Biological Implications of Drift from Sprayers in Tomato Fungicide Field Trials

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ABSTRACT

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Fungicide field trials on tomatoes were conducted in 1988 and 1989 to compare spray drift produced by three sprayers used to apply fungicides for control of fruit and foliar diseases. An air-assisted sprayer consistently provided greater coverage of tomato foliage and subsequent disease control than either a commercial or small-plot hydraulic sprayer. A significantly greater proportion of spray by the commercial hydraulic sprayer was prone to drift in 1988 and 1989. Comparison of the percentage of tomatoes with rot in adjacent downwind plots demonstrated that spray drift could be an interfering factor in tomato fungicide field trials.

Spray drift represents a loss of chemical from intended targets and implies dangers of air and water pollution. Pesticides can move off target by physical movement of spray cloud droplets or volatilization of pesticide active ingredient, which can occur for extended periods after application. Spray accountancy may be a parameter of future registration of newer, more active pesticides (6). Research efforts to reduce spray drift have typically dealt with improved equipment design or application techniques. The reduction of fine spray droplets in the droplet spectrum during atomization is the most promising area of improvement in application technology. However, developments in application technology have not kept pace with technical advances in fungicide chemistry. The need for improved application methods and machines has increased from the advent of fungicides that are effective at low application rates. Consequently, improvement of environmental conditions during application continues to be the most consistent means to reduce drift. Although the environmental aspects of spray drift are recognized, and buffer zones established in field plots, the quantitative implications of off-target placement of spray in pesticide field trials have not been identified.

Control of early blight (caused by *Alternaria solani* Sorauer) and anthracnose (caused by *Colletotrichum coccodes* (Wallr.) S. J. Hughes) of tomatoes grown in Ohio requires the application of fungicides every 10–14 days. Often nine or 10 applications are applied during the growing season. The purpose of this study was to assess spray drift into adjacent plot areas by three different sprayers. Each sprayer represented a different design with potential to reduce drift while applying protectant fungicides in a small-plot tomato trial.

MATERIALS AND METHODS

Field experiments. Field studies were conducted on the Vegetable Crops Research Branch, Ohio Agricultural Research and Development Center, Fremont, in 1988 and 1989. Plots were located on a level 48-ha field. H1810 tomato transplants grown in Georgia were planted on 18 and 24 May in 1988 and 1989, respectively. Each plot consisted of a single row 143 m long, bordered on each side by one nonsprayed row. Plants were 30 cm apart in the row, and main plot blocks were separated by a 4-m alleyway. Canopy height averaged 60 cm at maturity. Treatments were replicated four times, utilizing a split-split plot experimental design. Sprayer type was the main plot, distance of spray card stand placement off the centerline (leeward) was the subplot, and the vertical placement of spray cards on stands was the sub-subplot. Plots were sprayed on a 10- to 14-day schedule.

Sprayer description and fungicide application. The first sprayer was a tractor-mounted, small-plot sprayer calibrated to deliver 618 L/ha of spray suspension at 3.2 km/hr. Four hollow-cone nozzles (model HC-8, Delavan, Des Moines, IA) were centered over one row; nozzle spacing was 18.3 cm, and height above canopy was approximately 45 cm. A CO_2 pressure system was used to apply approximately 414 kPa at the nozzles.

The second sprayer was a high-volume field sprayer (model DO 35P/500S, FMC, Princeton, NJ) that was also calibrated to deliver 618 L/ha. Nickel alloy, hard-core nozzles with no. 2.5 disks (FMC) were used for the study. The travel speed was 6.4 km/h, and nozzle spacing was 30 cm. Only the nozzles of the middle boom section were operated at a boom height of approximately 75 cm above the plant canopy, with nozzle pressures of 1,445 kPa.

The third sprayer was an air-assist model (Mini-Variant, Hardi Inc., Davenport, IA). A single hydraulic nozzle was located at the end of each 10-cm-diameter flexible hose. Forced air from a centrifugal fan directed spray into the tomato canopy; both the fan and pump were power-takeoff operated. Two nozzle–air spouts were centered over each 40-cm row at a height of approximately 40 cm above the canopy at 45° angles. The sprayer was calibrated to deliver 330 L/ha of spray suspension at 690 kPa and 6.4 km/hr.

Metalaxyl + mancozeb (Ridomil MZ 58) was applied at the rate of 454 g in 95 L of water. Mixing and agitation were accomplished by bypass agitation in both the high-volume field and air-assisted sprayers. The small-plot sprayer relied upon hand mixing and, once loaded on the tractor, general machine movement.

The operating pressure and speed of each sprayer was adjusted to the previously stated requirements for attaining desired application rates prior to each run. A 3-m-high anemometer tower was utilized in the plot area to measure wind speed and direction. The average wind speeds during the 1988 and 1989 trials were 4.7 and 3.1 km/h, respectively, measured at 55 cm above the tomato canopy. When the wind direction appeared to be holding within 20° of the drift line, each treatment was initiated. One water-sensitive card (2.5 × 7.5 cm) was placed on each leaf surface at each location, (e.g., one on the upper and lower leaf surface). Leaf canopy locations were 0, 30, and 60 cm above the soil surface at both the periphery and near the stem area of each plant canopy. With one plant per replicate plot, this represented six cards per plant × two surfaces = 12 cards per plant × four replicates per treatment = 48 cards per treatment. Spray cards were displayed on one date each year, 6 wk after transplanting tomato plants on 5 and 8 July in 1988 and 1989, respectively. This enabled an assessment of tomato canopy penetration as well as spray accountability on the tomato plant.

Drift detection. At application, water-sensitive spray cards (2.5 × 7.5 cm) were also placed on three metal stands, with

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one stand at each distance of 1, 3, and 5 m off the centerline of the sprayer path at heights of 0, 19, and 25 cm, in accordance with ASAE standards (2), to account for any off-target spray movement (e.g., one water-sensitive card per height per distance displayed parallel to the ground). Spray cards were collected after each application. An image analyzer was used to measure droplet image sizes and to count droplet number per unit area on the spray cards. No attempt was made to measure drift deposits that moved beyond the drift stations.

Determination of droplet size. Droplet spread factors were required to calculate the true droplet size from the spray deposits (field) on the water-sensitive spray cards. Calibration of spray card deposits was achieved with a microapplicator (model M, ISCO, Lincoln, NE), using a 0.25-ml luer-tip tuberculin syringe that applied uniformly sized droplets of the metalaxyl + mancozeb spray suspensions to water-sensitive spray cards. The stain diameters of the spray suspension on the water-sensitive spray cards were used to calculate the spread factor of the spray suspension. The spread factor was equal to the stain diameter of the spray suspension divided by water drop diameter (CIBA-GEIGY, *unpublished*). Spread factors used for droplets with stain diameters of <1,000 and >1,000 μm were 1.9 and 2.3, respectively. Approximate spread factors are 1.8 for 100–300 μm, 2.0 for 400–600 μm, and 2.2 for 700–1,000 μm, according to Spraying Systems (Wheaton, IL) literature.

Statistical analysis. Mean droplet coverage (number of droplets per square centimeter) for the various sprayers was calculated from the tomato canopy coverage study. These values were subjected to analysis of variance procedures (14). Means were tested for significant differences according to Fisher's least significant differences (LSD) test (P = 0.05).

After the spread factors for various-sized droplets were established, data gathered from spray cards placed at the drift stations were used to calculate true droplet sizes of drift-prone droplets. Converted droplet sizes were subjected to analysis of variance procedures (14), and a mean droplet size and the percent area covered by spray per square centimeter of leaf area were subjected to Fisher's LSD test (P = 0.05).

After percent canopy coverage and droplet size data were obtained, tomato fruit were harvested from adjacent downwind plots. Harvested fruit were evaluated for the incidence (percentage) of rotten fruit; this variable was utilized as an indicator of drift in an effort to determine a drift interference threshold. The identities of all fruit rots were not determined, but rots caused by *A. solani* and *C. coccodes* were most common. Fruit incidence data were transformed (arcsine) prior to analysis of variance. Means were tested according to Fisher's LSD test (P = 0.05) (15).

RESULTS

Significant (P = 0.05) differences were observed in 1988 and 1989 among the different sprayers for percent area of tomato plants covered (Table 1). In both years of the study, decreasing spray deposition was observed with the air-assisted, small-plot, and high-volume field sprayers, respectively. The air-assisted sprayer provided significantly greater coverage compared with the others; there were no significant differences observed in coverage of the tomato canopy between the high-volume field and small-plot sprayers.

There was a significant (P = 0.05) interaction of sprayer, downwind distance, and height in both years of the study. Therefore, an interaction LSD (P = 0.05) was calculated to compare mean droplet size and percent area covered off-target (Table 2). Significant differences were observed among the various leeward distances from the centerline for percent area covered as well as various heights.

At the 1-m downwind distance, percent area coverage of spray cards capturing drift from the air-assisted sprayer was greater than the 3- and 5-m distances in both years; this is an indication of greater deposition by this sprayer (Table 2). In contrast, coverage by the high-volume field sprayer differed significantly among heights. For example, the 25-cm height drift target for the high-volume sprayer had the greatest percent area covered for any sprayer regardless of the downwind distance. The small-plot sprayer's greatest coverage of targets was at 1 and 3 m downwind and at a height of 25 cm, but it ranged from 50 to 10 times less than the coverage values produced by the high-volume sprayer for both 1988 and 1989, respectively. However, 5 m downwind at a height of 19 cm, the small-plot sprayer demonstrated the greatest percent area covered by drift of any sprayer in these

Table 1. Fungicide spray suspension deposition on tomato foliage[a] by three sprayer types

	Mean foliage area covered (%)[b]	
Sprayer	**1988**	**1989**
Small plot	11.9	28.1
Air assisted	28.7	57.7
High-volume field	8.3	24.0
LSD (0.05)	4.3	22.9

[a] Measured by attaching spray cards to upper and lower surfaces of leaves at 60, 30, and 0 cm above the soil surface.

[b] Means calculated from a one-card deployment each season; mean of three heights, two locations, and two leaf surfaces, and four replications (48 cards).

Table 2. Mean droplet size and percentage of tomato foliage area covered by fungicide from various sprayers at different distances and heights from the centerline

			1988		1989	
Sprayer	**Distance (m)**	**Height (cm)**	**Droplet size (μm)**	**Area covered (%)**	**Droplet size (μm)**	**Area covered (%)**
High-volume field	5	25	1,420[a]	1.78[a]	987	2.02
	5	19	50	0.02	267	0.57
	5	0	146	0.02	153	0.19
	3	25	1,586	1.02	1,857	1.58
	3	19	273	0.13	352	0.16
	3	0	740	0.36	217	0.78
	1	25	1,612	1.09	1,780	0.97
	1	19	895	0.50	672	0.28
	1	0	1,050	0.63	948	0.09
Small plot	5	25	190	0.09	185	0.10
	5	19	856	0.33	793	0.15
	5	0	739	0.17	762	0.09
	3	25	303	0.39	682	0.07
	3	19	980	0.04	1,023	0.18
	3	0	865	0.02	905	0.05
	1	25	550	0.34	893	0.11
	1	19	926	0.04	1,023	0.18
	1	0	0[b]	0.00	158	0.03
Air assisted	5	25	153	0.09	125	0.03
	5	19	330	0.17	413	0.07
	5	0	640	0.32	608	0.02
	3	25	155	0.02	170	0.01
	3	19	350	0.18	382	0.03
	3	0	386	0.17	217	0.07
	1	25	1,002	0.68	721	0.18
	1	19	536	0.54	878	0.19
	1	0	487	0.48	695	0.17
LSD (0.05)			354	0.09	228	0.04

[a] Mean of four spray cards.

[b] No residue detected.

trials during 1988.

Small droplets produced by the air-assisted sprayer were captured at the 25-cm height by the 3- and 5-m downwind target. Droplet deposit sizes produced by high-volume field sprayer were greater than any other sprayers at the 25 cm height regardless of downwind distance. In 1988 and 1989, the droplet size ranges deposited by the high-volume sprayer were 50–1,612 and 153–1,857 μm, respectively. In contrast, the small-plot sprayer droplet size range was narrower than that of the other sprayers in 1988. However, in 1989 the air-assisted model produced a droplet size range (125–878 μm) that was narrower than either of the other two sprayers. Regardless of downwind distance, drop sizes at the 25-cm height were significantly greater than either 19- or 0-cm heights for the high-volume field sprayer (Table 2).

The percentage of rotten tomatoes produced in adjacent, downwind plots that captured drift from the upwind plot in which the sprayer was applying fungicide was indicative of sprayer drift interference (Table 3). Main effects of sprayer drift interference during 1988 and 1989 were statistically significant ($P = 0.05$). Examination of adjacent sprayer drift interference plots indicated that the order of decreasing drift, by sprayer, was high-volume field > small plot > air assisted.

As a standard comparison, the untreated check had 42.3 and 38.3% rotten tomatoes for 1988 and 1989, respectively. Similarly, no significant differences were observed in the other untreated check plots that could capture drift from either the air-assisted or small-plot sprayers, with the exception of the high-volume field sprayer drifting to untreated checks during 1988 and 1989.

Table 3. Percent rotten tomatoes produced in fungicide sprayer plots that intercepted spray drift from another plot

Treatment[a]	Rotten tomatoes (%) 1988	Rotten tomatoes (%) 1989
SP→AA[b]	27.5[c]	17.3
HVF	33.2	22.5
CHK	44.1	32.7
A→SP	37.6	11.2
HVF	28.3	19.7
CHK	49.8	42.5
HVF→SP	29.3	15.2
AA	31.9	16.7
CHK	31.6	15.2
CHK→AA	47.5	17.6
SP	23.5	18.2
HVF	35.2	39.1
CHK	42.3	38.3
LSD (0.05)	4.1	6.8

[a] Sprayer drift to adjacent plot. Sprayer types: SP = small-plot CO_2, AA = air assisted, and HVF = high-volume field; CHK = untreated check.

[b] Arrow indicates direction of sprayer drift; first sprayer is applying fungicide treatment adjacent to another sprayer-applied plot, downwind.

[c] Means of four replicate plots.

Drift interference from small-plot sprayer to the air-assisted and high-volume field sprayers resulted in rotten tomato incidence of 27.5 and 33.2%, respectively, in 1988, but in 1989 the percentage of rotten tomatoes harvested from the small-plot sprayer to air-assisted plots was 17.3% and significantly less than the respective untreated check. True efficacy, as indicated by the untreated check to small-plot sprayer, was not significantly different from either small-plot sprayer drift to air-assisted sprayer plots in 1988 or 1989, or to high-volume field sprayer plots in 1989. Thus, relatively little drift interference was produced by the small-plot sprayer.

Drift interference associated with the air-assisted sprayer was significantly less than any other sprayer, as indicated by the air-assisted sprayer to untreated check values of 49.8 and 42.5% rotten tomatoes for 1988 and 1989, respectively. The percent rotten tomato values for the air-assisted spray to small-plot and high-volume field spray treatments were 37.6 and 28.3% in 1988 and 11.2 and 19.7% in 1989, respectively. Interference by the air-assisted sprayer was nonsignificant.

High-volume field sprayer drift interference in small-plot and air-assisted spray plots demonstrated that, regardless of year, the drift produced by the high-volume sprayer was enough to enhance deposit quality and interfere with adjacent sprayer plot results (Table 3). Hence, an approximate drift threshold for fungicides used on tomatoes may be defined as >1% coverage that can be attributed to drift.

DISCUSSION

The quality of spray deposit (4) as well as the amount of spray drift influenced fungicidal effects on experimental tomato plots where sprays were applied and in adjacent downwind, nontarget plots. Our results agree with the findings of other studies (7) in which it was shown that higher drift application volumes may also result in greater disease control in nontarget plots. In our study, the high-volume field sprayer produced significantly more drift-prone deposits than either the air-assisted or small-plot sprayer and resulted in greater spray deposition within the upper portions of the tomato canopy. This can be attributed to the high boom height (75 cm) and type of nozzles utilized on the sprayer. However, the differences between drift deposition and disease control may be masked, as in other studies (7), since they involve systemic, curative fungicides that have the potential for translocation inside the plant. The curative property of a systemic fungicide may interfere with detection of protective action provided by the actual spray deposit. However, a nontranslocated fungicide could test the deposition efficiency and associated control. This concept is often overlooked as a biological assay to assess drift of various pesticides.

An additional parameter overlooked in drift studies is the use of nozzles and sprayers that are representative of those used in the field. Other studies have confirmed that spray recoveries outside the spray swath were significantly lower when low-pressure fan nozzles were used (9). Low operating pressures are one way to reduce spray drift and yet retain a greater amount of spray on the intended target. Unfortunately, the high application volumes required by various sprayers to apply fungicides on tomatoes preclude the use of low operating pressures.

The magnitude of spray drift in decreasing order, by sprayer, was high-volume field > small plot > air assisted. This same relationship also existed between the mean droplet size of the deposits. To a lesser extent, mean droplet size followed the relationship of percent area covered by drift. One explanation for this lack of correlation may be that the resolution of the image analyzer utilized in this study was approximately 59 μm. Therefore, the entire droplet size spectrum could not be accounted for in this study with this measuring device. Second, vertical partitioning within the tomato canopy according to droplet size demonstrated the complex interactions of delivery energetics, droplet size, and canopy penetration. Methodology utilized herein only explains a partial, yet undefined, volume of each sprayer's droplet spectrum that is prone to drift.

To account for a larger portion of coverage and spray volume, other researchers (1) found that the volume contained in droplets <100 μm in diameter (most likely to drift) was four times greater in fine vs. coarse sprays. This interaction of droplet size and associated spray volume does not entirely explain the lack of accountability of fine droplets. The study (1) further demonstrated a greater volume of spray suspension was drift-prone, with larger droplets representing only 13–29% of the droplet size spectrum. In contrast, a wider size range of fine droplets (>42%) would be required to produce the same volume of spray suspension that is drift-prone. On the basis of droplet size, this agrees with our study concerning the partitioning of drift into nontarget areas, particularly by the high-volume field sprayer.

Since the question of defining the percentage of droplets of a given size that are prone to drift has been addressed (1,3), the question of where or upon what nontarget they drift must next be answered. Plant canopy architecture is dynamic throughout the growing season, and impingement of spray droplets may vary; thus, studies of droplet impingement and drift must focus upon only one stage of canopy growth. Merritt (10) suggested that the amount of fine drifting spray may be planar and deposited preferentially in the upper portions of a crop canopy. This concept is supported by droplet size and, more importantly, by the percent areas covered at the 25-cm heights for all sprayers. Another factor that appears to influence the capture efficiency of drift-prone droplets is the target leaf surface. Although other researchers (15) have suggested that droplets less than 100 μm were probably retained on a leaf surface, Hess et al (8) and Reichard (13) both demonstrated that the droplet size and dynamic surface tension, as well as leaf cuticle hydrophobicity and morphology, contributed to varying retention rates of different spray solutions on different leaf surfaces. Rebound of droplets could result in a greater proportion of droplets being reflected from the target. Thus, increasing the wettability characteristics of a droplet by using an adjuvant should lead to greater retention by reducing the surface tension of the spray droplet (13).

Pimentel and Levitan (11) suggested that only 1 or 2% of the pesticide ever reaches the target pest. However, this assertion does not comply with the concept of a drift threshold that revolves around a value of 1%. Our findings confirm that drift may account for 1-3% of the spray applied within 5 m of the target swath; this concurs with the results of Bode and Zain (3). However, the percent leaf area covered by the drift interference accounted for a significant amount of deposition. The driftable fraction appears to exert a biological effect that is out of proportion to its total deposition (Table 3). One explanation may be the actual size of deposits; the high-volume field sprayer had droplets >800 μm in diameter per square centimeter. By volume, this would represent approximately 3.8 μl of spray suspension per square centimeter. In addition, if the frequency of application (i.e., number of spray applications per season) is considered, this could result in a significant increase in dosage per hectare. Thus, not only has percent area treated been shown to be an important factor in determining the efficacy of the metalaxyl + mancozeb mixture in this study, but also the frequency of applications cannot be overlooked. Similar studies have shown the same relationship of application accuracy and frequency with dinocap for control of apple powdery mildew (5). Indeed, a drift interference threshold may actually reflect deposition error.

Merritt (10) suggested that the forward motion of ground-rig sprayers appears to lead to the formation of vortices that can displace the small droplet fraction of a sprayer, even under so-called ideal spraying conditions with wind velocity of 2 km/hr. Our findings indicate that a sprayer that applies proportionately more spray to the target will not produce as great a proportion of driftable spray. The use of either higher operating pressures in combination with lower boom heights, or air assistance and shrouds, as well as controlled droplet atomizing (rotary) nozzles, all have the potential to increase target deposition and reduce spray drift. Similar studies comparing hydraulic and rotary atomizers have demonstrated that greater velocities of drift-prone spray droplets that overcame the wind and spray vortices resulted in greater deposition and efficacy (12,16). The ever-increasing efficacy of the newer active ingredient pesticides will only exacerbate the problem of spray drift influences in adjoining plots. Therefore, not only must small-plot pesticide trials utilize adequate space (and buffer rows) as a means to reduce drift, but also researchers should consider the use and operation of spray application machinery with shrouding that will reduce drift yet represent the majority of sprayers (application parameters) used by growers. Indeed, contemporary equipment design may strive to reduce drift, but it may actually increase drift under the least desirable operating and environmental application conditions.

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