ies, bacterial blight of lettuce and Alternaria leaf blight of parsley appeared to be controlled in part by this fungicide. While it does not appear that maneb by itself could prevent all marketable losses due to these particular diseases, it does appear that it would be of significant benefit in a pest management program using additional control measures.

Literature Cited

Freie, R. L. and N. L. Pugh. 1994. Vegetable Summary 1992-1993. Florida Agricultural Statistics Service. Orlando, FL. 80 pp.

Johnston, S. A. 1991. Fungicide Benefits Assessment: Vegetables-East. National Agricultural Pesticide Impact Assessment Program. Washington D.C. 97 pp.

Morse Laboratories, Inc. 1993. Determination of maneb in RAC's (Crops). Standard Operating Procedure # Method-8, Revision #3. Morse Laboratories, Inc., 1525 Fulton Avenue, Sacramento, CA. 8 pp.

Morse Laboratories, Inc. 1992. Determination of ethylene thiourea in crops (RAC's and processed commodities). Standard Operating Procedure # Method-17, Revision #2. Morse Laboratories, Inc., 1525 Fulton Avenue, Sacramento, CA. 11 pp.

Raid, R. N. and L. E. Datnoff. 1990. Loss of the EBDC fungicides: Impact on control of downy mildew of lettuce. Plant Dis. 74:829-831.

Shimskey, D. 1989. Manufacturers cut EBDC uses. Farm Chem. 152(10):20,24.

Tomerlin, R. J. 1988. Dietary exposure analysis of maneb and maneb derived ethylenethiourea. U.S. Environ. Prot. Agency Eval. Div. Office Pestic. Programs, Washington D.C. 7pp. + attachments = 24 pp.

U.S. Environmental Protection Agency Office of Pesticide Programs. 1989. EBDC technical support document: Position document 2/3. Washington D.C. 289 pp.

Proc. Fla. State Hort. Soc. 108:212-216. 1995.

DEPOSITION OF SPRAY MATERIAL ON TOMATO FOLIAGE AS INFLUENCED BY VOLUME AND PUMP PRESSURE[1]

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Abstract. **Distribution of spray deposit was evaluated on tomato foliage from two hydraulic boom sprayers, a tractor-drawn hydraulic boom sprayer in the field, and a moving boom (chain-driven) table sprayer in a greenhouse. Water-sensitive paper cards were used to estimate spray coverage and a tracer dye (FD&C No. 1 blue dye powder, Warner-Jenkinson, St. Louis, MO) was used to estimate spray deposit. Two spray pressures (7 kg·cm^{-2} or 100 psi and 14 kg·cm^{-2} or 200 psi) and three types of ceramic nozzles of differing delivery rates (Albuz hollow cone tips: ATR red, yellow, and brown) were tested. Tracer dye analysis correlated well with evaluations of water-sensitive cards by visual and computer image analysis methods. No significant differences were found between sprayer types using the same spray pressure and nozzle type. More material was deposited on leaves in the outer plant canopy than within the plant interior. Best coverage on lower leaf surfaces was achieved with highest flow rates and pressure.**

Factors such as sprayer-type, nozzle output, and pump pressure interact to determine the distribution of spray deposits on plants, thereby determining the degree of pesticide contact with pest insects. Even under greenhouse conditions, only an estimated 16% of the spray may be delivered to plants with hydraulic sprayers, the remainder going to benches, aisles, the ground or elsewhere (Anonymous, 1992).

Analysis of spray deposit distribution at target sites is an important step toward evaluating and improving the efficacy of insecticides. Many arthropod pests, in particular whiteflies, live almost exclusively on lower (abaxial) surfaces of leaves (Mound, 1965). Efficient insecticidal control of these pests requires application techniques which provide good plant canopy penetration and coverage of abaxial leaf surfaces.

Uk and Courshee (1982) stated that measurement of deposits directly on the target plants gives the most accurate picture of spray effectiveness. Stermer et al. (1988) compared several artificial targets used to collect spray deposits, and concluded that deposits on those collectors which most nearly modeled live plants in physical size, orientation, and shape had the highest correlation with deposits on the plant leaves. They found that water-sensitive cards can provide useful information such as uniformity of swath, coverage, and relative droplet size.

Our objective was to evaluate a greenhouse table sprayer equipped with a chain-driven boom as a model for tractor-mounted boom sprayers. We also wished to evaluate the effects of pump pressures and nozzle delivery rates on coverage, especially of abaxial leaf surfaces.

Materials and Methods

Plants. Tomato plants (*Lycopersicon esculentum* Mill.), cv. Sunny were used in the field except for Test 4, and plants of the more compact cv. Lanai were used in the remaining tests (Tests 4 & 5). 'Sunny' tomato seedlings were transplanted into sand on polyethylene-mulch raised beds on 1.8 m (6 ft) centers in a seepage irrigated field on 22 Oct. and fertilized according to standard south Florida practice (C. Vavrina, personal communication). Plants were pruned twice to remove excess suckers and tied three times. 'Lanai' plants were indi-

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vidually transplanted into 30-cm plastic pots with standard potting medium. Plants were pruned two times, and watered and fertilized according to the standard practice.

Sprayers. We used two types of sprayers, a tractor-mounted hydraulic boom sprayer and a moving boom table sprayer. The tractor-mounted hydraulic boom sprayer was driven by a diaphragm pump at a ground speed of 3.2 to 4.8 km·hr^{-1} (2-3 mph) and carried two drop lines flanking the plant rows, each carrying either two, three or four nozzles according to plant size. Nozzles used were the hollow cone tips: ATR red, yellow, and brown (Carbone USA Corp. Boonton, NJ), which deliver 1.45, 0.787, and 0.503 liter·min^{-1}, respectively. The table sprayer was set-up in a greenhouse on a 1.8 × 7.0 m table and was equipped with an electric motor-driven piston pump and chain-driven boom carrying 2 drop lines flanking the median line of the table. Boom velocity, nozzle type, and number were set as needed for different tests.

Spray Deposition Evaluations. Water-sensitive paper (Spraying Systems Co., Wheaton, IL, USA, developed by Ciba-Geigy, Basle, Switzerland) was cut into 2.6 × 5.2 cm cards to evaluate spray coverage. The cards were stapled to the upper and lower leaf surfaces with sensitive (yellow) surface exposed. Coverage on the cards was estimated by two methods, visually and by a computerized image-scanning system. For the computerized image-scanning system, a 2.6-cm^2 piece was cut from the middle of the card and scanned using an HP Scanjet Plus (Hewlett Packard Co., Mountain-View, CA) with an IBM PC-type computer. Percent coverage was calculated using software developed and provided by the late Eric Franz (USDA-ARS, Aerial Crops Res. Lab., College Station, TX). Visual estimation was based on the following five criteria: 1 = 0 to 20% coverage; 2 = 21 to 40% coverage; 3 = 41 to 60% coverage; 4 = 61 to 80% coverage; 5 = >81% coverage. Sprays deposited on water-sensitive cards in Test 1 were evaluated using both methods, whereas only visual estimation was used for the remaining tests.

For quantitative estimation of spray deposition, FD&C No. 1 blue dye powder (Warner-Jenkinson, St. Louis, MO) was used as a tracer at dilutions of 1000 mg·liter^{-1} (all tests except Test 5) based on preliminary tests that showed sufficient deposit was obtained to insure spectrophotometric detection, even with minimal leaf coverage. A surfactant adjuvant [All Purpose Spray Adjuvant (APSA)-80, Amway Corp., Ada, MI] was added to all spray mixtures at the recommended rate of 0.05% (vol./vol.) to reduce beading and runoff.

Upon drying, we individually collected leaves into zip-lock sandwich bags from different canopy positions, top, middle, bottom, inner, and outer, depending on the test and size of plants. Leaves were sealed on one surface with transparent tape (3M Scotch Brand Transparent Premium Commercial Grade Box Sealing Tape, #3750) and dye recovered from the remaining surface by washing in a plastic bag with 10 ml of purified water (7 mg·liter^{-1} solid). Optical density of the eluant (@629.7 nm wavelength) from each leaf was measured using a Perkin Elmer Lambda 6 UV/VIS spectrophotometer (Perkin Elmer Co., New Haven, CT) linked to an IBM PC computer. Leaf areas were measured with a portable leaf area meter (Model LI-3000A, Li-Cor Inc., Lincoln, NE). Deposits of blue dye per leaf (μg·cm^{-2}) were calculated from the concentration (mg·liter^{-1}) determined by the spectrophotometer and leaf surface area.

Test 1. This test was conducted with the tractor-drawn boom sprayer on 7 Dec. 1993 when tomato plants were at the early flowering stage (average height 59 cm, 12 nodes) to evaluate spray coverage and distribution. We used six red Albuz nozzles giving a delivery rate of 910 liter·ha^{-1} (97.3 gal·ac^{-1}) and 14 kg·cm^{-2} (200 psi) at 3.2 km·hr^{-1} (2 mph). Nine leaves were selected at random from each of two canopy positions per plant, top and bottom. Water sensitive cards were attached to the top and bottom of 3 leaves at each position. The other six leaves at each position were collected for blue dye recovery, three for the abaxial surface and three for the adaxial surface.

Test 2. A second field test for the deposition and coverage with the tractor-drawn sprayer was performed on 10 Jan. 1994 (average plant height 93 cm with 14 nodes). Eight red Albuz nozzles with total delivery rate of 990 liter·ha^{-1} (105.8 gal·ac^{-1}) were attached to the boom on the tractor drawn sprayer which was operated at 14 kg·cm^{-2} (200 psi). We randomly selected nine leaves from each of three position levels in the plant canopy for treatments as in Test 1.

Test 3. This test was conducted on 1 Feb. 1994 to compare the effects of pump pressures (7 kg·cm^{-2} or 100 psi and 14 kg·cm^{-2} or 200 psi) on spray deposition. The tractor drawn boom sprayer traveled at 3.2 km·hr^{-1} (2.0 mph) with three yellow nozzles on each side (total six nozzles) with delivery rates of 765 liter·ha^{-1} (82 gal·ac^{-1}) at 14 kg·cm^{-2} and 580 liter·ha^{-1} (62 gal·ac^{-1}) at 7 kg·cm^{-2}. Six leaves (3 for abaxial and 3 for adaxial surface) were collected from each of outer, middle and inside of the canopy from the middle of the plants. Resulting deposition was weighted proportionate to the ratio of actual delivery rate with the average of the two delivery rates for analysis.

Test 4. This test was conducted on 16 Feb. 1994 to compare the effects of medium output yellow nozzles at lower pressure (7 kg·cm^{-2} or 100 psi) resulting in a higher delivery rate (765 liter·ha^{-1} or 82 gal·ac^{-1}), and low output brown nozzles at higher pressure (14 kg·cm^{-2} or 200 psi) resulted a lower delivery rate (652 liter·ha^{-1} or 62 gal·ac^{-1}) on spray deposition. The tractor-drawn boom sprayer traveled at 3.8 km·hr^{-1} (2.4 mph) with three nozzles per drop using each nozzle type. Six leaves (three for abaxial and three for adaxial surface) were collected from each of outer, middle, and inside of the canopy from the middle of the plants. When analyzed, the deposition was weighted proportionate to the ratio of actual delivery rate with the average of the two delivery rates.

Test 5. Effects of spray pressure (7 kg·cm^{-2} or 100 psi and 14 kg·cm^{-2} or 200 psi) and nozzle output (red, yellow and brown) on spray deposit were evaluated on 4 May 1994. Concentrations of blue dye were adjusted so that delivery rates of active ingredient were constant for the six configurations of spray pressures and nozzles. Concentrations (g·liter^{-1}) were as follows: at 7 kg·cm^{-2} pressure, 21.7, 37.0, and 61.7 g for red nozzles, yellow, and brown nozzles, respectively; and at 14 kg·cm^{-2} pressure, 16, 26.7, and 43.0 g for red, yellow, and brown nozzles, respectively. The tractor-drawn boom sprayer carried six nozzles and operated at 4.2 km·hr^{-1} (2.6 mph) and the table boom sprayer carried four nozzles operated at 3.2 km·hr^{-1} (2 mph). 'Sunny' tomatoes used in the field test were 85 cm high and 'Lanai' tomatoes used in the greenhouse were 60 cm in height.

Data Analysis: Analysis of variance (ANOVA) with mean separation by least significant difference was used to compare effects of application parameters on coverage and spray deposition. Separated analyses were conducted at all levels of each factor on the other factor because interactions in two-way factorial analyses were significant at $P = 0.05$ (PROC GLM

Table 1. Correlation between estimates by computerized image-scanning system and ranked visual evaluation for mean percent coverage of water sensitive cards sprayed by tractor-drawn boom sprayer (Test 1). Pump pressure was 14 kg·cm⁻² (200 psi) and delivery rate was 610 liter·ha⁻¹ (65.2 gal·ac⁻¹).

Leaf level	Leaf surface	Coverage % ± SD	Coverage Rank ± SD	Correlation coefficient (r)
Top	Adaxial	75.5 ± 17.4	4.4 ± 1.0	0.97
	Abaxial	43.7 ± 36.6	3.0 ± 1.9	0.99
Bottom	Adaxial	80.6 ± 13.8	4.4 ± 0.8	0.98
	Abaxial	62.4 ± 28.7	3.7 ± 1.4	0.99

procedure, SAS Institute 1988). Correlations between mean spray deposits obtained by the three evaluation methods, blue dye wash-off and water sensitive cards, and image analysis of the water sensitive cards and visual estimation (rank) were computed using PROC CORR procedure.

Results and Discussion

Test 1. Percentage coverage as determined by computerized image analysis and visual ranking of coverage (ranks of 1-5) was highly correlated (r = 0.97 to 0.99) (Table 1). Thereafter, we used visual ranking as the easier and faster method of evaluating coverage. Interactions between leaf location and leaf surface was significant for both deposition and coverage on water sensitive paper. Dye deposition and coverage on top and bottom leaves did not differ significantly on adaxial surfaces, but more dye and greater coverage were found on adaxial surface than on abaxial surface at both leaf levels (Table 2). Mean dye density recovered from leaf surfaces and coverage (ranks) from water sensitive papers were well correlated (r = 0.99).

Test 2. Interactions between leaf location and leaf surface were significant for both dye recovered and coverage on water sensitive papers. Coverage and deposit on foliage was less in the bottom canopy compared to the top and middle canopy except for coverage ranks on abaxial surfaces (Table 3). Coverage and deposit was less on abaxial surfaces compared to adaxial surfaces at all canopy positions. Again, mean dye density recovered from leaf surfaces and coverage (ranks) from water sensitive papers were well correlated (r > 0.95).

Test 3. After mathematical adjustment of deposition to compensate for differences in output, dye recovery from

Table 2. Density of blue dye deposits recovered from foliage of small tomato plants and coverage on water-sensitive cards stapled to tomato leaves sprayed by tractor-drawn boom sprayer (Test 1).

Leaf level	Adaxial surface	Abaxial surface
	Dye (µg·cm² ± SD)ˣ:	
Top	1.5 ± 0.5Aa	1.2 ± 0.5Ab
Bottom	1.3 ± 0.6Aa	0.8 ± 0.4Bb
	Coverage (Rank ± SD) on water sensitive cardsˣ:	
Top	4.5 ± 0.9Aa	3.6 ± 1.5Ab
Bottom	4.3 ± 1.2Aa	2.7 ± 1.6Bb
	Correlation between mean dye density and mean rank:	
r-value	0.99	0.99

ˣMeans in the same column within treatments followed by the same upper-case letters, or in the same row followed by the same lower-case letters are not significantly different at $P = 0.05$ (LSD, SAS Institute, 1988).

Table 3. Recovery of blue dye deposited on foliage and coverage on water-sensitive cards stapled to leaves of large tomato plants sprayed by tractor-drawn boom sprayer (Test 2).

Canopy level	Adaxial surface	Abaxial surface
	Blue dye (µg·cm² ± SD)ˣ:	
Top	2.1 ± 0.8Aa	1.6 ± 0.8Ab
Middle	2.2 ± 0.5Aa	1.3 ± 0.6Bb
Bottom	1.5 ± 0.8Ba	1.1 ± 0.7Cb
	Coverage (Rank ± SD) on water sensitive cardsˣ:	
Top	4.9 ± 0.9Aa	2.7 ± 1.3Ab
Middle	4.8 ± 0.2Aa	2.6 ± 1.4Ab
Bottom	4.3 ± 0.9Ba	2.5 ± 1.5Ab
	Correlation between mean dye densities and mean ranks:	
r- value	0.99	0.96

ˣMeans in the same column within treatments followed by the same upper-case letters, or in the same row followed by the same lower-case letters are not significantly different at $P = 0.05$ (LSD, SAS Institute, 1988).

Table 4. Recovery of blue dye deposited on tomato foliage with a tractor-drawn boom sprayer fitted with medium output Albuz "yellow" ceramic hollowcone nozzles operating at 7 kg·cm⁻² (100 psi) or low output "brown" nozzles at 14 kg·cm⁻² (200 psi) at delivery rates of 765 liter·ha⁻¹ (82 gal·ac⁻¹) and 580 liter·ha⁻¹ (62 gal·ac⁻¹), respectively (Test 3). Results were weighted by a factor equal to the ratio of actual delivery rate and mean rate.

Leaf location	Blue dye (µg·cm⁻² ± SD)ˣ Yellow nozzles 7 kg·cm⁻² Adaxial	Abaxial	Brown nozzles 14 kg·cm⁻² Adaxial	Abaxial
Outer	1.8 ± 0.5Aa	1.0 ± 0.5Ab	1.5 ± 0.5Aa	0.8 ± 0.4Ab
Middle	1.6 ± 0.8Aa	0.8 ± 0.6Ab	1.2 ± 0.6Ba	0.7 ± 0.7Ab
Interior	0.7 ± 1.3Ba	0.1 ± 0.1Bb	0.5 ± 0.7Ca	0.4 ± 0.7Ba

ˣMeans in the same column followed by the same upper-case letters, or in the same row within each pressure followed by the same lower-case letters are not significantly different at $P = 0.05$ (LSD, SAS Institute, 1988).

leaves sprayed at the two pressures was not significant ($P > 0.05$), although the interaction between leaf surface and leaf location was significant at both spray pressures. Less dye was deposited in the interior canopy than the middle and/or exterior canopy positions at both pressures (Table 4). Less de-

Table 5. Recovery of spray deposited on tomato foliage with a tractor-drawn boom sprayer with yellow nozzles operating with delivery rates of 765 liter·ha⁻¹ (82 gal·ac⁻¹) at 7 kg·cm⁻² (100 psi) and brown nozzles with 652 liter·ha⁻¹ (70 gal·ac⁻¹) at 14 kg·cm⁻² (200 psi), respectively (Test 4). Values for dye recovery were weighted by a factor equal to the ratio of actual delivery rates to a mean rate.

Leaf location	Blue dye (µg·cm⁻² ± SD)ˣ Yellow nozzles 7 kg·cm⁻² Adaxial	Abaxial	Brown nozzles 14 kg·cm⁻² Adaxial	Abaxial
Outer	1.1 ± 0.4Aa	1.0 ± 0.6Aa	1.0 ± 0.6Aa	0.6 ± 0.3Ab
Middle	1.0 ± 0.4Aa	0.8 ± 0.6Aa	0.9 ± 0.6Aa	0.4 ± 0.2Bb
Interior	0.6 ± 0.6Ba	0.4 ± 0.3Ba	0.5 ± 0.4Ba	0.3 ± 0.3Ba

ˣMeans in the same column followed by the same upper-case letters, or in the same row within each nozzle-pressure followed by the same lower-case letters are not significantly different at $P = 0.05$ (LSD, SAS Institute, 1988).

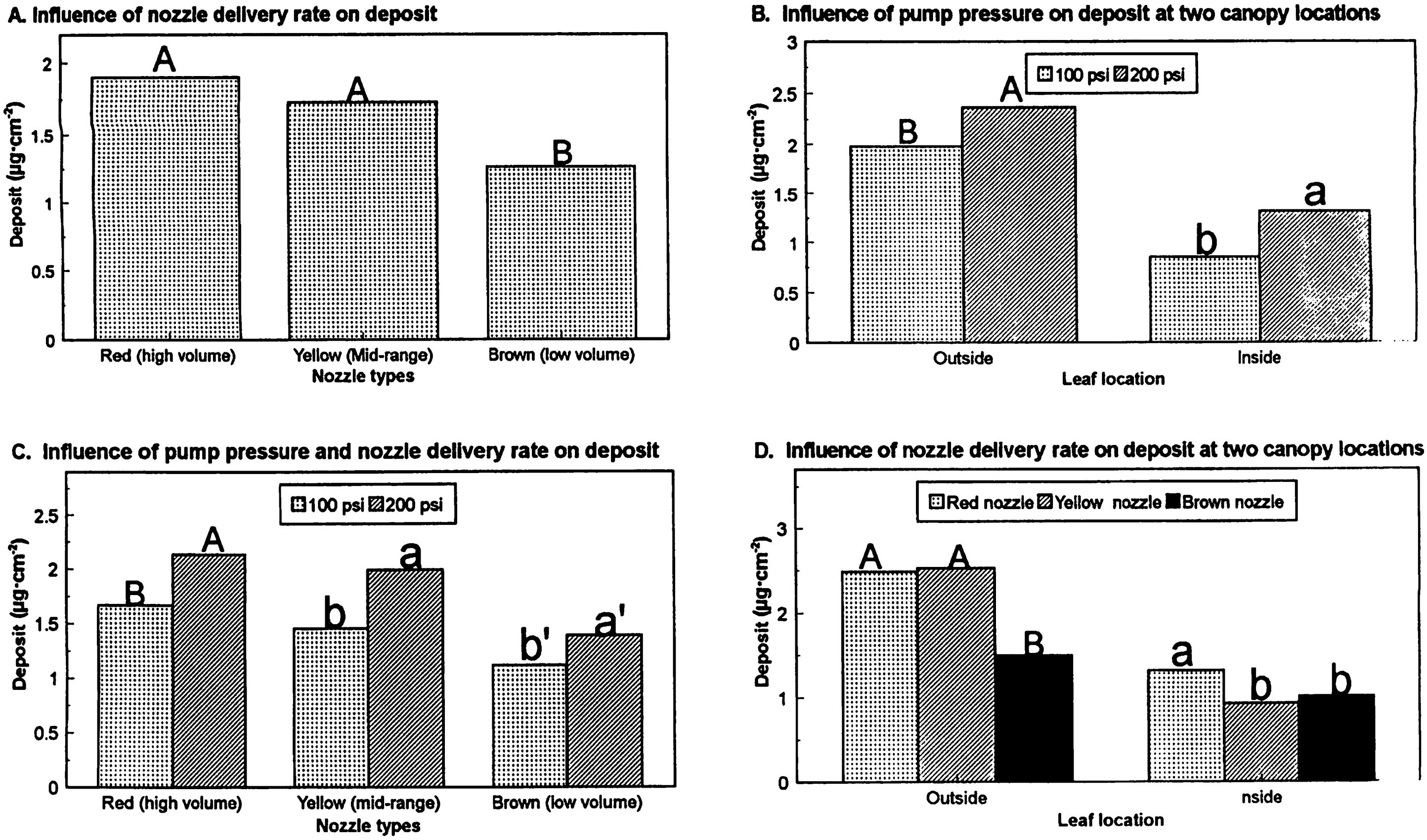

Figure 1. Recovery of spray deposit (µg·cm^{-2}) from on abaxial leaf surfaces of tomato plants by tractor-mounted boom sprayer. Concentration of active ingredient (blue dye) was adjusted for each nozzle/pressure combination to deliver equal rates between treatments (Test 5). Means represented by bars with different letters within groups are significantly different ($P = 0.05$, LSD, SAS Institute, 1988).

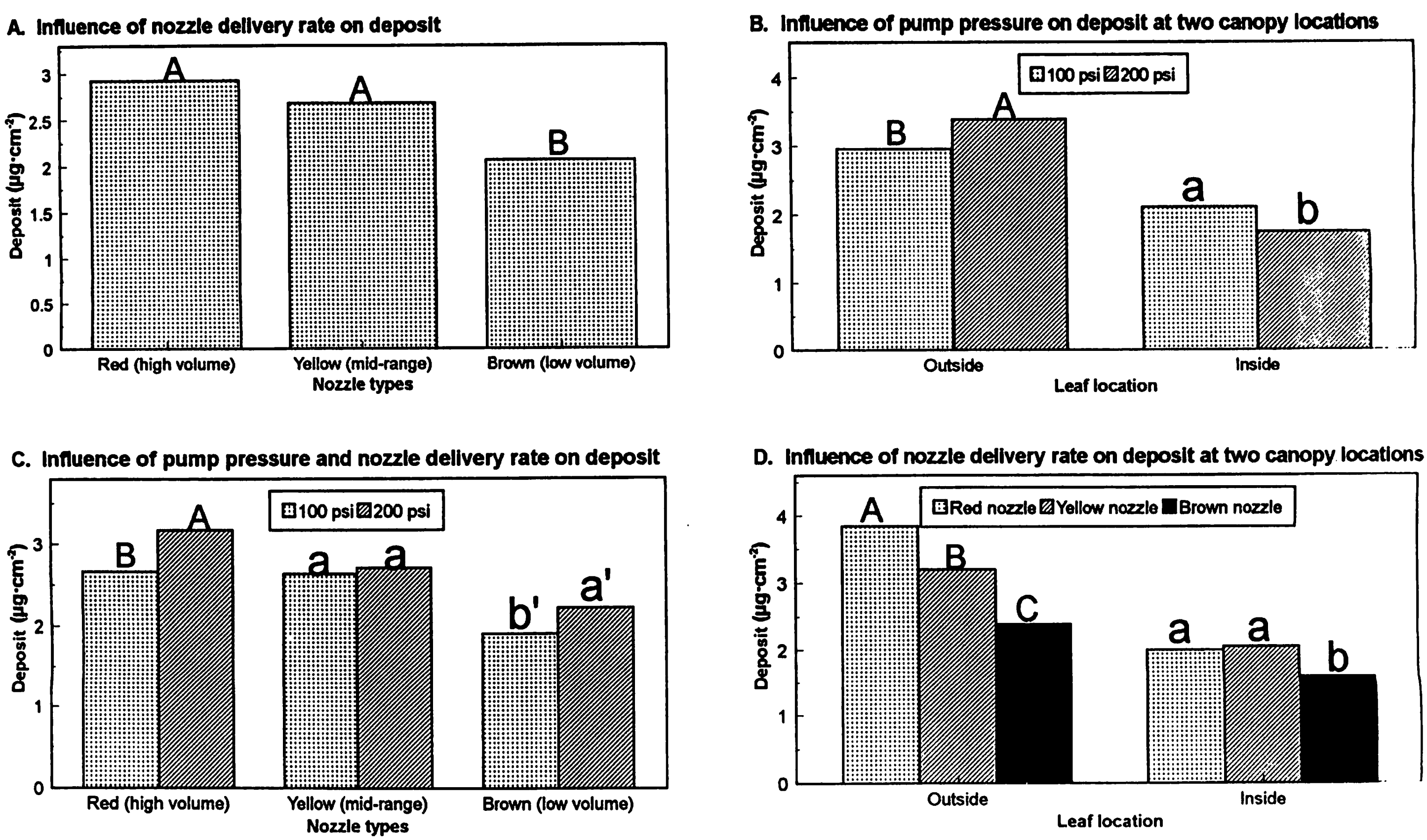

Figure 2. Recovery of spray deposit (µg·cm^{-2}) from on abaxial leaf surfaces of tomato plants by table-mounted boom sprayer. Concentration of active ingredient (blue dye) was adjusted for each nozzle/pressure combination to deliver equal rates between treatments (Test 5). Means represented by bars with different letters within groups are significantly different ($P = 0.05$, LSD, SAS Institute, 1988).

posit was recovered from abaxial surfaces compared to the combination of large orifice and high pressure, maxi-