

FOLIAR SPRAY BANDING CHARACTERISTICS

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ABSTRACT. Foliar spray banding was explored as a means of reducing pesticide use compared to broadcast applications. Various geometric spray patterns and delivery angles of foliar spray bands were investigated to increase spray deposits in a crop row at a constant spray rate of 94 L/ha. Wind-free laboratory results indicated that a banded application using three 65° hollow-cone nozzles, with a laser-measured volume median diameter (VMD) of 110 µm, resulted in the highest ($p = 0.05$) upper canopy coverage of water-sensitive paper (WSP) of 37%, compared to 31% for a broadcast, 80° flat-fan application (VMD = 152 µm). However, the fore-aft trajectory created by a twin-orifice nozzle (VMD = 135 µm) resulted in less upper canopy deposit and did not increase deposit in the lower canopy. No statistical differences were observed in lower canopy WSP coverage. Cumulative volume distributions (CVD) of deposit droplet spectra in the upper and lower canopy indicated that large droplets were deposited on WSP in the lower canopy. Field test results indicated that the broadcast, 80° flat-fan nozzle produced the numerically highest malathion residues of 7.5 ng/cm² on leaf tops, but this was not statistically different ($p = 0.05$) from a banded 40° flat-fan nozzle application. Banded twin-orifice and three-nozzle hollow-cone treatments produced the statistically lowest ($p = 0.05$) leaf-top residues of <3 ng/cm². No significant ($p = 0.05$) differences were observed in leaf bottom residues and boll weevil mortality. In summary, downward-pointed sprays produced the greatest leaf-top residue levels under field conditions with a weak crosswind. Banded, narrow-angle (40°) flat-fan nozzles resulted in more deposit than a three-nozzle hollow-cone nozzle arrangement in the field. Thus, light wind conditions appeared to negate any advantages offered by multiple geometric spray patterns and delivery angles.

Keywords. Application technology, Crop protection, Droplet, Environment, Pesticide reduction, Sprayer efficiency.

Delivering crop protection sprays in bands is an unpretentious means of reducing pesticide use. A banded application distributes product in parallel bands at a concentration equivalent to the broadcast concentration (ASAE Standards, 2000a). Banding reduces pesticide use because the total amount of applied pesticide is proportional to the ratio of band width to band spacing. Knowing and reporting the effective band width is very important to accurately define the treated area so as to not apply a concentration, or effective application rate, greater than that of a broadcast application. When chemical concentration per unit of treatment area is higher than the broadcast concentration of similar application rate, then it is clearly defined as a directed application (ASAE Standards, 2000a). Directed applications focus a concentration of product to a specific strip (ASAE Standards, 2000a) or reduced area, and may or may not reduce pesticide use compared to

a broadcast application. Though there are explicit differences between banded and directed applications, the terms are often used interchangeably, which leads to confusion in identifying and interpreting band application test results.

Foliar spray banding applies a horizontally measured band to row crop foliage. A few studies have examined the effectiveness of nozzle treatments on foliar banding. For example, Heim (1993) concluded that foliar banding of insecticides was viable based on the control of cotton bollworm (*Heliothis*) and European corn borers (*Ostrinia nubilalis*). The study compared insecticide efficacy and water-sensitive paper deposits for: (1) a band application with a single hollow-cone nozzle (although band width was not clearly reported), (2) a three-nozzle directed spray application with hollow-cone nozzles, and (3) a broadcast application with hollow-cone nozzles. Total spray rate ranged from about 74 to 100 L/ha, and mean cotton height ranged from 1.06 m to 1.3 m. Heim determined that each single-nozzle arrangement had significantly less deposit downwards in the canopy, and that the multiple-nozzle directed spray improved deposition at low canopy levels. It was not clear whether the improved deposition was a result of increased droplet targeting efficiency or increased concentration of the directed application.

Giles and Slaughter (1997) examined a broadcast application with 75 cm spaced fan nozzles at 223 L/ha, a 15 cm wide row directed application (they termed it "yawed band") with yawed fan nozzles at 223 L/ha, and a 15 cm wide banded application (they termed it "precision band") with yawed fan nozzles at 223 L/ha (treated area) to apply a 500 ppm Zn tracer to field tomatoes (14 cm wide × 25 cm high) grown in a single 1.5 m wide bed in two rows. They reported VMD droplet size from the nozzle manufacturer as 325 µm for

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broadcast and directed applications, and 425 μm for the banded application. Deposition results indicated that the upper foliage had 1.06, 2.63, and 0.77 $\mu\text{L}/\text{cm}^2$, and the lower foliage had 1.04, 2.47, and 0.55 $\mu\text{L}/\text{cm}^2$ for broadcasted, directed, and banded applications, respectively. The directed application deposition was significantly ($P = 0.05$) greater than that of the other methods, whereas the banded application had a significantly ($P = 0.05$) reduced deposit in the lower foliage. It is interesting to note that about 2.4-fold increase of directed versus broadcast is less than the expected increase of 5 fold (i.e., a ratio of 75/15) that may have been due to the row/bed configuration. They conducted another study on bedded rows of leaf lettuce. Results of tracer spray deposits indicated reduced values for the banded application. The ratio between banded and broadcast deposit ranged from 0.72 to 0.87, depending on sample location across the bed, and the pooled ratio was 0.80. This reduction was attributed to a gradually increased band width to accommodate the lettuce that grew wider than the original flow-calibrated band width.

An electronic literature search yielded other band spray studies, although it was not always certain whether the applications were banded or directed, based on the reported test conditions.

Reducing insecticide use in row crops through improved application method (Womac et al., 1992) and droplet size spectra (Luttrell and Smith, 1990; Womac et al., 1994) may be of interest. Analyses indicated that foliar spray banding of insecticides had potential economic benefit (Smith, 2001). The hypothesis of the research reported herein is that geometric spray pattern and delivery angle of foliar spray banding can be adjusted to compensate for reduced pesticide use in band applications, and may achieve spray deposits comparable with broadcast application.

The specific objective was to characterize broadcast and foliar band spray applications, of various geometric spray patterns and delivery angles, on the partitioning of spray deposit in a field crop row under similar droplet volume median diameter (VMD), band width, and spray rate.

MATERIALS AND METHODS

SPRAY NOZZLES

Spray nozzles were selected to examine broadcast and foliar spray banding deposits due to various geometric spray patterns and delivery angles. Nozzles were selected to hold VMD (for water), band width, and spray rate as nearly

constant as possible. Spray rate was calibrated so that the actual application rate was within 5% of the intended rate (*ASAE Standards*, 2000b). Broad categories of nozzles included 80° flat-fan, 65° twin flat-fan, 40° flat-fan, and 65° hollow-cone nozzles. Relatively narrow spray angles were identified to focus spray energy, based on spray impact factors (PNR America, 2003), and to potentially improve penetration in band widths appropriate for foliar banding of insecticides. Very narrow (25°) flat-fan nozzles were tested in preliminary studies on young stands of cotton; however, inconsistent row guidance and targeting led to abandonment. Major axes from fan nozzles were oriented normal to the direction of travel, and most spray patterns were oriented straight down, although there were exceptions. The 65° twin flat-fan emitted two 65° fans; the minor axis of one fan was angled 30° forward from a downward direction, and the minor axis of the other fan was angled 30° rearward from a downward direction. Three 65° hollow-cone nozzles per row were mounted with a row application kit. One of the three nozzles sprayed downward over the row center; the remaining two nozzles were each mounted 28 cm from the center on each side of the row, and 15 cm below the center nozzle. These side nozzles were canted 30° from vertical towards the row, with the outermost edge of each plume defining the edges of the three-nozzle spray band.

The previous paragraph described the general nozzle designs used to achieve the various geometric spray patterns and delivery angles. Table 1 lists additional details of the nozzles tested in the laboratory and in the field, including: XR80015 extended-range, single-elliptical orifice, 80° flat-fan nozzles (Spraying Systems Co., Wheaton, Ill.); TJ60-650134 dual single-elliptical orifice, 65° twin flat-fan nozzles (Spraying Systems Co., Wheaton, Ill.); 40-01 (and 40-015) single-elliptical orifice, 40° flat-fan nozzles (former Delavan, Inc., Lexington, Tenn.); and a three-nozzle arrangement, described above, of TY-2, 65° hollow-cone nozzles (Spraying Systems Co., Wheaton, Ill.). The 80° flat-fan and 65° twin flat-fan nozzles were used for broadcast application in laboratory and field tests. Broadcast nozzle heights ranged from 46 to 56 cm above the row foliage. The 40° flat-fan and 3-nozzle 65° hollow-cone nozzles each applied a 56 cm band in the laboratory study. The 65° twin flat-fan, 40° flat-fan, and three-nozzle 65° hollow-cone nozzles each applied a 56 cm band in the field study. Banding nozzle heights were closely adjusted to an actual measured band width of 56 cm. The reported nozzle heights are actual measurements and differed slightly from the theoretical height calculated using nominal spray angle.

Table 1. Spray nozzle parameters for laboratory and field applications of broadcast and foliar banding sprays.

Test	Nozzle Treatment	Method	Spray Mixture	Speed (km/h)	Nozzle Height (cm)	Nozzle Pressure (kPa)	Spray Rate (L/ha)
Laboratory	XR80015	Broadcast	Water	6.4	46	207	94
	TJ60-650134	Broadcast	Water	6.4	53	276	94
	40-01	56 cm band	Water	6.4	53	262	94
	TY-2	3-nozzle, 56 cm band	Water	6.4	53	269	94
Field	XR80015	Broadcast	Malathion	6.4	46	152	94
	TJ60-650134	Broadcast	Malathion	6.4	56	200	94
	TJ60-650134	56 cm band	Malathion	6.4	53	228	94
	40-015	56 cm band	Malathion	6.4	62	193	94
	TY-2	3-nozzle, 56 cm band	Malathion	6.4	46	372	94

In addition to a uniform band width of 56 cm for foliar band spray treatments, a constant application speed of 6.4 km/h and a total spray rate of 94 L/ha were held constant for all treatments. Reported pressures vary between laboratory and field tests because of different spray application systems described below.

SPRAY DEPOSIT TESTS

A laboratory track sprayer at The University of Tennessee, Knoxville, was used to consistently traverse a spray boom over water-sensitive paper (WSP) attached to a single row of 40 cm high artificial philodendra plants. The synthetic philodendra plants had 6 cm wide, 8 cm long heart-shaped leaves; stems were pruned to resemble soybean plants at approximately V6 stage of growth (vegetative, sixth node) (Hill, 1994). Plants were spaced 21 cm to form a continuous row canopy with a leaf area index of approximately 2, based on a survey of leaf density. A trolley, resting on a 12.2 m long steel track and cable-driven by a 90 VDC 0.7 kW motor (Magnetek, El Paso, Texas), carried a dry boom with three nozzle bodies spaced at 51 cm. Nozzles were supplied with liquid from a portable canister subjected to regulated air pressure. Application speed was maintained at 6.4 km/h with a motor controller (RG8 series, Dart Controls, Zionsville, Ind.). Limit switches stopped the trolley in both directions. Laboratory temperature and relative humidity ranged from approximately 21°C to 23°C and 60% to 70%, respectively. Very little air movement, or wind, existed since all laboratory fans were off and doors were closed. This test applied water that was collected as spray deposit with eight WSP stapled face-up on leaves marked so that sample locations were consistent among replications. Of the eight cards per replicate, four were placed at 30 cm height (upper canopy), and four were placed at 15 cm height (lower canopy). Collection interference between WSP in the upper and lower canopies was minimized, since no plant had WSP placed in both the upper and lower canopy. The test used a completely randomized split plot design with spray nozzle as the whole-plot treatment factor and canopy level as the sub-plot. Three replications per treatment were performed, and data were analyzed using PROC MIXED (SAS Institute, Cary, N.C.). Laboratory tests also included laser diffraction droplet sizing of spray treatments, as described below.

A tractor with a six-row, rear-mounted sprayer at the USDA-ARS (Stoneville, Miss.) applied field spray treatments to 81 cm tall, DPL-5409 cotton (Delta and Pine Land Co., Scott, Miss.) planted on 102 cm row spacing. The sprayer had a 6.1 m boom, 51 cm nozzle spacing, and a roller pump and pressure regulator setup. Travel speed was calibrated to 6.4 km/h using a tape measure and stopwatch, and was maintained with a selective gear transmission and engine speed tachometer. The field test applied an aqueous solution of malathion 4EC formulation mixed at 1.12 kg-a.i./ha. Six row plots, 14 m in length, were sprayed in the afternoon at an ambient temperature of 32°C, relative humidity of 73%, and light crosswind ranging from 4 to 6 km/h. Six 102 cm spaced cotton rows were left unsprayed between plots to serve as a buffer zone. Five WSP were randomly paper-clipped face-up in the top of the canopy (3rd node down from terminal); WSP in the lower canopy was activated by ambient moisture and was rendered useless. After spraying, ten leaves per plot from the 4th node down from the terminal were collected in iced, plastic bags for

malathion residue recovery from top and bottom leaf surfaces. In addition, ten leaves per replicate from the 3rd node down from the terminal were placed in plastic bags on wet ice, and five boll weevils were sealed with a given leaf in a Petri dish to study mortality. A completely randomized experimental design with four replicates was used. Leaf side was used as a subplot treatment factor for leaf washes, and all data were analyzed using PROC MIXED (SAS Institute, Cary, N.C.).

ANALYTICAL TECHNIQUES

Water-sensitive paper (WSP) (Ciba-Geigy brand, Spraying Systems Co., Wheaton, Ill.) was digitized using a Scanman 256 handheld scanner (Logitech, Inc., Fremont, Cal.) and corresponding software (FotoTouch Color v.1.3, Logitech, Inc.). Scanner resolution was set at 42.3 $\mu\text{m}/\text{pixel}$ (600 dpi). It should be noted that droplets with diameters greater than 50 μm activate WSP, so the method was biased toward larger droplets. Images scanned from cards were analyzed for percent coverage, spot density, and discrete size data for each spot using the software program L-Count (Franz, 1993). Droplet diameter was determined with a regression equation computed from spread factors supplied with the WSP (Franz, 1993).

Malvern laser diffraction droplet size analyses with an 800 mm lens set were conducted on the same nozzles, pressures, and heights as used in the laboratory tests. The instrument detector was polled 10,000 sweeps for a given run while the downward-directed discharge was completely traversed back and forth several times through the laser beam. Obscuration and lens fouling was checked to ensure accurate droplet sizing. Since the WSP has a 50 μm droplet-diameter activation threshold, and that the WSP was scanned at a 42.3 $\mu\text{m}/\text{pixel}$ resolution, the first ten Malvern size bin categories (4 to 58.4 μm) were collapsed into one category to facilitate comparisons with droplet spectra results from image scanner analysis. Mean cumulative volume percentages were concurrently graphed for Malvern laser droplet size and WSP determinations. In other words, each droplet size determined from WSP with image analysis was used to create a cumulative droplet size distribution using the bin sizes defined by the Malvern lens.

Malathion residue from the top and bottom surfaces of cotton leaves were removed with 3 mL of ethanol per leaf surface by using dual side leaf washers (Carlton, 1992). Aliquots (2 mL) were placed in autosampler vials for analysis by a gas chromatograph (Model 5890, Hewlett-Packard, Wilmington, Del.) equipped with a flame photometric detector and operated by Chemstation software (Hewlett-Packard). The residue analysis parameters were: injector temperature = 200°C; detector temperature = 200°C; oven program = 120°C initial temperature with a 25°C/min increase to 250°C for 1 min, then a 25°C/min increase to 280°C for 4 min. A Hewlett-Packard Ultra-1 cross-linked methyl silicone gum phase column (25 m \times 0.32 mm \times 0.52 mm) with a 2.65 mL/min flow of helium was used. Retention time of malathion was 5.597 min.

Boll weevil mortality studies were conducted with susceptible boll weevils provided by the USDA-ARS in Stoneville, Mississippi. Five weevils were placed on a sprayed leaf in a Petri dish (100 \times 15 mm). Dishes were covered and checked for mortality 48 h after placement of

weevils. Control treatment leaves were taken from unsprayed regions of the cotton field.

RESULTS AND DISCUSSION

LABORATORY SPRAY APPLICATIONS

The laboratory spray deposit test indicated wide variation in WSP coverage in the upper canopy, whereas no statistical difference ($p = 0.05$) was observed in WSP coverage in the lower canopy due to nozzle treatment (table 2). The broadcast treatments had statistically identical WSP coverage in the upper canopy, and this coverage fell between the extremes produced by the banding treatments. The broadcast XR80015 treatment had less WSP coverage and droplet density than the banded three-nozzle TY-2 treatment, and this may be partly attributed to the greater VMD produced by the flat-fan nozzle. For coverage and droplet density pooled for all nozzles, upper canopy coverage had low correlation with upper canopy stain number ($r = 0.34$), whereas lower canopy coverage was highly correlated with stain number ($r = 0.95$).

Among broadcast treatments, the TJ60-650134 had a droplet VMD reduced by 11% and slightly numerically less WSP coverage and droplet density in the lower canopy, although no statistical difference ($p = 0.05$) was observed. In contrast, the reduced VMD significantly increased WSP droplet density in the upper canopy. Evidently, the dual fore-aft spray directions at a reduced VMD of the TJ60-650134 did not improve droplet penetration to the lower canopy compared to the downward-aimed larger VMD of the XR80015. Thus, it appeared that the discharged spray with a slightly larger VMD and downward direction performed as well as the fore-aft spray directions in terms of canopy penetration.

The band application with the 40-01-nozzle treatment produced the least WSP coverage ($p = 0.05$), and the banded three-nozzle TY-2 treatment produced the greatest WSP coverage ($p = 0.05$) in the laboratory test (table 2). It was interesting to compare the performance of sprays with similar droplet VMD values. The broadcast TJ60-650134 (VMD = 135 μm) and the banded 40-01 (VMD = 136 μm) treatments had statistically different ($P = 0.05$) WSP coverage and droplet density in the upper canopy, although no statistical difference was observed in the lower canopy. Either the dual fore-aft spray directions or the multiple-nozzle arrangement associated with the similar VMD from the TJ60-650134 broadcast treatment affected WSP coverage and droplet density in the upper canopy. The high WSP coverage in the upper canopy from the three-nozzle TY-2 treatment was primarily attributed to the multi-directional spray plume due to the wide positioning of the outermost hollow-cone

nozzles, and due to droplet size. Laser-measured droplet VMD was 18% less for the three-nozzle TY-2 treatment than for the broadcast TJ60-650134 treatment (table 2). The three-nozzle TY-2 treatment produced WSP coverage and droplet density, in the lower canopy, that was not statistically greater than at least one other treatment, although the TY-2 resulted in the highest numeric values in the lower canopy. This, too, was attributed to the many droplet vectors associated with the three nozzle orientations and hollow-cone spray pattern. Womac et al. (1992) noted in a previous study that droplet vectors played a crucial role in targeting the undersides of leaves, and hence showed that drop nozzles rigidly affixed to trip-type supports effectively improved spraying pest on the underside of leaves. In retrospect, the multi-vectorized droplet effect of the study herein improved canopy penetration and more than offset any tendency for reduced penetration from small droplets. It should be emphasized that these laboratory results pertain to a "no-wind" situation, but they should at least provide a benchmark in determining the role of geometric spray patterns and spray delivery angles.

LABORATORY DROPLET SPECTRA COMPARISONS

Cumulative volume distributions (CVD) of the droplet spectra from the Malvern laser and the WSP from upper and lower canopy levels, for each laboratory-tested nozzle, are shown in figures 1-4. On these graphs, the abscissa is droplet size, based on the Malvern droplet size bins, and the ordinate is percentage of spray volume. Cumulative spray volume is plotted, i.e., the percentage volume is progressively incremented by the volume in each progressive bin. Inspection of figures 1-4 indicates that the largest droplets penetrated and deposited on the WSP placed in the lower canopy, as similarly reasoned by examination of WSP coverage in the previous paragraphs. Another overall observation is that in two cases (figs. 1 and 4) all WSP droplet spectra tended to be larger than that of the Malvern. The other two cases (figs. 2 and 3) had a sharp rise in upper canopy distributions at VMD values less than the Malvern VMD.

The laboratory broadcast application with the XR80015 flat-fan nozzle resulted in upper and lower canopy WSP-collected VMD values of 355 and 650 μm , respectively (fig. 1). Previous studies either assumed that the CVD produced by the sprayer was the same as that collected by the WSP (Fox et al., 2001); or they used a volume mean diameter (Salyani and Fox, 1999), which is different from the VMD (volume median diameter) used herein; or they examined a narrow droplet size range from 70 to 350 μm (Thacker and Hall, 1991); or they focused primarily on percent coverage (Panneton, 2002). Thus, recent comparisons between Malvern- and WSP-determined VMD are not widely available

Table 2. Laboratory spray droplet and deposit data for broadcast and foliar band sprays.

Nozzle Treatment	Method	Malvern $D_{v0.5}$ (VMD) (μm)	WSP Coverage (%) [CV] ^[a]		WSP Drop Density (drops/cm ²) [CV]	
			Upper Canopy	Lower Canopy	Upper Canopy	Lower Canopy
XR80015	Broadcast	152	30.7 b ^[b] [18.2]	5.2 a [21.2]	192 c [20.7]	72 ab [25.1]
TJ60-650134	Broadcast	135	29.6 b [15.6]	3.3 a [22.9]	226 a [16.0]	65 b [20.2]
40-01	56 cm band	136	19.1 c [16.4]	2.6 a [24.3]	202 bc [17.4]	56 b [28.3]
TY-2	3-nozzle; 56 cm band	110	36.8 a [15.3]	6.5 a [18.8]	217 ab [19.2]	95 a [25.6]

[a] CV = coefficient of variation (%).

[b] Means followed by the same letter in a given column do not differ in pairwise comparison test ($p = 0.05$).

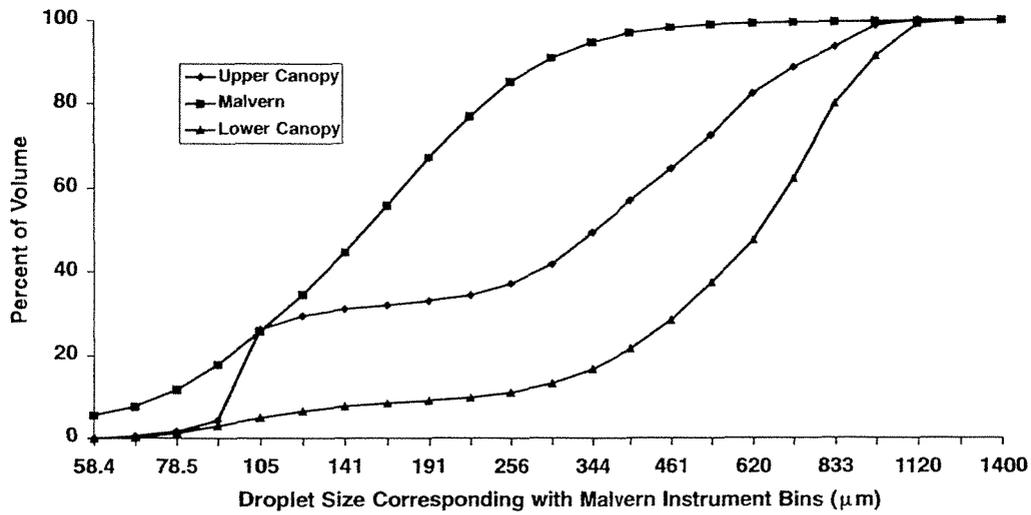


Figure 1. Droplet spectra distributions determined for upper and lower canopy with water-sensitive paper collections versus Malvern laser diffraction measurements for a flat-fan nozzle (XR80015) broadcast spraying from a laboratory track sprayer.

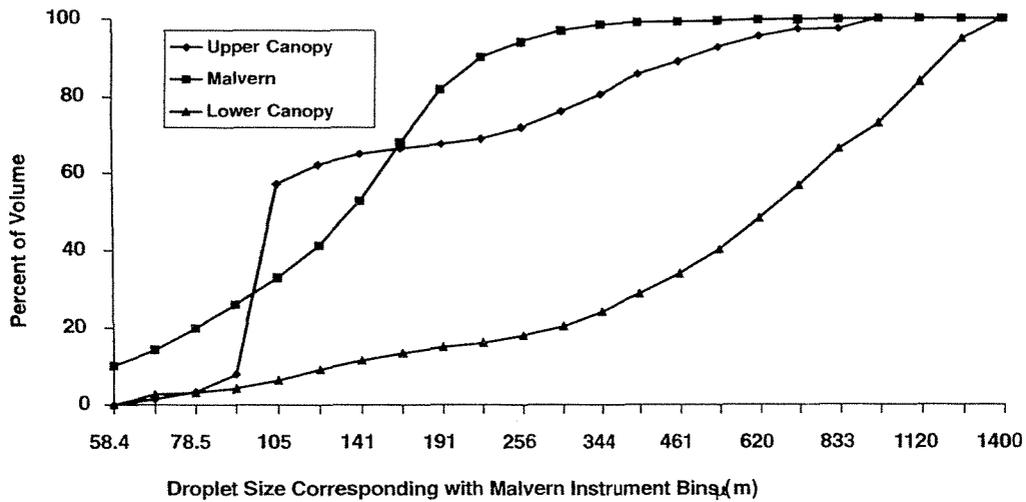


Figure 2. Droplet spectra distributions determined for upper and lower canopy with water-sensitive paper collections versus Malvern laser diffraction measurements for a twin-orifice flat-fan nozzle (TJ60-650134) broadcast spraying from a laboratory track sprayer.

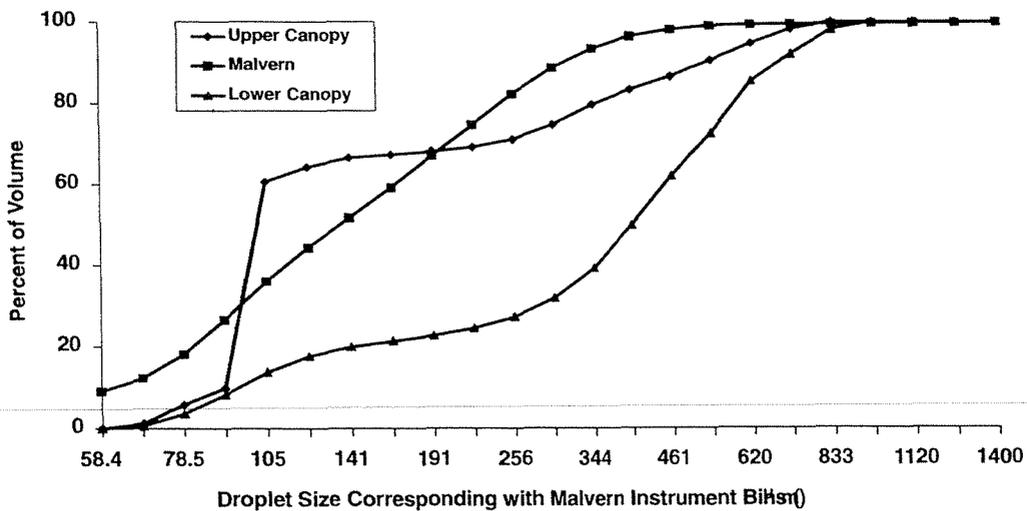


Figure 3. Droplet spectra distributions determined for upper and lower canopy with water-sensitive paper collections versus Malvern laser diffraction measurements for a flat-fan nozzle (40-01) foliar band spraying from a laboratory track sprayer.

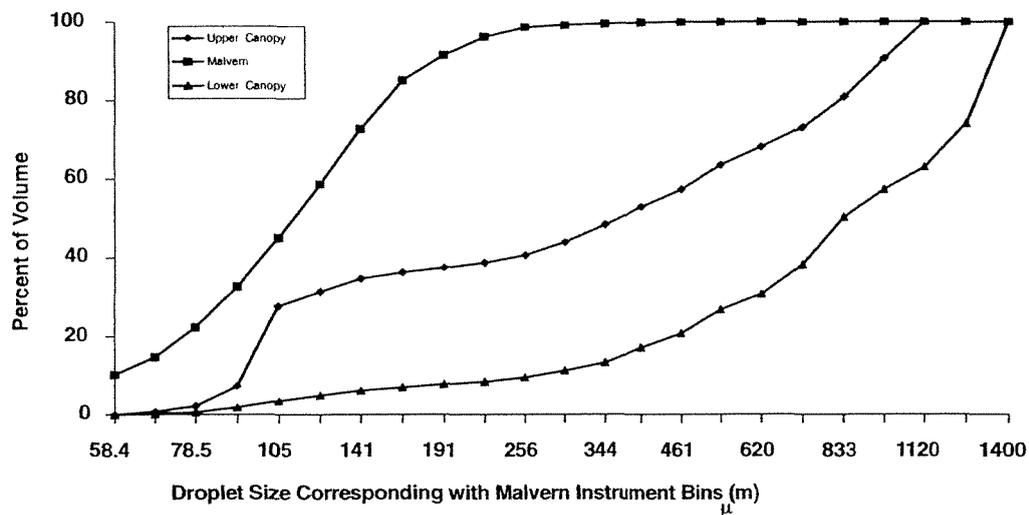


Figure 4. Droplet spectra distributions determined for upper and lower canopy with water-sensitive paper collections versus Malvern laser diffraction measurements for three-hollow-cone nozzle arrangement (TY-2) foliar band spraying from a laboratory track sprayer.

in the literature. Potential sources of error include the acknowledged, minimum droplet activation size of 50 μm for WSP; a lack of small droplets settling onto WSP; no accounting for droplet coalescence; the range of spread factor, which varies by more than that accounted for by the calibration equation; some small droplets that were missed by the image analysis system; the documented bias that the Malvern has towards small droplets (Womac et al., 1999); or some combination of the above.

The laboratory broadcast application with the TJ60-650134 dual flat-fan nozzle resulted in upper and lower canopy WSP-collected VMD values of 103 and 640 μm , respectively (fig. 2). The CVD for the upper canopy WSP upwardly crossed the Malvern CVD due to much spray volume collection in the 91-105 μm size range, downwardly crossed the Malvern CVD at about 164 μm , and finally merged with the Malvern CVD at 965 μm . Regardless of differences between Malvern- and WSP-determined CVD, WSP collections clearly demonstrated a filtering and partitioning effect occurring between upper and lower canopy levels for this nozzle and all the other nozzles as well. Small droplets were best intercepted and collected in the upper canopy, whereas large droplets penetrated and were collected in the lower canopy. It should be noted that the CVD curves characterize the droplet spectrum reaching the WSP and not the quantity of deposit. WSP coverage and droplet density, previously presented in table 2, provide quantitative measures of the deposit quantity. WSP coverage and droplet density correlate with the summations of spray volume and droplet numbers, respectively, that populate each CVD size range.

The laboratory band application with the 40-01 flat-fan nozzle resulted in upper and lower canopy WSP-collected VMD values of 100 and 400 μm , respectively (fig. 3). WSP CVD curve shapes somewhat resembled those of the nozzle treatment discussed immediately above. The WSP-determined CVD for the upper canopy looped above the Malvern CVD.

The laboratory band application with the three-nozzle TY-2 hollow-cone nozzle resulted in upper and lower canopy WSP-collected VMD values of 370 and 830 μm , respectively (fig. 4). Both WSP curves lagged joining the Malvern CVD curve near 100%, compared to the previously discussed nozzle treatments.

FIELD SPRAY APPLICATIONS

Field-applied nozzle treatment results are presented in table 3. Field performance of WSP coverage and droplet density for broadcast nozzle treatments (table 3) was very similar to the upper canopy results of the laboratory test (table 2). The broadcast XR80015 nozzle treatment resulted in the numerically highest leaf-top residue, although it was not statistically ($p = 0.05$) different from the band 40-015 treatment. In contrast, band nozzle treatment results differed between field and laboratory. Field WSP coverage performance of the 40-015 flat-fan nozzle (table 3) resulted in significantly greater coverage than the three-nozzle TY-2 nozzle treatment, which was a complete reversal of the laboratory results (table 2). Visual observations indicated that the spray from the three-nozzle TY-2 nozzle treatment tended to be blown off the row by a light crosswind ranging from 4 to 6 km/h. On the other hand, the increased nozzle size and reduced operating pressure of the 40-015 in the field, compared to the 40-01 used in the laboratory, created the largest CVD of all the field-tested nozzles (fig. 5). This largest droplet size corresponded with the least droplet density (table 3). These differences resulted in WSP coverage and leaf-top residues for the banded 40-015 nozzle treatment that were significantly greater ($p = 0.05$), by a factor of 2, than those of the banded three-nozzle TY-2 nozzle treatment (table 3). The advantage of the fore-aft dual fan spray from the TJ-650134 was evident for the broadcast application, but not the banded application, based on leaf-top residue (table 3). No significant ($p = 0.05$) differences were observed in leaf bottom residue or boll weevil mortality (table 3).

WSP-determined CVD for field-tested nozzles are plotted in figure 5. VMD of broadcast XR80015, broadcast TJ60-650134, band TJ60-650134, band 40-015, and three-nozzle TY-2 band application treatments were approximately 890, 785, 833, 1070, and 250 μm , respectively (fig. 5). The smallest CVD of the TY-2 was distinctly different, whereas the other nozzle treatments were grouped together. It is interesting to note that the CVD from the WSP in the field (fig. 5) were generally much coarser than the CVD obtained from either upper or lower canopy CVD from the laboratory, except for the TY-2 hollow-cone nozzles.

Table 3. Field data of spray deposit and boll weevil mortality for broadcast and foliar band sprays.

Nozzle Treatment	Method	WSP Coverage (%) [CV] ^[a]	WSP Drop Density (drops/cm ²) [CV]	Leaf Top Residue (ng/cm ²) [CV]	Leaf Bottom Residue (ng/cm ²) [CV]	Susceptible Boll Weevil Mortality (%) ^[b] [CV]
XR80015	Broadcast	31.20 ab ^[c] [20.7]	133 c [24.3]	7.52 a [13.2]	0.11 a [62.7]	100.0 a [0]
TJ60-650134	Broadcast	27.54 b [17.8]	172 b [20.3]	5.17 b [19.4]	0.33 a [45.2]	100.0 a [0]
TJ60-650134	56 cm band	29.51 b [18.0]	177 b [21.8]	2.60 c [25.7]	1.11 a [34.5]	100.0 a [0]
40-015	56 cm band	37.94 a [19.8]	78 d [19.4]	6.32 ab [15.6]	0.14 a [58.3]	100.0 a [0]
TY-2	3-nozzle; 56 cm band	19.08 c [24.2]	295 a [27.9]	2.94 c [24.2]	0.13 a [46.1]	97.93 a [3.1]

[a] CV = coefficient of variation (%).

[b] Control had 0.5% mortality.

[c] Means followed by the same letter in a given column do not differ in pairwise comparison test (p = 0.05).

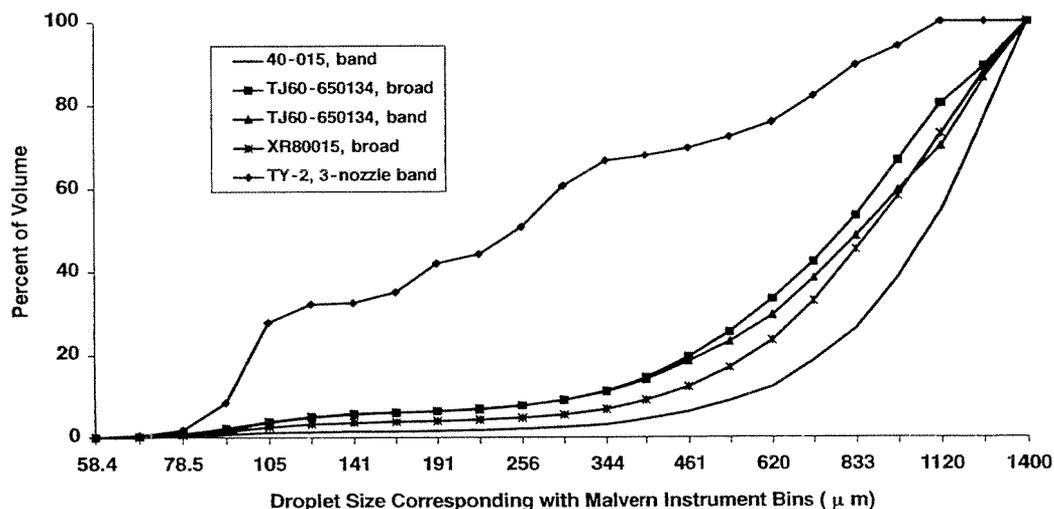


Figure 5. Cumulative volume droplet spectra determined from water-sensitive paper for field trial of foliar banding and broadcast nozzle treatments.

CONCLUSIONS

- Foliar spray banding provides an avenue to significantly reduce pesticide use in row crops without loss of spray deposit coverage or reduced leaf-top chemical residues compared to a broadcast application from flat-fan nozzles.
- Under application conditions with virtually no crosswind, foliar banding with multiple spray delivery angles per row, such as that delivered by multiple hollow-cone nozzles, produce the greatest potential for increased spray coverage in the upper and lower canopy of a row crop.
- Under application conditions with a light crosswind, foliar banding with a downward-pointed spray with minimum delivery angles, such as that created by a single, narrow-angle flat-fan nozzle per row, produce the greatest potential for increased spray coverage and leaf-top residue.
- The plant canopy filters droplets by size, whether applied as broadcast or a foliar band, such that larger droplets are deposited at lower canopy levels when the droplets are allowed to settle without forced air.
- Lower canopy coverage and droplet density and leaf bottom residue levels are small fractions of the total deposited spray, as compared to upper canopy and leaf-top residue levels.

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