressure and spray volume, 1994.

Sprayer	Speed (mph)	Pressure (psi)	GPA
Diesel engine driven FMC 937 CPD	1.40	150	100
PTO driven FMC 450	1.41	200	90
Bell UH1B Huey helicopter	20.7	43	20
Curtec	3.40	—[z]	31.4

[z]The sprayer utilized a low pressure rotary atomizer and was not equipped with a pressure gage.

side (away from the tree trunk) and inside (toward the tree trunk) surfaces of fruit and on upper(adaxial) and lower (abaxial) surfaces of leaves. Targets were placed on two fruit and two leaves in the east-top, east-bottom, west-top, and west-bottom positions of the canopies of all test trees. On the hedgerow side, targets were placed on leaves only in the north-top and north-bottom positions in the canopy of the tree. There were a total of 40 targets per tree with two sample test trees per plot. Spray was allowed to dry and targets were removed with tweezers. Four targets (2 per tree at each position) were placed into labeled 20 ml polyetheylene vials.

Table 2. Tank mixtures used in 1994 spray test.

Sprayer	GPA	Mixture for X acres	Total Mix (gal)	Citrus Spray Oil (gal)	lb ai dye[z]	Water (gal)
FMC 937 CPD	100	1	100	5	1	92
FMC 450 PTO	90	1	90	5	1	82
Curtec	31.4	2	62.8	10	2	46.8
Huey	20.3	5	101.3	25	5	65.3

[z]Added as solution of .33 lb ai/gal dye to ground sprayers. Helicopter received 3 gal of .33 lb ai/gal mixture and 8 gal of a .5 lb ai/gal mixture.

Number of targets in each sample vials was verified and 10 ml of water was added to each vial. Vials were then shaken for approximately 3 hours on a Eberbach (Ann Arbor, Mich.) soil shaker. The concentration in ppm of the dye solution in each sample bottle was determined by comparison to a set of standards using the Lambda 6 UV/VIS Spectrophotometer. Samples which exceeded the range of the spectrophotometer were diluted (2:1) and then reprocessed. Dye concentration in ppm was converted to μg/cm², taking into account the number (total surface area) of targets in each sample vial and dilution factors, including actual spray volumes applied.

Data Analysis. Data were subjected to analysis of variance using the General Linear Models procedure with mean separation by Fisher's protected least significant difference test (SAS Institute, 1988).

Results

1993 Trial. The actual rate of spray applied by the helicopter was 23.6 gallons per acre (GPA), only 0.1 GPA more than expected from the pre-calibration. The actual applied rate from the

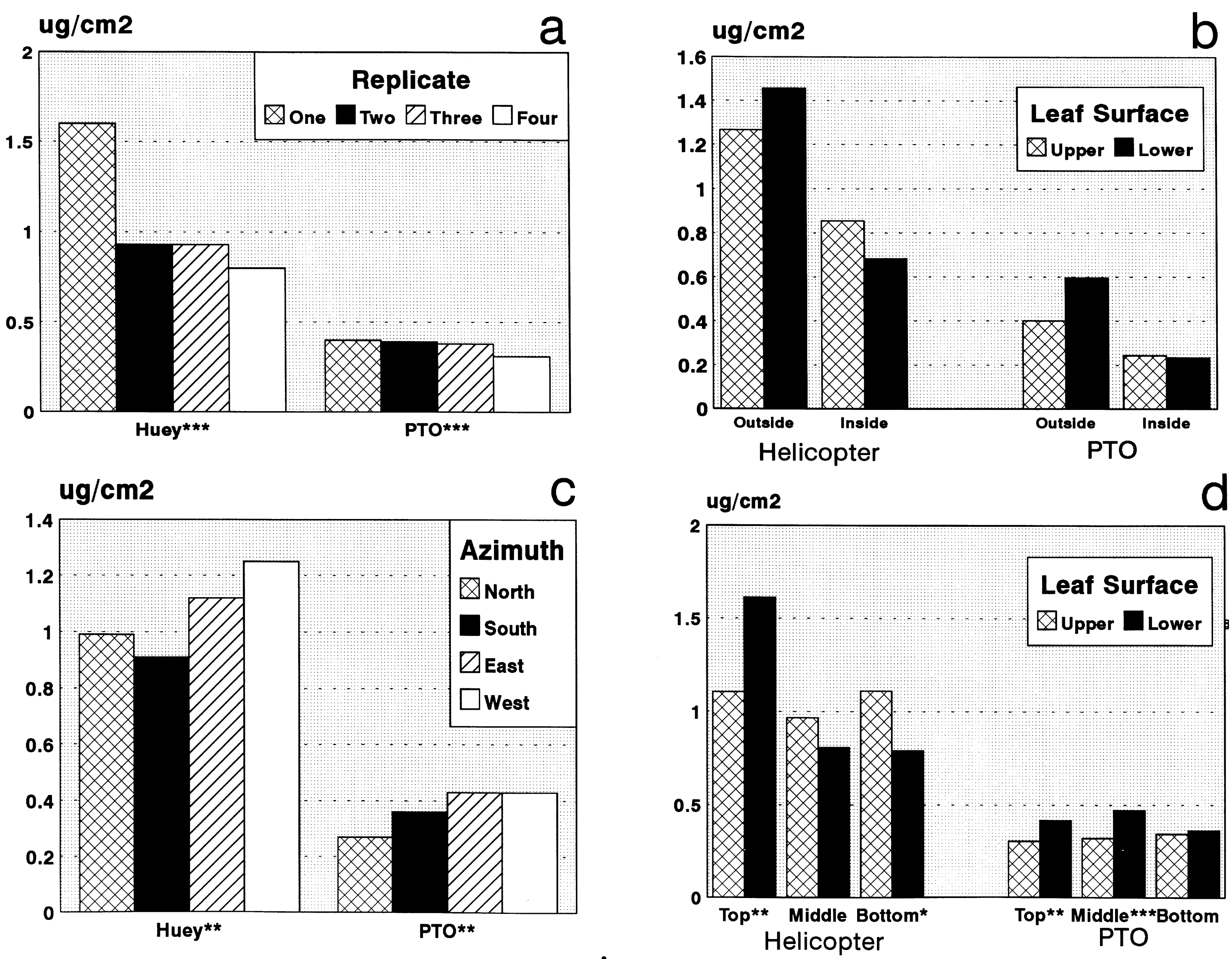

Figure 1. Deposition of brilliant blue dye on sprayed leaves (1993).

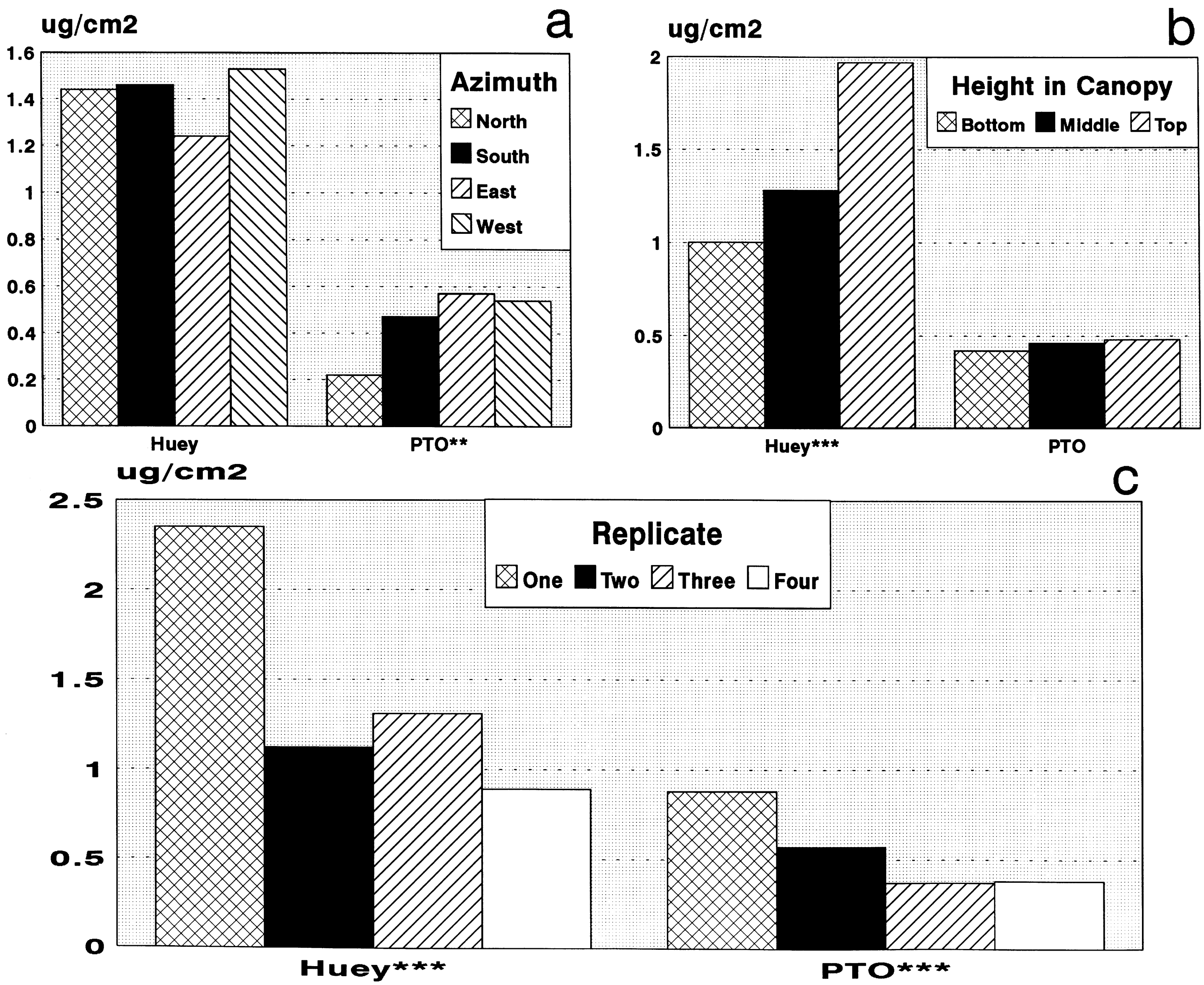

Figure 2. Deposition of brilliant blue dye on sprayed fruit (1993).

ground sprayer was 119 GPA, 11 gallons less than the pre-calculated 130 GPA.

It was observed in the laboratory that the ground sprayer tank mix separated rapidly into a thin layer of foam and oil over the aqueous phase containing the dye leaving no coating on the side of the flask. In contrast, the solution from the helicopter remained emulsified for days, and coated the sides of the flask. When the tank mixtures were reproduced in the laboratory, both separated immediately into a thin layer of oil and foam over the dye-water solution, neither coating the flask as had the helicopter's tank mix. Centrifugation separated the mixture from the helicopter spray tank into an aqueous phase on the bottom, covered with an oil phase topped by a stable foam on top. When actual and reproduced spray mixtures were combined with chloroform and agitated, all but the actual helicopter mix separated into two distinct phases. However the sample drained from the helicopter emulsified the chloroform into one uniform phase that did not separate after two days. It was concluded that the helicopter mixture contained an extra surfactant causing emulsification of the chloroform and water. Spray company representatives were certain that no surfactants had been added, but that the tank may have contained residues of an adjuvant, Poly Control 2® (JLB International Chemical Inc.) containing 30% polyacrylamide copolymer plus other ingredients, routinely used by them to control spray drift. The product also serves as a spreader sticker at low rates (1-3 ml/gal). Addition of small amounts of Poly Control to the reproduced helicopter mix did indeed look and act like the actual mix. It was also observed

Table 3. Volume of spray material applied in 1994 test.

Sprayer	Volume Sprayed (gal)	Area Sprayed (ac)	GPA
FMC 937 CPD	73	0.716	102
FMC 450,PTO	68	0.706	96.3
Helicopter	97.25	4.37	22.25
Curtec	9.3	0.386	24.1

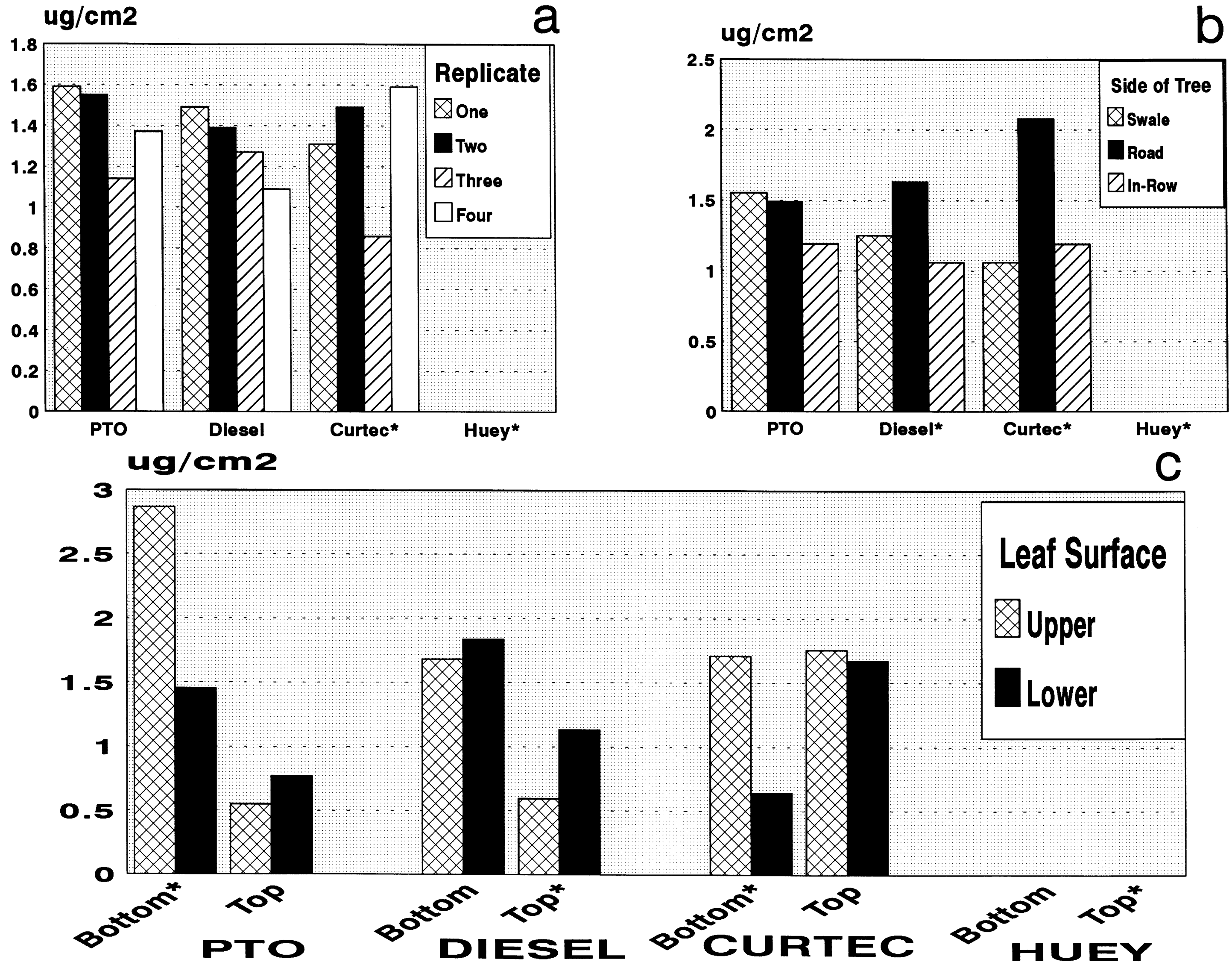

Figure 3. Deposition of brilliant blue dye on sprayed leaves (1994).

that Poly Control 2 tended to polymerize into an amorphous mass upon addition of water so that the residue explanation was feasible.

Mean recovery of dye for all sample positions was 1.07 and 0.37 µg/cm^2 of leaf surface and 1.42 µg/cm^2 and 0.45 µg/cm^2 of fruit surface for the helicopter + adjuvant and ground sprayer, respectively. The degree to which the adjuvant increased the amount of spray deposition on leaves and fruit sprayed by the helicopter, presumably by decreasing runoff, cannot be determined from the data. However, the thrust of our analyses deals with uniformity of coverage rather than total amounts of material deposited.

Differences among replicates in dye recovered for both leaves and fruit were highly significant for both helicopter and ground sprayer. For some reason, most dye was recovered in replicate one from fruit and leaves sprayed by helicopter and from fruit sprayed by ground. Less dye was recovered from leaves on both in-row sides of trees sprayed with the helicopter and from both fruit and leaves on the north side of trees sprayed with the ground rig (Fig. 1c, 2a). The Huey helicopter deposited more dye on fruit in the upper canopy and least on the lower canopy, while application to fruit by the ground rig was uniform over heights (Fig. 2b). Leaves in the outer canopy sprayed by both helicopter with adjuvant had 1.7 times more material than leaves in the inner canopy compared to 3.2 times more material in the outer canopy sprayed with the ground sprayer. The helicopter deposited more dye on the underside of leaves in the top canopy and the upper side of leaves in the bottom canopy (Fig. 1d). In contrast, the ground sprayer deposited more on the undersides of leaves in the top and mid-canopy and uniformly over both surfaces in the bottom canopy. These differences in deposition between leaf surfaces were notable in the outer canopy only; there were no significant differences between leaf surfaces in the inner canopy (Fig. 1c).

1994 Trial. Volumes sprayed per acre were again close to pretest calibration levels (Table 3). The helicopter spray company requested prior to sample collection that data from the helicopter sprayer not be included in the report based on their determination that the application had been made incorrectly. Therefore, this data is not given although it will be considered in the discussion of deposition uniformity.

Both FMC air blast sprayers deposited spray material uniformly among replicates on both leaves and fruit, in contrast to the Curtec and the Huey which varied significantly among replicates (Figs. 3a, 4a). In the case of the helicopter, variation in deposition among replicates was related to variation in ground speed. Deposition on fruit by the air blast sprayers and the helicopter was uniform between swale and row-middle sides but the Curtec deposited more on fruit

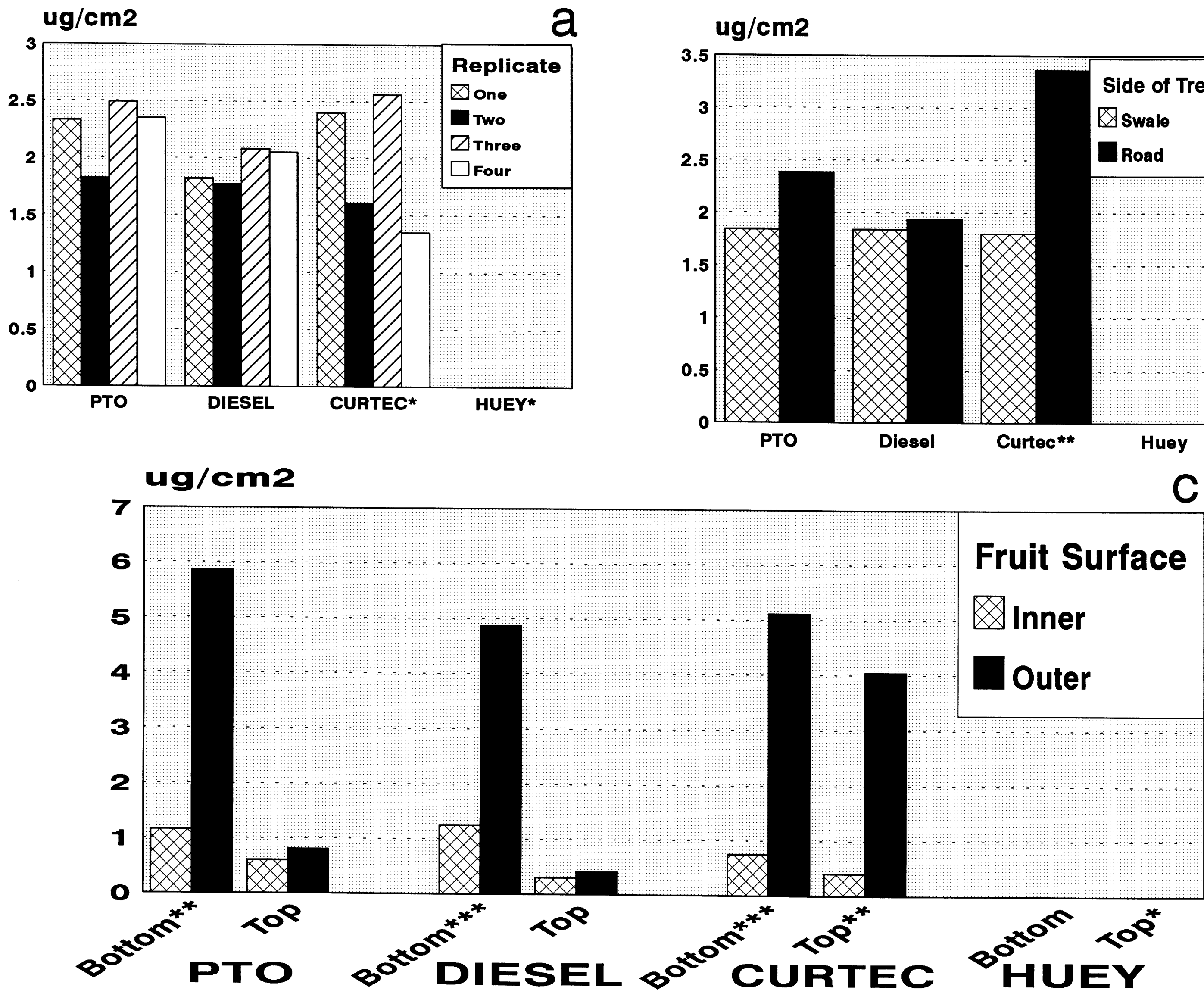

Figure 4. Deposition of brilliant blue dye on sprayed fruit (1994).

facing the row middle (Fig. 4b). All sprayers but the PTO-driven air blast deposited more on leaves facing the bed middle than the swale or in row. Deposition was uniform between leaf surfaces for each sprayer at one of the two canopy heights, top for the PTO and the Curtec, bottom for the diesel and the helicopter (Fig. 3c). Upper leaf surfaces received considerably more spray from the PTO and Curtec at the lower canopy position and in the top canopy position from the helicopter. The under surface was favored only by the diesel at the top canopy position. Deposition between fruit surfaces was very non-uniform, especially by the ground sprayers on fruit directly in line with the moving air. Fruit received more than 5 times more material on the outside surface compared to the inside surface in the bottom canopy sprayed by the air blast sprayers, and at any height sprayed by the Curtec. Discrepancy in deposition between fruit surfaces from the helicopter's application was on the order of 2 or 3:1 and most severe in the top canopy.

Discussion

Brilliant blue dye proved to be a safe and effective tracer, although the fine powder easily becomes airborne and is difficult to handle. The use of paper targets was a vast improvement over the previous technique by eliminating the need to measure surface area and tape leaves to evaluate individual surfaces. Furthermore, it provided a means of evaluating fruit surfaces separately which was not previously possible. These techniques allowed us to evaluate coverage on leaves and fruit throughout the tree canopy by ground and air sprayers.

None of the sprayers tested produced an ideal application. Each had its strengths and weaknesses, producing different types of inconsistencies. There was little difference between the air blast sprayers tested. All tended to favor the lower and middle sections of the tree and were relatively consistent between swale and bed. The helicopter favored the top canopy but the Curtec, being a tower sprayer, was uniform over heights. All sprayers favored one leaf surface or the other in different parts of the outside canopy. It appeared that leaves closest to the wall of moving air were laid back in one position or the other so that the exposed surface received most spray material. In contrast, we observed in 1993 that leaves in the inner canopy were more uniformly covered, even though they received less spray material. More uniform coverage in the inner canopy may have occurred because the air stream had been broken into turbulent eddies by passage through the outer canopy, causing the leaves to flutter, exposing both surfaces to spray. The worst inconsistencies occurred with coverage of fruit by the ground sprayers which the paper targets permitted us to observe in 1994. Again, outside surfaces closest to the fan outlets received the majority of spray. However, coverage of inward-facing fruit surfaces was better at greater distance from the source of air, low in the canopy for the helicopter and high in the canopy for the air blast sprayers.

One explanation for apparently more uniform coverage of fruit at greater distance from the sprayer, may be that spray material approached from a more vertical angle, giving greater exposure to the paper target placed on the back surface. In this case, the observation is largely an artifact of target placement and half of the fruit would still have been shaded from spray. However, it is possible that coverage of fruit really improved with distance from the sprayer where air speed would be lower but turbulence greater so that more spray material was carried to the sheltered side of the fruit. Air speed is highest close to the fans where air movement would be largely unidirectional. As energy dissipates further from the fan, turbulence should increase so that air movement would be more multi-directional. Since the Curtec's tower placed all parts of the outer canopy close to the fans, inside surfaces of all fruit were deprived of spray. At the other extreme, the helicopter blades which drive the air carrier are a considerable distance from the tree so turbulence may have been greater at all tree locations.

Turbulence is clearly desirable to move spray material in different directions and also to flutter leaves and move fruit to expose otherwise sheltered surfaces. Slowing the fans is probably not a good means to this end because the air carrier must be accelerated sufficiently to move spray material effectively through the entire canopy. However, it might be possible to introduce additional sources of turbulence with some device that produced a rapid pulsation of the air stream to increase movement of fruit and leaves, thereby improving coverage over otherwise sheltered surfaces.

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MANAGEMENT OF GLYPHOSATE-RELATED CITRUS FRUIT DROP

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Abstract. **Citrus fruit drop resulting from glyphosate applications has become more of a concern over the last several years. The objective of this research was to understand the mechanisms behind glyphosate related fruit drop and determine how to reduce these effects in standard grove practices. Specific amounts of glyphosate were applied to individual 'Hamlin' oranges at various stages of maturity and percentage of drop determined. The data indicate 'Hamlin' orange sensitivity in the fall at 0.1 µl per fruit. This rate roughly corresponds to 4 spray droplets of a 2 quart/acre glyphosate application at 20 gallons/acre. Field experiments were conducted comparing herbicide effects from various boom designs and nozzle configurations. The experiments were designed to determine levels of naturally occurring fruit drop, drop occurring from shielded booms without herbicide, as well as herbicide effects. Natural fruit drop ranged from 15 to 33 fruit per tree, mechanically induced fruit drop ranged from 1 to 6 fruit per tree, glyphosate induced fruit drop ranged from 0 to 26 fruit per tree in these experiments. Fully enclosed booms with heavy back covers and plugged off center nozzles had significantly less fruit drop than open booms with no back cover and open off center nozzles.**

Grower concern over glyphosate-related citrus fruit drop has increased over the past several years (Hest, 1996). Glyphosate-related fruit drop seems most likely to occur from late summer and fall glyphosate applications and is observed most frequently on early season oranges and grapefruit. Tucker (1977) reported that 6 week old fruit sprayed in May, showed no external damage and no abnormal drop. However, 5 month old fruit sprayed in September, resulted in peel burn on the exposed surfaces where most of the spray contact occurred and that extensive drop followed, suggesting that fruit is more susceptible to glyphosate as it nears maturity. Glyphosate has been shown to enhance ethylene production in