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Bulletin 1003
May 2006

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Pesticide application may sometimes be a necessary component of crop protection for growing healthy, marketable crops. The severity of plant disease and actual or potential crop losses; the properties and efficacy of fungicides available for control; and the characteristics of the crop in the field all combine to determine the frequency and application method of fungicides necessary for effective disease control.

Blue mold of tobacco, caused by *Peronospora tabacina*, taxes the limits of all three aspects of fungicide usage cited above, in particular for shade-grown cigar wrapper tobacco. Blue mold, a leaf spot disease, is very damaging to cigar wrapper leaves that have virtually no tolerance for imperfections. The potential for pathogen increase and the speed of epidemic development are both considerable and rapid. The practical result is that if growers wait to spray fungicides until the blue mold pathogen is present in their fields, the entire crop will likely be lost within a matter of two to three weeks (LaMondia and Aylor, 2001). Fungicides used for management of this disease depend on widespread overall leaf coverage for efficacy. At the same time, the physical nature of the crop inside shade tents makes fungicide application and coverage of foliage difficult (LaMondia and Horvath, 2001).

Between 1980 and 1996, few pesticide applications to foliage were required to produce a healthy shade tobacco crop in the Connecticut Valley. During this time period, a systemic fungicide applied to the soil (metalaxyl fungicide) was absorbed by roots and translocated throughout the entire plant to provide excellent blue mold control. Applications of insecticides for control of aphids and hornworms could be accomplished without foliar sprays or with sprays that were not as coverage-dependent, allowing effective application using large-diameter spray droplets applied over the top of the shade tent.

After 1996, metalaxyl-resistant isolates of the blue mold pathogen introduced into the region caused tens of millions of dollars in losses to shade-grown cigar wrapper tobacco in the Connecticut River Valley. In 1997 alone, at least 30% of the shade tobacco crop in Connecticut was lost due to blue mold infection. Alternative fungicides to control the new strains of the pathogen were identified (Acrobat MZ and Quadris). However, these chemicals were at best translaminar and did not provide the full systemic protection previously afforded by metalaxyl. Thus, the control of losses due to blue mold required an increased frequency of fungicide application and better overall leaf coverage (LaMondia and Horvath, 2001).

The increased frequency of fungicide application and attempts to achieve better leaf coverage led to concerns about off-target drift. Off-target pesticide drift may impact human health, domestic animals and nearby crops, as well as sensitive, adjacent environmental areas. Fungicide application to shade tobacco by air, not common in Connecticut on any crop, is often more visible and remarkable to the general public than other spray techniques. Public concerns that aerial applications represented increased spray drift potential (Bird et al., 1996: Willis and McDowell, 1987) resulted in opposition to aerial spray programs by neighbors in the vicinity of shade tobacco fields (Stacom, 2001).

In July of 2001, The Connecticut Agricultural Experiment Station was charged with conducting a study of aerial pesticide application to shade tobacco to investigate off-target drift (General Assembly Bill 7507 Sec.71). The primary objectives of the project were (1) to determine if helicopter-delivered fungicides for the control of plant disease drifted off target; (2) if so, to determine the distance out to which pesticide drift was of concern; and (3) to measure the amount of pesticide deposited at a given distance from the point of application. In addition, the research was designed to (4) determine the spray coverage within the crop and (5) to evaluate alternative application techniques, as well as (6) to investigate alternatives to fungicides for disease control. This report is primarily concerned with the first three objectives.

MATERIALS AND METHODS

The study was conducted in and around a 4.5-acre shade tobacco tent on a commercial shade-grown tobacco farm (55 acres under cloth) in Enfield, CT over the 2001 and 2002 seasons. Acrobat MZ fungicide was applied commercially by helicopter on 5 dates in 2001: July 27, August 7, August 15, August 27, and September 7, 2001. In 2002, Acrobat MZ fungicide was applied at labeled commercial use rates by three different spray techniques: boom sprayer on June 11; helicopter on June 27 and August 8; and mist blower on July 15 and August 22, 2002.

Samples were collected from approximately 100 sites in and around the shade tent on each spray date. Sample locations were: (1) above and outside the tent structure, (2) inside the tent within the crop canopy and (3) outside the tent at distances of 25, 50, 100, 200, 500 and 1000 feet from the area of application. Within the target tent, samples were collected on the support wires under the cloth (about 6 feet in height); on leaves in the mid canopy (about 4 feet above the ground); and in the lower plant canopy (2 feet above the ground). There were 4 replicate samples at each height within and above the tent. Outside the shade tent the sample locations were distributed over approximately 50 acres. The majority of the sampling sites were located downwind of the treatment tent, from 25 to 1000 feet to the northwest, north and northeast of the treated shade tent. Some sample locations were placed from 25 feet, up to 300 feet, away from the treated tent to the southwest, south and southeast (upwind of most sprays applied to the tent) (Figure 1). All sample sites were located and mapped using a handheld GPS unit.

Two types of sample collection devices were used: filter paper discs for analysis of the fungicide active ingredient (AI) and water sensitive papers for determination of spray droplet number and size. Both filter paper discs and water sensitive papers were placed at each sample point immediately prior to spraying and collected shortly after the application (Figure 2). Fallout deposits such as these have been shown to effectively differentiate exposure to drift for insecticide application (Bui et al., 1998.) In addition, suction air samplers were utilized at distances outside the shade tent in 2002. Two weather stations were set up inside and outside the shade tent to measure environmental data such as wind speed, direction, temperature and relative humidity. Samples collected in the tent, samples collected from between 25 and 350 ft distant, and the most distant samples at locations farther than 350 ft from the tent were collected by three different teams to avoid any potential for cross-contamination between samples. Samples for AI analyses were coded and submitted as blind samples to the Analytical Chemistry Department. Unexposed filter papers were included as additional blind field blanks.

Acrobat MZ fungicide is a formulation of two active ingredients, dimethomorph and mancozeb. Both are considered to have only slight or very low toxicity to mammals. The presence and amount of Dimethomorph in any sample was analyzed directly by high-pressure liquid chromatography (HPLC) and ultra-violet detection at the correct retention time. Mancozeb was analyzed by an indirect method using inductively coupled plasma (ICP) analysis. Authentic AI samples were obtained from which calibration standards were prepared. Each filter paper sample was cut into halves and one-half of each sample was analyzed for each fungicide active ingredient for a total of approximately 1,000 samples during the 2001 experiment. Detected active ingredients were reported as quantity of AI per cm^2 for each sample.

Water sensitive papers were scanned and converted to black and white images and the number and area of particles determined using a software program (Rasband 2003: ImageJ) and visual confirmation. Movement of droplets and detection of AI outside the tent were modeled using AgDrift 2.0, a spray drift model published by the USDA (Teske et al., 2002). Model parameters included aircraft specification, flight speed, propeller backwash, droplet size distribution, wind speed and turbulence and relative humidity. Large droplets, >300µ, are deposited quickly due to gravity and are little affected by wind and turbulence. Smaller droplets, below 150µ, fall slowly and are more affected by wind and turbulence. The size (diameter) of the spray droplet is the most important factor determining how far that droplet will move before being deposited.

Sprays were applied in different ways. In 2001, all spray treatments were applied by a Hillman UH 12E helicopter with a Simplex hydraulic spray system, AgNav2 moving map GPS, and a CropTank 7 computer used to monitor tank volume, gpa (gallons per acre), flow, and other parameters. The helicopter spray was applied at 15 gpa at 35-40 psi through 57 T-Jet nozzles with #45 swirl plates on a 32 foot boom. Fungicide application rates and environmental conditions are reported in Table 1. Nozzles were angled at 45 degrees below horizontal to reduce wind shear of the spray drops.

In 2002, spray applications were made by helicopter, boom sprayer and mist blower. Early in 2002 (June 11), one spray was applied with a boom sprayer consisting of ten 8001 nozzles on a 15 foot boom at 32 inches above the ground. The spray was applied at 65 psi and the boom traveled at 5 feet per second to yield 28 gpa. A Tifone fruit and crop air sprayer (model 1500) mist blower was used to apply 0.5 lb per acre Acrobat MZ fungicide on July 15 and 2.0 lb per acre Acrobat MZ on August 22, 2002. The mist blower emitter was operated at 2 feet off the ground and angled at 15 degrees above horizontal.

RESULTS

2001 - The farthest detection distances of the dimethomorph active ingredient of Acrobat MZ fungicide were 100, 200, 50, 480, and 100 feet downwind of the application site on each of the July 27; August 7; August 15; August 27; and September 7, 2001 application dates, respectively (Table 2). The analytical detection of the mancozeb active ingredient of the Acrobat MZ fungicide was detected downwind of the application site at similar distances and distribution (Table 3).

The number of droplets detected per cm^2 on spray paper sample sites decreased dramatically from the top of the tent and plant canopy to the lower plant leaves; additionally, the number of droplets decreased dramatically with increasing distance from the tent (Table 4). Drop size also became smaller from the top of the tent/canopy to the lower canopy as well as with distance from the tent (Table 5 and Figure 3). We determined that half of the droplets collected within the target area above the tent were greater than 225 µ in diameter, while droplet size became much smaller as samples were collected at distances away from the tent or further into the plant canopy (lower leaves on the plant). For example, half of the droplets collected at 100 or 200 feet from the tent were smaller than 25 to 30 µ. It would take nearly a thousand of these sized droplets side by side to equal one inch. Larger droplets contain more volume and a much greater amount of fungicide. For example, a 300 µ drop contains 1000 times the fungicide contained in a smaller one-tenth diameter 30 µ drop.

2002 - The dimethomorph active ingredient of Acrobat MZ fungicide was only detected within the shade tent (no detection at 25 feet or greater outside the tent) for the boom sprayer on June 11; within the shade tent for the helicopter application on June 27; within the shade tent for the mist blower application on July 15; 100 feet from the tent for the helicopter application on August 8; and 50 feet from the tent for the mist blower application on August 22, 2002 (with the suction sampler only). Each of these detections was at trace levels, testing positive for the AI, but at non-quantifiable levels (below the quantification limit of 0.016 µg/cm^2 dimethomorph), with the exception of the suction sampler results, which were at quantifiable levels of 3.36 µg/cm^2 dimethomorph.

DISCUSSION

We did not have sufficient numbers of sprays to compare helicopter to boom or mist blower applications. Even with large numbers of spray applications, slight changes in environmental conditions would make direct comparisons between sprayers inappropriate. Therefore, an empirical sampling approach and the development of predictive models to determine the critical factors affecting drift are important. The Spray Drift Task Force (SDTF), a joint development project of 40 agricultural chemical companies, created a large database of repeated experimental field-drift evaluations (161 trials) for the purpose of modeling the parameters that affect drift (Hewitt et al., 2002). These applications were under conditions suitable for experimentation, and were not applied to a commercial crop. The SDTF developed AgDrift, a model for estimating near-field spray drift from aerial pesticide applications (Teske et al., 2002). We used this model to assist us with interpretation of the results from our spray drift trials under commercial crop production conditions.

Averaged over the sample dates in 2001, 93.6% of the fungicide spray applied by the helicopter was deposited within the target shade tent, 99.1% within 25 feet of the tent, 99.3% within 50 feet, 99.4% within 100 feet and 99.6% within 200 feet of the tent. The dimethomorph fungicide that was deposited outside the tent was at trace levels (below the quantifiable limit of 0.016 µg AI/cm^2) for all samples but one. A single sample at 25 feet on August 27 had 0.21 µg AI/cm^2 dimethomorph. To put the analytical detection levels into meaningful terms, we can compare the amount of dimethomorph drift away from the tent to the EPA Food Tolerance allowed on food crops. This fungicide is currently labeled for use on tomato. If we can assume that the lowest quantifiable limit of 0.016µg AI/cm^2 was deposited on the entire surface area of a tomato fruit 8-cm (nearly 3.25 inches) in diameter and weighing 250 grams (0.55 lb) at a location outside the shade tent, the fruit would at most contain 3.2 µg of dimethomorph. The EPA Food Tolerance for dimethomorph for tomatoes is 0.5 ppm or 125 µg of dimethomorph for the same tomato (Federal Register: September 29, 2000 (Volume 65, Number 190) Rules and Regulations Page 58385-58390). The dimethomorph spray drift beyond 25 feet from the tent did not exceed trace levels and would have been less than 3% of the allowable levels of the dimethomorph on a tomato for all the sprays examined.

In the second year of the study, dimethomorph was detected at lower quantities and at smaller distances from the application site, most likely due to the reduced application rates of Acrobat MZ applied in 2002.

The helicopter spray drift data that we collected were quite comparable to published results for fixed wing aerial application and (airblast) for ground based spraying of orchards. Off-target drift around the shade tent was intermediate between orange (airblast) and apple data and fell from 0.6% of the application rate at 50 feet to less than 0.02% at 100 feet (Figure 4) (Bird *et al.* 1996). Results from fixed wing aircraft developed by the Spray Drift Task Force indicated that 98% of the applied AI was deposited on the target field, with only 2% drift off-site (Bird et al, 1996). However, field size may affect the percentage drift from fields. Smaller fields had a greater percentage drift as drift usually occurs from the most downwind swath rather than from more upwind passes through the field. Smaller fields have a greater percentage of the total applied pesticides in these downwind border areas. However, the actual fungicide AI concentration at the same distance from small fields would be less than from large fields, even though the percentage of the total off target was higher. The 2% drift reported previously was from a 1200 foot wide field. Sprays from a 180 foot wide field had a 92% deposition rate and 8% drift. Aerial pesticide applications to commercial shade tobacco fields in Connecticut over the past few years ranged from small fields of 7 acres up to large fields of 35 acres (C. Webber, pers. comm.). Our results were from an experimental site half the size of a small field, 300 foot wide field 660 feet long, and fell within this range.

Based on our data and similar results from previous studies, the 200 foot buffer zone established around target shade tobacco fields by the Connecticut Department of Environmental Protection would appear to be sufficient to protect nearby sensitive areas or neighboring properties when sprays were conducted in a similar manner to those included in these studies.

Data from our studies and those developed by the Spray Drift Task Force allow us to determine the important factors affecting drift and focus on means of reducing the potential for future spray drift. The most important factors that affect fungicide spray drift are physical and environmental. Physical factors that may affect spray drift include overspray (inadvertent application beyond the target field), spray droplet sizes, the release height of the pesticide, and the spray boom length. GPS tracking and printouts of the helicopter spray applications, on-site observation, and analyses of samples 25 feet from the target shade tent indicated that sprays were made to the edge of the experimental field and that little or no overspray occurred.

Droplet size distribution is the single most important spray factor associated with downwind drift (Bird et al., 1996). Small droplets, particularly those below 150 μ in diameter, are most likely to move off-site. We determined that half of the droplets sprayed over the shade tent were greater than 225 μ in diameter, while droplet size became much smaller as samples were collected at distances away from the target. Increased air shear at the nozzles has been shown to reduce spray droplet size and, therefore, increase the potential for off-target drift. Air shear is most severe when nozzles are pointed directly down at a 90 degree angle to the horizontal and least when pointed back away from the forward direction of the boom (0 degree angle) (Bird et al., 2002). In our studies, the spray nozzles were angled at 45 degrees back from the boom to reduce wind shear of spray droplets.

Helicopter application has a potential to reduce drift in comparison to fixed wing aircraft, as flight speeds and, therefore, wind shear are typically lower for helicopter applications, producing sprays with larger droplet sizes (Bird et al., 2002, Hewitt et al., 2002). Flight speeds for the helicopter application during our experiments were 40 mph. Previous fixed-wing aircraft applications over the same fields were made at 130 mph (C. Webber, pers. comm.). The relatively slow air speed and the fact that spray nozzles were angled at 45 degrees back from the boom reduced wind shear of spray droplets and maintained larger spray droplet sizes. Release heights over the shade tent were also low, within 6 feet of the top of the tent. Boom length was 75% of the helicopter blade diameter, and within the recommended lengths to limit turbulent vortices that may contribute to drift.

Environmental factors that affect spray drift include wind speed, atmospheric stability or turbulence, evaporation, and terrain effects. Bird et al. (2002) determined that as wind speed increased from 5.6 to 11.2 mph (2.5 to 5 m/second), the amount of pesticide drift doubled. In our experiments, wind speed ranged from trace to 6 mph in 2001. Wind speeds ranged from trace to 4 mph in 2002. In all cases, winds were below 10 mph and not conducive for increased drift.

Atmospheric stability may also have a large impact on drift. Inversions may be difficult to measure and were beyond even the scope of the Spray Drift Task Force and AgDrift model. In general, wind speed effects have been associated with increased drift near the application point, and atmospheric stability (inversions) associated with increased drift at greater distances away from the application (Bird et al., 1996). Evaporation of water from spray droplets under low humidity may reduce spray droplet size and, therefore, increase drift. Bird et al., (1996) determined that even under low humidity conditions, relative humidity had no significant impact on spray drift. In our experiments, relative humidity was fairly high, ranging from 35 to 86% and should not be expected to evaporate spray droplets rapidly. In fact, high humidity made it difficult or impossible to measure spray droplets on several occasions as spray papers changed color due to humidity over 80%. Finally, the AgDrift model assumes level terrain. While our experimental field was relatively flat, there was a slope off to the north-northwest which may have drained air from the treated shade tent. The furthest detection of trace levels of dimethomorph at 480 from the tent on August 27, 2001 was found downwind along this slope (about a 10-foot drop in elevation).

Spray coverage on and inside the shade tent was determined by collecting samples on top, outside the tent; inside on the support wires under the cloth (6 feet in height above the ground); on leaves mid canopy (4 feet); and in the lower plant canopy (2 feet above the ground). Spray residues deposited above the tent should have been and were similar to concentrations in the spray tank. Spray residue deposits decreased with distance from the top of the tent into the plant canopy. Averaged over the five occasions in 2001, dimethomorph spray residues were 33.8%, 12.8% and 4.8% of those outside and above the tent at 6, 4 and 2 feet in height under the shade cloth, respectively.

Scientists at the Connecticut Agricultural Experiment Station also continue to research alternatives to fungicide use for future management of tobacco blue mold. Two promising alternatives are genetic plant resistance to the blue mold pathogen and the initiation of a plant resistance response in an otherwise susceptible cultivar by means of a biochemical trigger (a phenomenon called Systemic Acquired Resistance). Plant genes conferring resistance to the blue mold pathogen *Peronospora tabacina* have been identified and transferred into shade and broadleaf tobacco types. The future development of blue mold-resistant cultivars would reduce the fungicide use requirements to control this disease.

HIGHLIGHTS

1) Analytical detection of Acrobat MZ fungicide was successful and very sensitive. Approximately 2,000 samples were analyzed over ten sample dates over two consecutive growing seasons.
2) The USDA AgDrift model is applicable to Connecticut and will help predict ways to further reduce drift without loss in crop protection.
3) All detections beyond 25 feet from the target shade tent were at trace levels below the quantifiable limit of 0.016 μg AI/cm^2. Trace levels of dimethomorph were found outside the tent with the farthest detection ranging from 50 feet to a single sample at 480 feet.
4) If tomatoes were grown as close as 25 feet from the shade tent, the levels of dimethomorph on fruit would not exceed established EPA Market Basket Food Tolerances.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Walter Krol, Craig Musante and Terri Arsenault in the Analytical Chemistry Department and Jane Morrison, Rich Horvath, Steve Lamoureux, Jason Parent, Rose Hiskes and Carole Cheah of the Valley Laboratory for their assistance with this project.

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Table 1. Environmental conditions during spray applications of Acrobat MZ fungicide on data collection dates in 2001 and 2002.

Spray date	Sprayer	Time	Wind mph, direction	Temp ˚F	RH	lb Acrobat MZ per acre
July 27 2001	Helicopter	8:00 PM	< 2 N	71	66	1.5
Aug 7 2001	Helicopter	6:45 PM	Trace SE	94	50	1.5
Aug 15 2001	Helicopter	6:30 PM	3.5 - 5.0 SE	79	64	1.0
Aug 27 2001	Helicopter	6:00 PM	<2 N gust to 3	75	86 (light rain)	1.0
Sept 7 2001	Helicopter	6:15 PM	2 - 6 SSW	84	60	1.5
June 11 2002	Boom sprayer	2:25 PM	3-4 SSW	88	50	0.5
June 27 2002	Helicopter	6:02 PM	<2 SSE	82	67	0.5
July 15 2002	Mistblower	12:00 PM	<2 SSW	86	58	0.5
Aug 8 2002	Helicopter	5:25 PM	2-3 N	77	35	1.0
Aug 22 2002	Mistblower	10:15 AM	2-3 NW	77	58	2.0

Table 2. Analytical detection of the dimethomorph ingredient of Acrobat MZ fungicide (µg AI/cm^2) on filter paper at different sample locations for five aerial spray applications in 2001.

Sample site	27 July	7 August	15 August	27 August	7 September
Tent surface	1.59 *	1.68	0.48	2.43	0.99
Top canopy	0.30	0.96	0.11	0.77	0.41
Mid canopy	0.21	0.13	0.004	0.49	0.06
Low canopy	0.09	0.05	0.00	0.25	0.02
25 **	0.01	0.03	0.001	0.02	0.007
50 **	0.006	0.008	0.005	0.008	0.010
100 **	0.002	0.007	0.00	0.006	0.006
200 **	0.00	0.006	0.002	0.004	0.001
500 **	0.00	0.00	0.00	0.002	0.00
1000 **	0.00	0.00	0.00	0.00	0.00

* Analytical detection at µg AI/cm^2.

** Feet from the target tent

Table 3. Analytical detection of the mancozeb ingredient of Acrobat MZ fungicide (µg AI/cm^2 manganese) on filter paper at different sample locations for five aerial spray applications in 2001.

Sample site	27 July	7 August	15 August	27 August	7 September
Tent surface	2.80 (µg AI/cm^2)	2.45	0.74	3.91	1.61
Top canopy	0.44 *	1.64	0.30	1.39	0.76
Mid canopy	0.31	0.36	0.05	0.68	0.15
Low canopy	0.15	0.21	0.07	0.42	0.15
25 **	0.02	0.13	0.00	0.14	0.05
50 **	0.06	0.04	0.003	0.09	0.03
100 **	0.00	0.03	0.00	0.04	0.02
200 **	0.00	0.03	0.06	0.04	0.00
500 **	0.00	0.00	0.00	0.00	0.00
1000 **	0.00	0.00	0.00	0.00	0.00

* Analytical detection at µg AI/cm^{2}.

** Feet from the target tent

Table 4. Spray droplets per cm^2 on water-sensitive spray cards at different sample locations for three aerial spray applications in 2001.

Sample site	7 August	15 August	7 September
Tent surface	91.1	24.0	65.4
Top canopy	39.6	10.4	47.8
Mid canopy	5.0	3.1	6.3
Low canopy	0.7	1.8	4.0
25 **	1.9	0.7	1.7
50 **	1.7	1.9	2.3
100 **	0.04	0.3	0.5
200 **	0.01 *	0.2	0.1 *
500 **	0.0	0.1 *	0.2 *
1000 **	0.0	0.0	0.0

* Results from a single drop per spray paper

** Feet from the target tent

Table 5. Spray droplet size (maximum and mean diameter in µ) at different sample locations for three aerial spray applications in 2001.

	7 August		15 August		7 September	
Sample site	Maximum	Mean	Maximum	Mean	Maximum	Mean
Tent surface	647.7	134.6	1264.9	129.5	609.5	106.6
Top canopy	503.0	134.6	609.5	116.8	515.6	104.1
Mid canopy	342.3	147.3	350.5	106.6	325.1	99.1
Low canopy	241.3	114.3	254.0	119.3	368.3	106.6
25 **	101.5	66.0	177.3	68.5	233.6	99.1
50 **	101.5	61.0	157.4	63.5	147.3	73.7
100 **	50.3 *	50.3 *	139.7	81.2	119.3	71.1
200 **	25.4 *	25.4 *	76.2	61.0	76.2 *	63.5 *
500 **			50.3 *	27.9 *	127.0 *	99.1 *
1000 **			76.2 *	50.3 *		

* Results from a single drop per spray paper

** Feet from the target tent

Figure 1. Map of spray drift study site, Enfield CT. Black dots on the contour map represent sample locations.

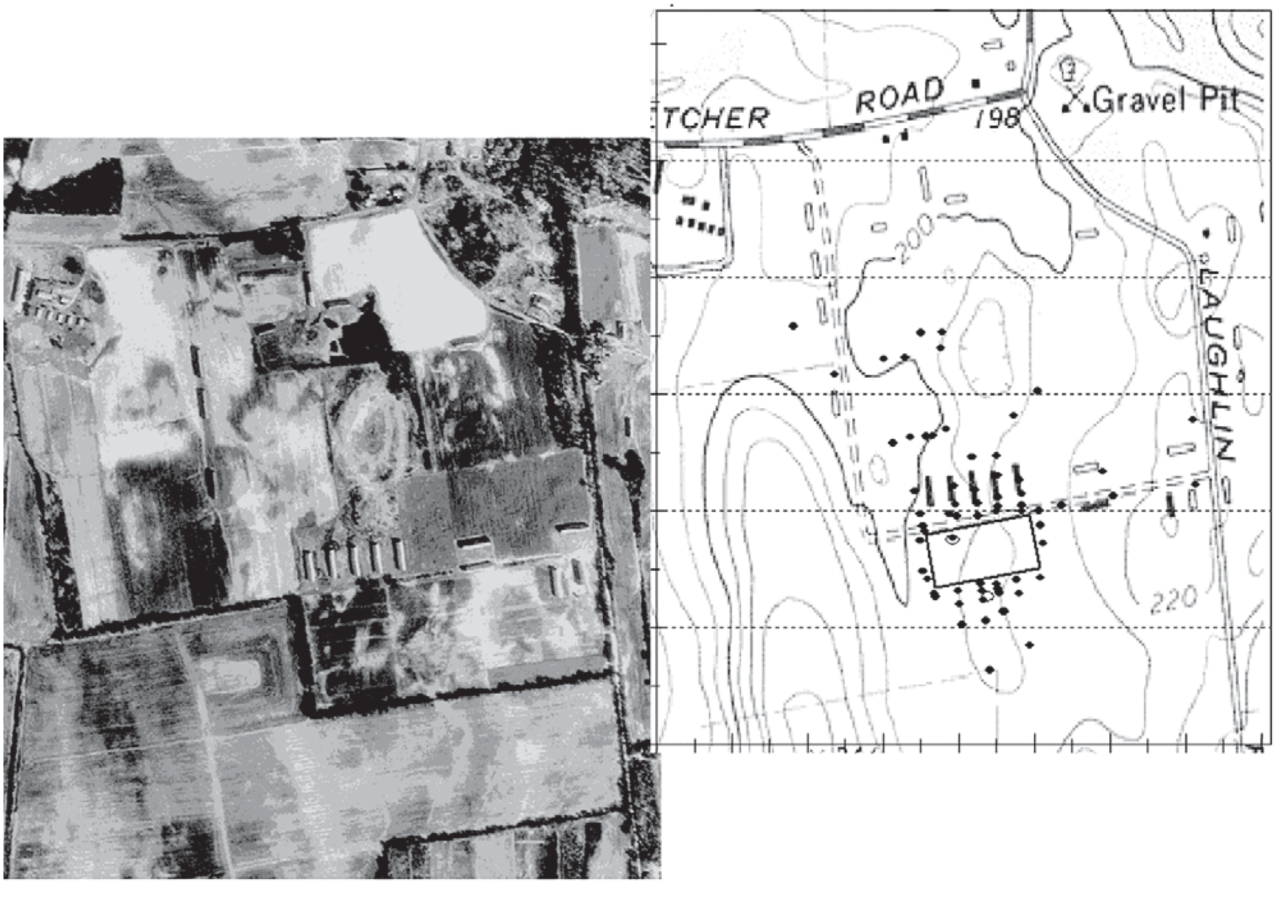

Figure 2. Water sensitive papers (yellow rectangle on left) for analysis of spray droplet number and size and circular filter paper discs for analysis of the fungicide active ingredient (AI).

Figure 3. Droplet diameter distribution within the shade tent (wire) and at distances of 25 to 200 feet from the target tent, 2001.

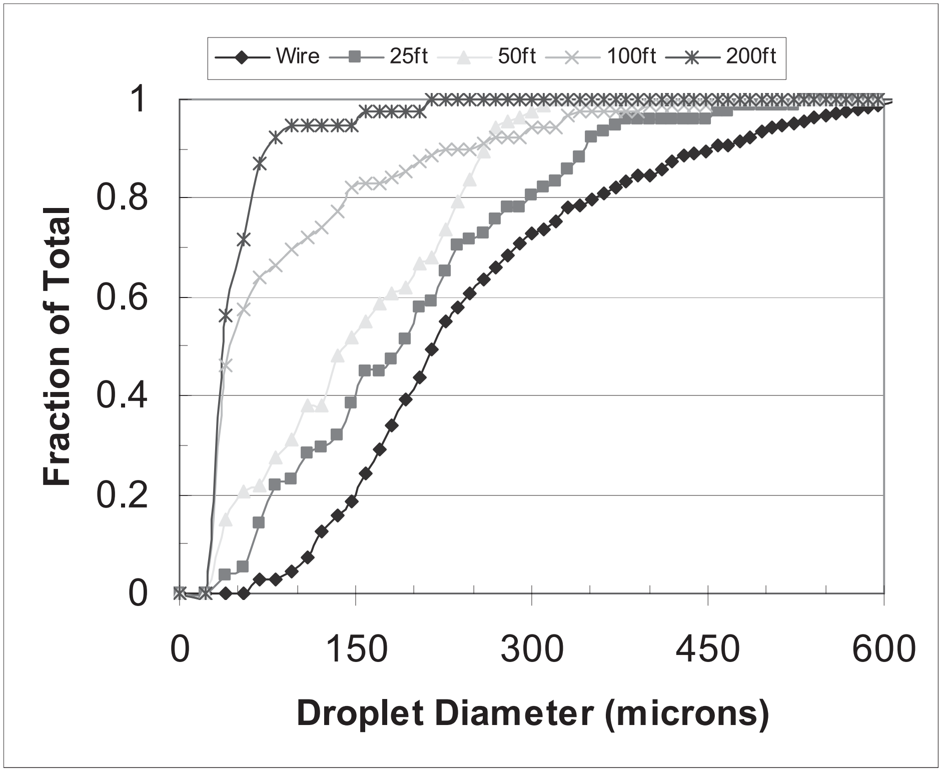

Figure 4. Comparison of 2001 shade tent data with pesticide drift data from apples and oranges developed by the Spray Drift task Force.