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Evaluation of Spray Deposition on Plant Foliage with Self-Adhesive Paper Targets

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ABSTRACT

Self-adhesive paper microscope slide labels were used as targets to evaluate spray coverage on tomato and citrus foliage. Labels were attached to both upper and lower leaf surfaces throughout the plant canopy before spraying with a solution of brilliant blue dye (FD&C No. 1) as a tracer. The dye was subsequently eluted into vials of water and concentration of the rinsate determined spectrophotometrically. Spray coverage was also evaluated for comparison with similar sized squares of water-sensitive paper stapled onto leaves, and by measuring dye concentrations on actual leaf surfaces, which require sealing the other surface with cellophane tape. Applications were made with a hand pump sprayer, a hydraulic chain-driven table sprayer, a tractor-drawn hydraulic sprayer, and an airboom sprayer in different experiments. Label types of two thicknesses were tested. The thicker one captured more dye and held better to the leaf surface. Although more dye was recovered from labels than from actual leaf surfaces, recovery by the two methods was well correlated (*r*-values: 0.83-0.99). Dye recovery from paper labels was also well correlated with the coverage measured using yellow water-sensitive paper cards (*r*-values: 0.72-0.95) when they were placed on upper surface in the field. The paper label technique was time-efficient compared to evaluations from actual leaf surfaces and more qualitative than water-sensitive paper.

RESUMEN

Se utilizaron etiquetas autoadhesivas de papel para portaobjetos de microscopio como objetivos para evaluar la cobertura del asperjado en follaje de tomate y cítricos. Las etiquetas se pegaron a las superficies superior e inferior de las hojas en diferentes puntos del follaje de las plantas antes de asperjar con una solución de colorante azul brillante (FD&C No. 1) como indicador. El colorante fue posteriormente colectado dentro de viales y su concentración se determinó espectrofotométricamente. La cobertura de aspersión tambien se evaluó mediante la comparación de cuadros de papel sensitivo al agua cortados en cuadros de tamaño similar que fueron grapados a las hojas y tambien mediante la medición de las concentraciones de colorante sobre la superficie foliar directa, lo que requirió sellar la restante superficie foliar con cinta de celofán. Las aplicaciones se hicieron en varios experimentos usando un atomizador manual, un aspersor hidráulico de mesa, un aspersor hidráulico en un tractor y una aspersor aéreo. Se probaron dos tipos de etiquetas de diferente grosor. La mas gruesa capturó mas colorante y se pegó mejor a la superficie de la hoja. Aunque se recuperó mas colorante de las etiquetas que de la superficie de las hojas, la recuperación mediante los dos métodos estuvo bien correlacionada (r = 0.83 - 0.99). La recuperación de colorante a partir de las etiquetas de papel también estuvo bien correlacionada con la cobertura evaluada con tarjetas de papel amarillo sensitivas al agua (r = 0.72 - 0.95) cuando se colocaron en la superficie superior en el campo. La técnica de las etiquetas de papel fue eficiente en lo referente al tiempo invertido cuando se comparó a las evaluaciones en la superficie directa de la hoja y fue mas cualitativa que el papel sensitivo al agua.

Action of most pesticides requires contact with the target pest, therefore efficacy is in direct proportional to coverage of the inhabited surface. Factors such as sprayer-type, nozzle size and application pressure interact to determine the distribution of spray deposit on plants and thereby coverage. Evaluation of the distribution of spray deposits in foliage is an important step for improving coverage and therefore the efficacy of insecticides (Hedden, 1961,; Uk and Courshee, 1982). Low spray deposition indicates off-target movement of spray by runoff or drifting. Some pests, such as the silverleaf whitefly (*Bemisia tabaci* [Gennadius]), reside almost entirely on the underside (lower) leaf surface (Mound and Halsey, 1978), which must therefore receive uniform coverage for optimal efficacy of contact insecticides. Consequently, coverage of both leaf surfaces should be evaluated individually.

Stermer et al. (1988) compared several artificial targets to collect spray droplets, and concluded that depositions on collectors that most nearly modeled the live plants in physical size, orientation and shape had the highest correlation with deposits on the plant leaves. They found that water-sensitive cards could provide useful information on uniformity of swath and coverage and relative droplet size. Monofilament has also been used to collect spray deposit and a dual-side leaf washer was developed to elute spray deposit separately from either surface of cotton leaves (Carlton, 1992a,b). 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. Their leaf-washing method was later refined by taping one leaf surface so as to recover dye from only the untapped surface (Whitney et al., 1989). Rouse et al. (1994) and Liu et al. (1995) used a similar modified technique to evaluate deposition of a dye tracer from plant foliage. Liu et al. (1995) employed self-adhesive paper labels as targets, but did not provide an evaluation of the labels as collectors of spray deposit. Our objective here was to develop and evaluate a simple and accurate method to evaluate spray deposition on plant foliage by using self-adhesive paper labels, commonly used for microscopic slide-mounted specimens, as target surfaces to model spray coverage on plant foliage.

MATERIALS AND METHODS

Spray Deposition Evaluations. We applied a blue dye (FD&C No. 1, Warner-Jenkinson, St. Louis, MO) solution at 1 g/liter rate as a tracer (Liu et al., 1995). This rate was sufficient to insure spectrophotometric detection, even when leaf coverage was minimal. A spray adjuvant (APSA-80, Amway Corp., Ada, MI) was added at the recommended rate of 0.05% (vol./vol.) as a wetting agent to reduce runoff. Paper squares were placed on either the upper or lower leaf surfaces before spraying. Two types of self-adhering paper microscopic slide labels (22 x 22 mm) were used: thicker labels (Shamrock Co., Bellwood, IL) and thinner labels (Cat. #: 11-863C; Fisher Scientific, Pittsburgh, PA). Whole leaves or leaf squares of tomato or rough lemon the same size as the paper squares leaves or water-sensitive paper were used for comparison in some tests. Leaf squares were taped on one side after spraying to prevent elution of dye as described in Liu et al. (1995). Labels or leaves were allowed to dry for 30-40 min after spraying. Labels were collected directly into 20-ml glass vials filled with 10-ml water purified by reverse osmosis and leaves were collected into ziplock plastic bags. Labels or leaf squares inside the vials were shaken using an Innova Model 2300 large capacity platform shaker (Fisher Scientific, Pittsburgh, PA) for 30 min to elute the dye. Dye was eluted from whole leaves taped on one surface by two washes of 10 ml each. Rinsate was placed in 20 ml glass vials for measurement of optical density (629.7 nm) using a computer-linked Perkin Elmer Lambda 6 UV/VIS spectrophotometer (Perkin Elmer Co., New Haven, CT). Deposits of dye µg/cm^2) were calculated from the concentration determined by the spectrophotometer for the surface area of the leaf squares or paper labels.

Effect of Target and Solvent Type. This test was conducted to compare recovery of dye using water and ethanol (EOH) from sprayed paper and leaf surfaces. The dye was used at a rate of 1 g/liter of water. Tomato leaf squares and three3 types of paper targets: thick label, thin label and a square of white A84 bright white copy paper (Georgia Pacific, Atlanta, GA) (22 x 22 mm) were used for comparison. Four squares of each type were placed randomly on a sheet of plain white paper and sprayed by hand with a plastic Spritzer (Bel-Art Products, Pequannock, NJ). After the sprays dried, the targets were placed immediately in separate glass vials in which 10 ml of 70% EOH or water was added. Concentration (µg/cm^2) was measured spectrophotometrically as described above.

Paper Squares Versus Citrus Leaves. Dye recovery was compared from paper labels and leaf surfaces of 20 potted seedlings of rough lemon (*Citrus jambhiri* Lush) sprayed with a hydraulic boom table sprayer. The sprayer was equipped with a motor-driven piston pump delivering 689.5 kPa (100 psi) pressure. The dye was used at a rate of 1 g/l of water. The pump was plumbed through a coil of flexible hose to a chain-driven boom traveling at 53.3 m/min carrying two vertical drop booms flanking the median line of a 1.8 x 7 m table, with a 1 m separation between nozzles on the two opposing drop booms. Drop booms carried two Albuz® (Carbone USA Corp., Boonton, NJ) yellow ATR hollow-cone ceramic nozzles, each delivering 0.76 l/min or a total of 570.4 l/ha for all four nozzles. A thick label was applied to the lower surface of one leaf and the upper surface of another leaf randomly chosen from the middle of each plant. Upon drying, the leaf was cut around the perimeter of the label that was then separated from the underlying leaf square. Labels and leaf squares were placed in separate vials with 10 ml of water and treated as above. The upper surface of an additional leaf, and the lower surface of a second were covered with self-adhering tape. Dye on the uncovered leaf surface was then washed off using 10 ml of water and analyzed as described in Liu et al. (1995).

Effects of Spray Volume. The first of two experiments was conducted to evaluate deposition on label targets sprayed at two volumes of water with the same amount of dye. Each drop boom on the table sprayer carried two red or brown Albuz ATR hollow cone ceramic nozzles according to the treatment, with delivery rates of 1.44 and 0.50 l/min, respectively, operating at the same speed and pressure as above. Tomato plants, *Lycopersicon esculentum* Miller, 'Lanai' (50-60 cm in height with a dense canopy) were arranged along the median line of spray table. Treatments consisted of the two spray volumes and effects were compared between two canopy locations (outside and inside), and two leaf surfaces (lower and upper). One leaf from each

Table 1. Blue dye (FD&C #1) deposited on self-adhering paper squares and leaf squares using a hand sprayer in the laboratory.

	Dye (µg/cm^2) ± SE[1]		
Treatment	R.O. water	70% EOH	
Thicker paper square	6.2 ± 1.9a	6.4 ± 1.9a	n.s
Thinner paper square	5.6 ± 1.6a	6.0 ± 1.8a	n.s
Normal paper square	6.3 ± 0.8a	6.6 ± 1.0a	n.s
Leaf square	3.4 ± 1.8b	4.0 ± 1.6b	n.s
$F_{3,30}$	12.23**	11.36**	

[1]Means in the same column followed by the same letters, and n.s. indicates the means in the same row were not significantly different at $P = 0.05$; and '**' indicates significant at $P = 0.01$ (LSD, SAS Institute, 2000).

Table 2. Dye deposited on self-adhering paper squares placed on citrus leaves, leaf squares and whole-leaf wash-off methods using yellow (0.76 l/min each) Albuz ATR nozzles and sprayed with 689.5 kPa (100 psi) at a delivery rate of 348 l/ha (37.2 gal/ac).

	Dye (µg/cm^2 ± SE)[1]			
Leaf surface	Paper square	Leaf square	Whole-leaf wash-off	$F_{2,57}$
Upper surface	6.22±0.28Aa	3.14±0.30Ba	2.32±0.13Ca	68.37***
Lower surface	1.88±0.17Ab	1.55±0.15Ab	1.58±0.10Ab	1.67
$F_{1,114}$	177.48***	22.39***	25.50***	

[1]Means in the same row followed by the same upper case letters and in the same column followed by the same lower case letters are not significantly different at $P = 0.05$; and '***' indicate significant at $P = 0.001$ (LSD, SAS Institute 2000).

Table 3. Dye deposited on self-adhering paper squares placed on tomato plants using red (1.44 l/min each) and brown (0.5 l/min each) Albuz ATR hollow cone nozzles and sprayed with 689.5 kPa (100 psi) at delivery rates of 640 l/ha dye (µg/cm^2) ± SE and 219 l/ha (23.4 gal/ac), respectively.

		Dye (µg/cm^2) ± SE		
Leaf Position	Leaf surface	Red nozzle	Brown nozzle	$F_{1,16}$
Outside canopy[1]	Upper	5.22 ± 1.24 Aa	1.67 ± 0.34 Ab	7.60*
	Lower	2.30 ± 0.58 Aa	0.55 ± 0.13 Bb	8.51*
	$F_{1,16}$	4.52	9.49*	
Inside canopy[a]	Upper	4.66 ± 0.81 Aa	2.76 ± 0.34 Aa	4.62
	Lower	1.73 ± 0.28 Ba	0.43 ± 0.13 Bb	19.35*
	$F_{1,16}$	11.62*	42.30***	

[1]Spray means in the same column (surface) followed by the same upper case letters and in the same row (nozzle = volume) followed by the same lower case letters are not significantly different at $P = 0.05$; '*' and '***' indicate significant at $P = 0.05$ and $P = 0.001$, respectively (LSD, SAS Institute, 2000).

position was randomly selected from each and labels were applied to the upper and lower surfaces. Labels were removed upon drying and processed as described above within 2 d. For the second experiment, three delivery rates were achieved by utilizing red, yellow and brown Albuz ATR ceramic hollow cone spray tips again at 689.5 kPa. Labels were placed on both leaf surfaces from a randomly selected leaf from the middle canopy of each of 20 plants. Dye concentrations were adjusted to compensate for differences in volume so that delivery rates of dye were the same for all treatments.

Evaluation of a Hydraulic Sprayer and an Airboom Sprayer. Performance of a tractor drawn boom hydraulic sprayer was compared to an airboom sprayer (Airtech Sprayers, Winter Haven, FL) on tomato plants based on two criteria: deposition of dye on paper labels and coverage on same-sized squares of water-sensitive paper (Syngenta, Greensboro, NC). The hydraulic sprayer was driven by a diaphragm pump and carried two drop-booms per row flanking the plant rows, each with two yellow Albuz ATR hollow cone nozzles. The pump was operated at a pressure of 1379 kPa (200 psi), delivering 645 l/ha (69 gal/ac) at 3.2 km/h (2 mph) traveling speed. The airboom sprayer also had two drop-booms per row carrying two nozzles each operated at a pressure of 344.7 kPa (50 psi) to deliver 234 l/ha (26 gal/ac) at the same ground speed through brown Albuz ATR hollow cone nozzles. Spray was atomized by an air blast of 282 km/h as measured by a swing vein anemometer composed of an ellipsoidal tip pitot tube coupled to a Magnehelic® differential pressure gage (Dwyer Instruments Inc., Michigan City, Indiana). Three leaves were randomly selected, one from the top, middle and bottom of each of 20 tomato plants (50 cm high, 10-12 node). Water sensitive squares were stapled to and paper labels adhered to the upper and lower leaf surfaces of the same randomly selected leaf. Deposition and coverage on water-sensitive yellow cards were evaluated based on five categories as described in Liu et al. (1995) and deposition on paper labels (µg/cm^2) was evaluated as described above.

Data Analysis. Dye or coverage on self-adhering paper squares and leaf squares with different solvents, on different leaf surfaces with different spray pressures, nozzle types, canopy positions, or delivery rates were analyzed by analysis of the variance (ANOVA) with mean separation by least significant difference test (LSD), and correlations between related parameters in related tests were computed using PROC CORR procedure (SAS Institute, 2000).

RESULTS

Effect of Target and Solvent Type. Slightly more dye was recovered using ethanol as an eluent compared to water, but differences were not significant ($F = 1.10$; df = 1, 57; $P = 0.297$) (Table 1). The leaf square rinsate had the least amount of dye ($F = 11.36$-12.23; df = 3, 36; $P = 0.0032$-0.0041), while dye recovered from the three types of paper squares was not significantly different ($P > 0.05$). The dye recovered on the four different squares between the two solvents were well correlated ($r = 0.9988$, $P = 0.0012$)

Paper Verses Citrus Leaves Sprayed at High Volume. On the upper leaf surface, most dye was recovered from paper labels and least from whole leaves with leaf squares intermediate ($F = 68.37$; df = 2, 57; $P = 0.0001$, Table 2). However, there were no significant differences in recovery among target types from the lower surfaces ($F = 1.67$; df = 2, 57; $P = 0.1964$). More than three times more dye was recovered from paper labels on the upper leaf surface than from labels on the lower leaf surface whereas the disparity in recovery between upper and lower leaf surfaces themselves was <1.5. It would seem that paper labels absorbed some excess dye that would otherwise have run off upper leaf surfaces. In contrast, the same amount of dye was recovered from leaf and label targets on the lower surface, probably because less spray reached these surfaces so there was potentially less runoff to be soaked up by the labels. Correlation coefficients for the dyes on both leaf surfaces between paper square and leaf square, paper square and whole leaf, and leaf square and whole leaf, were well correlated with *r*-values of 0.9102, 0.9405 and 0.9721, respectively.

Effects of Spray Volume. Significantly more dye was recovered from paper squares on the upper leaf surface compared to the lower surface except for the outside canopy sprayed with the high volume red nozzles (Table 3). Also, significantly more dye was recovered at all locations from plants sprayed with the higher volume red nozzles compared to brown nozzles except the upper surface of the inside canopy.

In the second experiment, generally greater recovery of dye was observed at higher volume, although not always significantly so (Table 4). Significant differences were seen between upper leaf surfaces and lower surfaces when paper targets were used. More dye was recovered from upper surfaces compared to lower surfaces, regardless of target type. The dyes recovered from the paper squares and leaf squares were well correlated, $r = 0.9451$ for upper surface for leaf and paper at the lowest spray rate, $r = 0.9112$ for the upper surface at the middle spray rate, and $r = 0.8576$ at the highest spray rate.

Evaluation of a Hydraulic Sprayer and an Airboom Sprayer. Significant treatment effects of sprayer type were observed with both evaluation methods on deposition ($F = 12.15$; df = 11, 388; $P < 0.0001$ and coverage ($F = 298.96$; df = 11, 388; $P < 0.0001$, Table 5). The airboom sprayer deposited more on the lower surface at all plant positions than did the hydraulic sprayer. The airboom sprayer also deposited more on the upper surface at the lower plant position. Differences in coverage were confined to the upper surface in favor of the hydraulic sprayer. Dye recovered on the paper squares and coverage on the water-sensitive paper cards was correlated over all locations [r = 0.7438 ($P = 0.03$) and 0.7204 ($P = 0.02$) for the hydraulic and airboom sprayers respectively]. The dyes recovered from the paper squares and the coverage from the water sensitive paper squares on upper surface for the hydraulic sprayers were not well correlated, with the *r*-values of 0.6967, 0.7103, and 0.7968, respectively, for the leaves at top, middle and bottom of the plant canopy, respectively. In contrast, the correlation between the paper squares and water sensitive paper square on upper surface for the airboom sprayers were well correlated, and the *r*-values were 0.8927, 0.9431, and 0.9243, respectively, for the leaves at top, middle and the bottom plant canopy.

DISCUSSION

This study tested a new technique to evaluate spray deposition. Paper squares were very useful for evaluating spray deposition on plants (foliage, fruits and other organs). In

Table 4. Comparison of dye density deposited on self-adhering paper squares and tomato leaf surface delivered using a table-chain hydraulic sprayer at 3 delivery rates of 187, 374 and 561 l/ha (same ingredient per ha).

Delivery rate (l/ha)	Dye (µg/cm²) ± SE[1]					
	Leaf surface			Paper square		
	Upper	Lower	$F_{1,38}$	Upper	Lower	$F_{1,38}$
187	1.77 ± 0.14a	0.54 ± 0.06a	65.55***	3.39 ± 0.37a	0.43 ± 0.07b	57.44***
374	1.65 ± 0.13a	0.77 ± 0.16a	14.61***	4.35 ± 0.93a	1.09 ± 0.12a	12.19**
561	1.90 ± 0.13a	0.71 ± 0.11a	46.48***	4.40 ± 0.49a	1.34 ± 0.10a	37.75***
$F_{2,57}$	0.81	0.81		0.95	22.34***	

[1]Means in the same column followed by the same letters do not differ significantly at $P = 0.05$; '**' and '***' indicate significant at $P = 0.01$ and $P = 0.001$, respectively (LSD, SAS Institute, 2000).

Table 5. Dye deposited on self-adhering paper squares and coverage on yellow water-sensitive cards placed on tomato leaves. Dye data were adjusted by a factor of 2.65 with an assumption that the two sprayers had the same delivery rates.

Leaf position	Leaf surface	Dye (µg/cm²) ± SE[1]			Coverage (rank ± SE)		
		Hydraulic sprayer	Airboom sprayer	$F_{1,38}$	Hydraulic sprayer	Airboom sprayer	$F_{1,38}$
Top	Upper	3.45±0.31a	2.44±0.23a	6.82**	4.45±0.11a	3.13±0.18a	40.11***
	Lower	1.31±0.22c	2.30±0.25ab	8.77**	2.93±0.24c	2.93±0.20a	0.00
Middle	Upper	2.02±0.16b	1.70±0.28b	0.60	3.65±0.27b	1.75±0.18b	34.04***
	Lower	0.81±0.07cd	1.80±0.25b	12.69**	2.15±0.25d	1.75±0.20b	1.51
Bottom	Upper	2.23±0.17a	2.94±0.24a	5.65*	4.63±0.12a	3.35±0.16a	40.59***
	Lower	0.57±0.10d	1.91±0.21b	39.64***	2.90±0.23c	2.88±0.19a	0.01
$F_{5,194}$		25.18***	3.46**		22.40***	9.90***	

[1]Means in the same column followed by the same letters do not differ significantly at $P = 0.05$; '**' and '***' indicate significant at $P = 0.01$ and $P = 0.001$, respectively (LSD, SAS Institute, 2000).

comparing the dye recovered from paper squares, leaf squares (tomato) and whole tomato and rough lemon leaves, it was unexpected that the rinsate of whole leaf wash-off and leaf squares had less dye. The possible explanations are: (1) less runoff from the paper squares than from the leaf surface because the upper waxy leaf cuticle causes more runoff; (2) paper squares absorbed some sprays from the leaf surface around the edges especially at high delivery rates that caused runoff; and (3) the leaf tissue may bind some dye that could not be rinsed or completely dissolved in water.

We had an early hypothesis that when delivery rates were great enough to cause run-off on plant foliage, paper squares would absorb much more spray (dye) than on leaf surface. Data from Table 4 provided useful evidence that proportion of the dyes recovered from paper squares at the greatest delivery rate (561 l/ha or 60 gal/ac), which was 3-fold greater than the lowest rate (187 l/ha or 20 gal/ac), tended to be greater than from the lower delivery rates, but were not significantly different. This evidence indicates that the delivery rates did not significantly affect the dye recovered from the paper squares.

Self-adhering paper squares have at least three major advantages compared with the use of paper squares with water-sensitive yellow cards. First, while both can be used in a similar manner for a visual evaluation and assessment of coverage, the paper squares can also be used to obtain quantitative (disposition) information. Secondly, the water sensitive paper could only show coverage up to 100%, when spray droplets had covered the surface, whereas the paper square could go beyond the 100% surface coverage because the paper squares could absorb more dye before it was saturated, and the dye could then be recovered quantitatively. Finally, the simplicity and speed of application of the paper squares used with this technique are additional major advantages; the self-adhering paper squares are much easier to place and remove from any plant surface than the water-sensitive cards that are generally stapled to the leaves. This technique compared with other techniques, is simple, practical and accurate, and could save as much as 80-90% of the time used for the evaluation of samples compared with leaf-washing and other methods.

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