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A COMPARISON OF TWO SPRAY NOZZLE SYSTEMS USED TO AERIALLY APPLY THE ULTRA-LOW–VOLUME ADULTICIDE FENTHION

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ABSTRACT. Field experiments with the mosquito adulticide fenthion (Baytex®) compared the conventional flat-fan nozzle system (Tee Jet 8002SS) and a new high-pressure hollow-cone nozzle system (1/8 M1SS). Ground deposition and aerial flux of the mosquito adulticide fenthion were measured up to 4.83 km downwind by using filter paper and yarn collectors, respectively. Biological efficacy was investigated by using caged salt-marsh mosquitoes (*Ochlerotatus taeniorhynchus*), and caged fiddler crabs (*Uca pugilator*) were exposed to quantify nontarget impact. Peak deposits to the ground were 1,729 μg/m² and 240 μg/m² for the flat-fan nozzles and high-pressure cones, respectively. Deposits from the flat-fan nozzles resulted in a cumulative fiddler crab mortality of 80%, whereas no deaths were recorded with the high-pressure system. The range of fenthion flux detected in the air when using the yarn collectors was similar for the 2 systems, with both showing drift through 4.83 km. For the flat-fan spray nozzle system, the aerosol flux ranged from 3.02 to 67.33 μg/yarn collector. The range of aerosol flux for the high-pressure nozzle spray system was 0.15–50.66 μg/yarn collector. Although the 2 systems produced comparable ranges of flux, the high-pressure system provided higher control efficacy against mosquitoes. Maximum mosquito control when using the flat-fan spray nozzle system against female salt-marsh mosquitoes was 26.6%, whereas maximum control with the high-pressure spray system was 92.9%.

KEY WORDS Ultra-low–volume aerial spray, high pressure, droplet size, salt marsh mosquitoes, ground deposition

INTRODUCTION

Aerial spray technology used in agriculture and forestry pest control is similar to that used to control adult mosquitoes. The goal for agricultural pesticide application is to ensure deposition onto the target crop while minimizing drift. Off-target movement of pesticide aerosols, which is how drift often is defined, may cause environmental contamination and nontarget impact (Murray and Vaughan 1970, Bache and Lawson 1988). Conversely, drift of pesticide aerosols actually is necessary for the control of adult mosquitoes.

Aerial application of adulticides continues to be an important public health protection measure in large populated areas adjacent to extensive mosquito developmental habitats. In such areas, aerial ultra-low–volume (ULV) application of adulticides is one of the most effective techniques for controlling mosquitoes and for the prevention of mosquito-borne diseases (Mount et al. 1968, Mount 1970). Although insecticides often are distributed at uniform rates from the aircraft, the ultimate fate of the aerosol depends on the volume of individual droplets and specific gravity of the material being applied. Large aerosol droplets that deposit rapidly onto the ground's surface are not available for control of adult flying mosquitoes and, therefore, are considered waste. Furthermore, large droplets may increase the risk of exposure of nontarget species as a result of greater levels of deposition.

Fenthion is a compound labeled for aerial mosquito control use in Florida. During conventional mosquito control applications, large droplets of this pesticide may be deposited onto tidal wetlands and wildlife areas and may result in nontarget mortality. Invertebrates residing in the intertidal zone have been shown to be susceptible to fenthion exposure (McKenny et al. 1985; Clark et al. 1986, 1987). A recent study at the Rookery Bay National Estuary Research Reserve near Naples, FL, found that ground deposition was associated with decreased populations of fiddler crabs (*Uca repax*) (McKenney et al. 1997, Schoor et al. 2000). Fenthion deposits in water and sand habitats have been shown to reduce survival and reproduction of the panacea sand fiddler (*Uca panacea*) in a controlled laboratory habitat (Schoor et al. 2000).

Optimal pesticide application requires that the maximum quantity of chemical reach the target, which in this case is the adult mosquito (Haile et al. 1982a; Mount et al. 1968, 1970b, 1970c; Mount 1970). Control is most successful when mosquitoes are active or in flight. Therefore, the aim is to apply the aerosol at the correct time, height, dose, and droplet size. Mount (1970), in a review of previous laboratory and field research, suggested that 5- to 10-μm and 10- to 25-μm droplets are optimal in mosquito control for ground and aerial sprays, respectively. The efficacy of insecticide aerosols against adult mosquitoes is greatest in the range of

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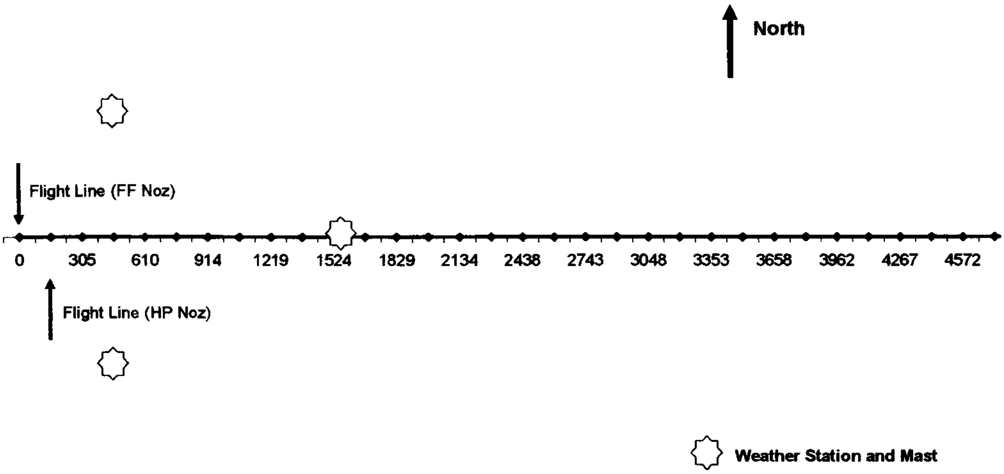

Fig. 1. Schematic of the sample line, weather station location, and flight line for the 2 treatment nozzles.

7–22 μm and diminishes quickly outside of that range based on wind tunnel studies (Latta et al. 1947, Haile et al. 1982b). The drift of small (<100-μm) aerosol droplets, which is undesirable from an agricultural standpoint, has been found to effectively kill mosquitoes for many kilometers downwind (Mount et al. 1970a, Haile et al. 1982a). Conventional ULV flat-fan nozzle systems can have volume median diameters (VMDs) ranging from 30 to 60 μm, depending on the nozzle (Mount et al. 1970b). This means that a significant fraction of the spray volume consists of droplets greater than 100 μm in diameter. These large droplets may not contact the mosquitoes, but rapidly fall out, potentially causing nontarget mortality or sublethal effects.

Priorities in the selection or design of new spray systems include maintaining control efficacy against adult mosquitoes and protecting the public health and welfare of residents and tourists, while reducing insecticide deposition to better protect the natural environment. Therefore, aerosol drift dynamics and reduction of ground deposition are 2 important factors for improving mosquito adulticide effectiveness.

In this study, we have compared downwind aerosol movement and the deposition profile of the adulticide fenthion when using 2 spray nozzle systems, a conventional flat-fan nozzle system and a new high-pressure hollow-cone nozzle system. The primary objective at this stage of the research was to assess nontarget mortality as a result of use of these 2 application systems. Concern has been increasing about nontarget species mortality with conventional spray equipment, so ground deposition at distance downwind was measured. The nontarget animals were fiddler crabs (*Uca pugilator* (Bose)). Detailed atmospheric readings were taken to help understand the movement of the different pesticide clouds produced by the different systems. Aerial flux and caged salt-marsh mosquito (*Ochlerotatus taeniorhynchus* (Wiedemann)) bioassays were used to measure application efficacy at distance for further development and optimization of the systems.

MATERIALS AND METHODS

Location: The study site was located at Golden Gate Estates approximately 8 km east of Naples, FL. Vegetation surrounding the sampling site was uniform woodland 8–15 m in height. The area contains a vast network of paved roadways; sample sites were located on road edges. Data were collected for 4.88 km on the eastern end of the study site (Fig. 1). Thirty-three collection stations for fenthion residue were established at 153-m intervals adjacent to an east–west roadway. At every other station, caged mosquitoes were positioned next to the residue collectors. Fiddler crabs were exposed at 3 stations, 437, 2,743, and 4,420 m downwind of the spray line.

Application equipment: Adulticide application was conducted by the Collier Mosquito Control District with a DC-3 airplane equipped with a global positioning guidance system. Three replicates were completed for each spray nozzle system during a predominately west wind. The chemical was applied in 1 swath from an altitude of 91.4 m (300 ft) and was discharged at an air speed of 240 kph (150 mph) for both systems. The flight line was north-south and was aligned with 0 m for the flat-fan spray but the high-pressure spray was offset to 153 m (Fig. 1).

The 1st system tested used conventional flat-fan nozzles (Tee Jet 8002SS, Spraying Systems Co., Wheaton, IL), with 414-kPa (60 psi) liquid pressure and at a nozzle angle of 45° forward (into the wind). The spray pump was calibrated to deliver 47.5 ml/ha (0.65 oz/acre). In this study, the flat-fan nozzle system generated aerosol droplets within a

79- to 94-μm VMD range. Currently, this nozzle system is the most commonly used nationwide for mosquito control via aerial application of adulticides.

The 2nd spray system used high-pressure hollow-cone nozzles (1/8 M1SS; Spraying Systems Co.) operated at 20,684 kPa (3,000 psi), positioned on the tail boom pointing straight back. This system was developed at Pasco County Mosquito Control District and produced droplets with a VMD of 14 μm (Malvern laser data, Lee County Mosquito Control District laser facility [unpublished data]). Fenthion was applied at 35 ml/ha (0.48 oz/acre), a 25% reduction from the intended flow rate (47.5 ml/ha) because of loss of pressure in the high-pressure system caused by an increase in hose length (between the pump and tail boom) relative to the bench-tested model.

Meteorological monitoring: Three weather stations that used CR10X data loggers (Campbell Scientific, Lakeland, FL) were positioned downwind in a triangular arrangement approximately 1.6 km (1 mi) apart. One weather station was on the east–west roadway that was the established sample transect and the other 2 stations were on a north–south roadway, with 1 placed 0.8 km (0.5 mi) north of the sample transect and another 0.8 km south of the sample transect. Each weather station consisted of a 10-m mast with CSI (Campbell Scientific) weather monitors (propeller and wind vane) at 2- and 10-m heights. Each mast also had 3 temperature sensors positioned at 1.5, 4.3, and 7.9 m. A humidity sensor at 4.3 m and a Gill UVW anemometer (Campbell Scientific, Logan, UT) at 5.5 m were incorporated into the weather station positioned along the east–west sample transect. The Gill UVW anemometer measures the U, V, and W orthogonal wind vectors, along the 2 horizontal axes and 1 vertical axis. A barometric pressure sensor at ground level also was incorporated into the weather station located on the south side of the triangle. Weather data were collected at a sampling rate of 1 Hz at the sampling transect station and 0.5 Hz at the other 2 weather stations. Data were internally averaged and recorded at 15-min intervals.

Bioassay—fiddler crabs: Cages of fiddler crabs were used to assay the effects of fenthion deposition on nontarget animals. Fiddler crabs used in this study were collected from a pristine area outside the mosquito control application zone. Twenty-four hours before the scheduled spray time, 5 males and 5 females were placed in each of 12 dishpan mesocosms (30.5 × 40.5 cm) (Zhong et al. 2004). Three dishpan mesocosms with 30 fiddler crabs were placed at each exposed location and at an unexposed upwind control location. Beach sand (25.4 mm) was placed in each dishpan mesocosm, and the sand was wetted with 35 parts per thousand salt water. Mesocosms were covered with hardware cloth to prevent escape or predation by other animals. Crabs were picked up within the 1st hour after sunrise after the application of fenthion. All dead crabs were removed and crab mortality was recorded (Zhong et al. 2003).

Fenthion sampling: Filter papers (24-cm diameter, Whatman International Ltd., Maidstone, United Kingdom) were used to collect fenthion that had deposited on the ground. Two filter papers were pinned side by side on a Styrofoam board (40 × 80 cm) covered with aluminum foil. The boards were placed at each downwind sampling station (153-m intervals) at ground level for 4.8 km. Fenthion droplets were collected on a piece of acrylic, mohair-look yarn (Lion Brand Yarn Co., New York, NY) measuring 6.7 m in length. The yarn was vertically oriented and suspended from crossarms from a height of 1.5–8.2 m on a 10-m steel mast. Vertical yarn deposits represented chemical in flux. The residue samples were collected approximately 3 h after fenthion spray application to allow spray droplets to settle.

Chemical analysis: Each filter paper was removed from the Styrofoam board and folded by using 2 pairs of forceps and placed into individual screw-top 40-ml Pyrex® culture tubes. Each yarn sample was removed from the mast and placed into individual screw-top 40-ml Pyrex culture tubes. Tubes were filled with 30 ml of hexane for subsequent gas chromatography analysis. All samples were placed in a cooler held at 4°C. Quality control of residue recovery from field samples was conducted by spiking 50-μl fenthion standards (1 mg/ml) to filter papers at the time of the aerial spray. All field and spiked samples were transported to the laboratory at the Public Health Entomology Research and Education Center (PHEREC), Florida A&M University (FAMU), Panama City, FL, for fenthion residue analysis. To ensure analytical data quality, one of the paired filter paper samples from each sampling station was shipped to the U.S. Environmental Protection Agency (U.S. EPA) Laboratory at Gulf Breeze, FL, for analysis.

Fenthion residue was determined by a Varian 3400 gas chromatograph equipped with a thermionic specific detector (TSD) and 8200 auto-sampler (Varian Analytical Instruments, Sugar Land, TX). Results were transferred to a PC equipped with data-handling software for processing (Star Chromatograph Version 4.51, Varian Analytical Instruments). The injector was operated at 250°C in 10 to 1 split mode with the detector functioning at 300°C. A DB-5 capillary column (30 m, 0.25-mm inner diameter, 0.1-μm film thickness; J&W Scientific, Folsom, CA) bonded with fused silica also was used. The column oven starting temperature was 130°C with an increase at 15°C/min to 275°C, then holding for 3 min. Fenthion retention time was 5.6 min and the total analytical time was 10 min. A standard injection volume of 1 μl was used for all standards and samples. The fenthion standard calibration consisted of a 5-point calibration curve ranging from 0.1 to 10 μg/ml with $R^2 \geq 0.995$.

Table 1. Maximum meteorological values during each drift period.

	Wind monitor at 10 m			Gill UVW anemometer					
Date (1998)	Mean (m/sec)	Gust (m/sec)	Direction	Mean (m/sec)	Direction	Gust (m/sec)	Vertical gusts (m/sec)	Temperature range 7.9 m to 1.5 m (°C)	Relative humidity (%)
April 21	<1.1[1]	1.1	SW	0.4	SW	0.8	<0.3	0.1–0.8[3]	96
April 22	<1.1	1.5–2.0	WNW	0.8	W	1.5	0.4	0.2-1.0[3]	88
April 23	<1.1	1.1	NW	<0.3[2]	SW	0.4	<0.3	1.5–2.5	94
May 12	1.4	2.8	WNW	1.5–2.5	NW	6.2	0.7	0.3–1.5	88
May 13	<1.1	1.5	W	3.8	N	5.2	<0.3	1.0–3.0	87
May 14	<1.1	1.1–1.3	NW	1.7	S	1.9	<0.3	0.7–1.0	86

[1] Threshold of wind monitor.

[2] Threshold of Gill UVW anemometer.

[3] Sensor and shield were touching; values probably are incorrect.

Continuous calibration at 2 μg/ml was conducted every 10 samples. Continuous calibration must pass the criterion of 100 ± 10% recovery each time; otherwise, a new calibration curve must be generated. Laboratory and field spikes should pass the limit of 100 ± 20%. Blanks were used to ensure quality control of field samples.

Bioassays—mosquitoes: Caged mosquitoes were used to determine the efficacy of the fenthion aerial sprays and to assay drift (Riley 1995). Only 1 swath was applied so control was expected to be low; the main purpose of this was to help calculate required swath widths for further optimization of these systems. The species used was a laboratory strain of *Oc. taeniorhynchus* reared at PHERC, FAMU. Approximately 25 adult female mosquitoes, 6–8 days in age, were placed in each cylindrical cage (14-cm diameter by 3.5-cm height, with a 14 × 14 mesh size). Cotton pads moistened with sugar water were placed between the cages both before and after testing for the adult mosquitoes. At every other sampling station, 2 cages of adult *Oc. taeniorhynchus* were positioned on stakes at a height of 1.5 m above the ground surface. Eight mosquito cages, used as controls, were placed several kilometers upwind of the spray line. Approximately 3 h after spray application, cages were picked up and mosquitoes were transferred to clean cages (Rathburn et al. 1969). The mosquitoes were counted at 12–14 h after treatment for percent mortality. Control cages were handled in the same manner as treatment cages.

RESULTS

Meteorological monitoring

Weather variables shown in Table 1 are the maximum values recorded, and primarily reflected the 1st hour after spray. Only the values from the data logger on the sample line are shown. Wind speeds were low and often were below the anemometer thresholds for most of the testing sample periods.

Bioassay—fiddler crabs

The accumulation of fenthion deposition from 3 consecutive tests with the flat-fan nozzle system resulted in 80% total fiddler crab mortality. However, no fiddler crab mortality was observed with the high-pressure system during exposure on 3 consecutive nights.

Chemical sampling

On April 21, substantial amounts (16–67 μg) of fenthion applied with the flat-fan nozzles were recovered from the yarn in the 1st 0.8 km. On April 22, the highest residue recovered from yarn was 45 μg at 1.98 km from the spray line, with almost the same amount recovered at 0.9 km downwind. Except for 1 station, the range of recovery from yarn between 0.9 and 1.98 km, inclusive, was 20–45 μg (Table 2). On April 23, the range of recovery from yarn generally was from 10 to 20 μg within the 1st 1.6 km. However, fenthion residue recovered from yarn at 0.6 km was 48 μg.

On May 12, the range of fenthion applied with high-pressure hollow cones recovered from yarn was 13–51 μg from 1.2 to 4.4 km downwind. The recovery from yarn from 0 to 1.0 km and 4.6 to 4.9 km generally was low (< 15 μg; Table 2). On May 13, recovery was very low, below 5 μg for the entire transect; and this also was true on May 14, with only a few points above 10 μg.

Similar residues (≥10 μg/yarn) were found for both spray systems but the profile downwind was different. Measurements on yarn of ≥10 μg/yarn were found between 0.31 and 1.98 km for the flat-fan nozzle system and 1.52 and 3.66 km for the high-pressure nozzle system (Table 3).

The greatest residues on filter paper were 1,729, 1,213, and 657 μg/m^2 on April 21, 22, and 23, respectively, for the flat-fan nozzle system with a droplet VMD of 81 μm. The greatest average ground deposition was 742 ± 890 μg/m^2 at 0.31 km (Table 3). The high-pressure nozzle system, with a droplet VMD of 14 μm, eliminated the large

Table 2. Comparison of deposit, drift, and mortality from flat-fan nozzles (April 22, 1998) and high-pressure hollow-cone nozzles[1] (May 12, 1998).

Distance (m)	Filter paper (μg/m^2)		Yarn (μg)		Percent mortality	
0	0	0	0	0	0	0
152	0	0	0	0.16	3.1	
305	0	0	0	0	0	0
457	0	0	0	0	2.4	
610	0	0	0	3.23	0	6.8
762	256.94	0	20.62	0	0	
914	1,212.64	0	44.98	3.11	10.5	13.6
1,067	135.99	0	24.17	5.45	12.6	
1,219	189.04	0	9.68	4.91	6.9	2.2
1,372	147.92	0	24.14	12.68	3.6	
1,524	121.84	0	21.45			73.5
1,676	146.6	0	29.98	25.78	11.4	
1,829	142.18	0	38.62	21.61		28.8
1,981	160.92	0	45.34	22.42	26.6	
2,134	75.6	0	14.6	27.42		92.9
2,286	88.59	0	11.85	23.77	0	
2,438	151.11	67.2	24.79	28.7		34.9
2,591	93.19	80.9	16.24	18.26	0.3	
2,743	93.81	0	12.7	13.61		38.2
2,896	0	68.08	7.33	18.71	0	
3,048	102.92	65.34	16.04	27.79		57.4
3,200	71.97	0	16.11	40.86	5	
3,353	72.77	0	16.42	36.37		25.6
3,505	75.51	68.79	9.9	50.66	16.9	
3,658	0	0	11.94	35.6		22.2
3,810	65.08	64.63	14.27	40.66	5.4	
3,962	0	0	14.84	17.42		13.2
4,115	0	0	11.5	17.86	12.6	
4,267	0	0	13.26	14.88		3.8
4,420	72.59	0	16.81	14.1	8.4	
4,572	74.09	0	15.2	15.25		9.6
4,724	0	0	11.18	9.76	16	
4,877	0	0	9.04	6.06		10.8

[1] The spray line of the high-pressure system trials was at a distance of 152 m.

ground deposits found with the flat-fan system. Instead, a low-level deposit was evenly distributed downwind with the high-pressure nozzle system on May 12, 13, and 14. The greatest ground deposition averaged 106 ± 130 μg/m^2 at 1.98 km (Table 3).

On April 21, the 1st 0.8 km was the heavy deposition zone, with fenthion detected at 400–1,700 μg/m^2. On April 22, the highest amount of ground deposition, as found from filter paper, was 1,213 μg/m^2 at 0.9 km downwind. On April 23, the range of ground deposition was 360–660 μg/m^2 within the 1st 0.8 km and was 200–400 μg/m^2 in next 0.8 km.

On May 12, low deposition, between 60 and 80 μg/m^2 was recovered from filter paper between 2.3 and 3.7 km downwind. On May 13, the plume touched down at 0.61 km, with filter paper recovery ranging from about 70 to 110 μg/m^2 for the rest of the sample line. On May 14, offset was small (0.3 km) and the filter paper deposition was much higher than on the previous 2 nights, with a high of 238 μg/m^2 at 0.8 km and generally above 100 μg/m^2 for most of the other sampling points.

Bioassay—mosquitoes

Table 2 shows mosquito mortality for 2 nights, April 22 and May 12. During the tests of the flat-fan nozzles in April, only April 22 had significant mortality. Several stations had mortality between 10 and 20% with the highest mortality of 26.6% at 1.98 km downwind. May 12 was the only test with the high-pressure system that had significant mortality. The highest mortality was 92.9%, also at 1.98 km downwind, with mortality ranging from 28.8 to 92.9% for the middle 1.5 km of the drift zone. The 1st one third of the drift zone had low mortality and the last one third had moderately low mortality with mortality at some stations between 20 and 30%. Mosquito mortality on May 13 was low, generally below 6% except for 3 points where it was 10–11% (not shown). The adult mosquitoes were not used on May 14 because of high mortality that occurred in transport.

DISCUSSION

To be able to optimize a piece of application equipment, one must find the best technique for im-

Table 3. Monthly averaged (3 replicates) filter paper deposit and yarn drift data for flat-fan nozzles (April 1998) and high-pressure-cone nozzles[1] (May 1998).

Distance (m)	Filter paper (μg/m²)				Yarn (μg/m²)			
	Flat-fan		High-pressure		Flat-fan		High-pressure	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0	21.5	37.2	0	0	1.01	1.75	0.16	0.15
152	0	0	0	0	0	0	0.23	0.12
305	742.2	889.8	0	0	23.9	37.67	0.08	0.14
457	419	438.7	28.8	49.9	9.68	10.28	1.1	1.91
610	377	339	79.3	137.4	21.34	24.56	5.45	4.07
762	337.9	71.3	88.1	99.7	17.97	2.38	1.32	2.16
914	582	547.4	65	64.1	25.22	18.14	3.08	2.51
1,067	236.3	88	46.6	80.7	14.71	8.78	5.57	4.99
1,219	253.6	114.6	37.7	65.2	10.74	5.2	7.64	9.04
1,372	180	32.7	49	84.9	12.8	9.87	8.85	7.13
1,524	164.3	36.8	68.4	68.5	13.33	7.98	0	0
1,676	165.2	16.2	27.1	47	15.21	12.99	11.52	12.73
1,829	143.8	20.8	72.2	74.1	17.03	18.8	11.45	10.2
1,981	126.6	32	106.4	129.9	18.25	23.5	15.12	12.38
2,134	113.4	47.1	87.1	93.3	7.98	5.84	12.95	12.68
2,286	110.9	30.1	67.9	60	6.71	4.46	11.01	11.05
2,438	139.1	41.7	87	19.6	9.53	13.35	12.04	14.43
2,591	109.8	21.9	90.3	12.7	7.93	7.2	8.94	8.18
2,743	102.9	12.7	67.3	58.5	5.41	6.55	6.27	6.48
2,896	34	58.9	89.4	19.1	6.02	1.2	8.02	9.51
3,048	95.1	8	103.2	36.2	8.32	6.7	11.41	14.42
3,200	94	34	67.6	62.4	7.61	7.37	15.98	21.72
3,353	89.3	16.9	64.6	56.7	7.92	7.37	14.94	18.61
3,505	104.7	38	99.6	30.7	6.04	3.34	19.15	27.41
3,658	63.8	58.9	70.9	61.4	6.79	4.49	17.87	16.31
3,810	94.6	37.1	83.2	16.3	7.54	5.86	17.92	19.89
3,962	58.7	50.9	50.8	44.4	7.42	6.45	8.85	7.51
4,115	81.8	79.5	30	52	6.85	4.03	8.53	8.09
4,267	98.6	109.6	28.3	49	7.57	4.94	5.29	8.33
4,420	87.8	18.6	27.4	47.5	7.85	7.77	5.82	7.33
4,572	95.7	43.1	32.6	56.5	7.64	6.55	9.2	8.55
4,724	58.5	55.7	29.8	51.7	6.37	4.19	4.28	4.95
4,877	56.2	48.8	29.3	50.7	6.53	2.19	3.15	2.96

[1] The spray line of the high-pressure system trials was at a distance of 152 m.

pacting the target and yet not affecting nontarget animals. In aerial pesticide applications this is best done through manipulation of droplet size and careful exploitation of atmospheric conditions. Published studies indicate that droplets between 7 and 22 μm in diameter are most effective for impingement on flying mosquitoes (Haile et al. 1982b). Technology that can produce droplets in this range will allow mosquito control districts to reduce pesticide use by many times (Koutzenogii 1989). Use of Tee Jet 8002SS flat-fan nozzles operating at 414 kPa (60 psi) was the accepted method to disperse aerosols aerially in mosquito control. These nozzles produce a polydisperse aerosol with a VMD of 81 μm. About 13% by volume of the material was in droplets of 5–30 μm in diameter; this was found not to be sufficient for mosquito control. Moreover, because 50% of the volume was in droplets with diameters above about 80 μm, those droplets that represent waste for mosquito control probably also represent the portion that is environmentally harmful.

The challenge was to develop a better spray nozzle system, to produce sprays with at least 75% of the volume in droplets smaller than 30 μm in diameter. This would achieve the goals of effective abatement of adult mosquitoes and the reduction of environmental contamination, thereby protecting nontarget species. This was achieved by using the high-pressure hollow cone (1/8 M1SS) operated at 20,684 kPa (3,000 psi). The high-pressure system produced a spray with a VMD of 14 μm, with 79% of the droplets having a VMD of less than 30 μm.

Application equipment efficacy in this set of trials was measured principally by off-target deposition, with the hypothesis that the fewer nontarget animals affected, the more successful the mission. Efficacy also was measured in terms of mosquito control and airborne flux, but because of a lack of acquired data, no significant conclusions can be reported.

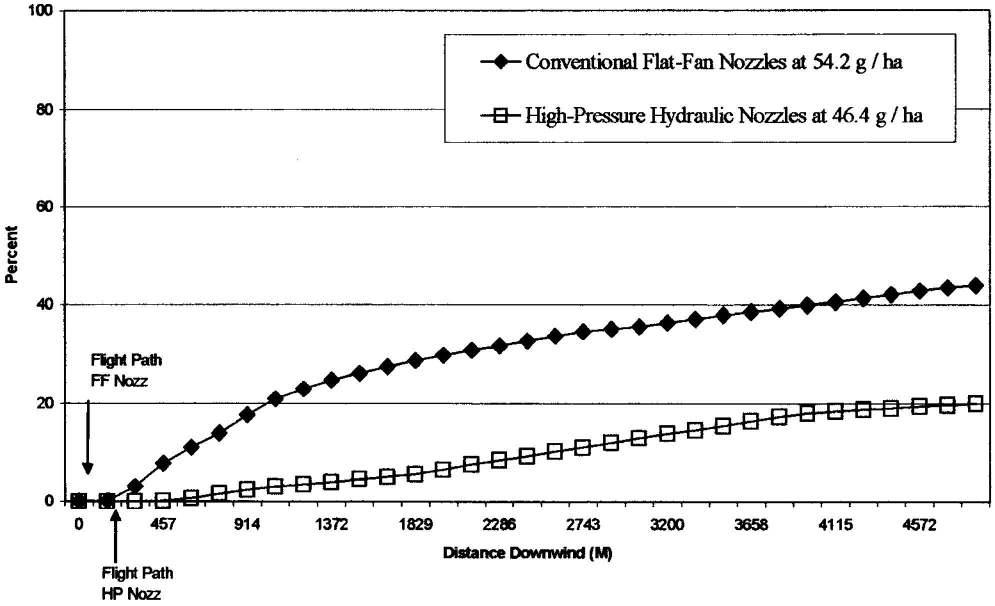

Fig. 2. The cumulative percent recovery of fenthion deposition from 2 aerial mosquito control applications.

The primary aim for this phase of the project was to reduce the amount of wasted material, that is, ground deposition. The accumulated deposition for both nozzle systems demonstrated that the flat-fan nozzle system had twice the ground deposition of the high-pressure nozzle system at 4.88 km downwind (Fig. 2). A measurement of the percent fraction of material recovered shows that almost 44% of the material applied was recovered from the ground for the flat-fan nozzle system (Fig. 2). In comparison, only 20% of the material applied with high-pressure nozzles was recovered from the ground (Fig. 2). The accumulation of fenthion deposition on 3 consecutive nights with the flat-fan nozzle system resulted in 80% fiddler crab mortality. Use of the high-pressure hollow-cone nozzle eliminated fiddler crab mortality.

To quantify the downwind movement of fenthion to make comparisons between the 2 different nozzle types, only 1 swath was applied in each replicate. However, normal applications consist of more than 1 swath; the overall dose in these trials was lower than normal, accounting for the poor efficacy. Moreover, the rate of application of the high-pressure nozzle system was equal to only 75% of the flat-fan nozzle system. Therefore, measurements of the effect on mosquito populations took a secondary role to measurements of ground deposition. The range of fenthion flux detected in the air by the yarn collectors was similar for the 2 systems, with both showing drift through 4.83 km. The aerosol flux for the flat-fan spray nozzle system ranged from 3.02 to 67.33 μg/yarn collector. The aerosol flux for the high-pressure nozzle spray system ranged from 0.15 to 50.66 μg/yarn collector. Although the 2 systems produced comparable ranges of flux, the high-pressure system provided higher control efficacy against mosquitoes. Maximum mosquito control with the flat-fan spray nozzle system against female salt-marsh mosquitoes was 26.6%, whereas maximum control with the high-pressure spray system was 92.9%. Because of the lack of successful replication, no statistical comparison can be made to verify any apparent differences. The 2 reasons for poor mosquito control were the low overall dose and the prevailing weather at the time of application.

Under low wind speed conditions and radiative cooling of the surface, an inversion sets in that inhibits turbulent fluxes between the atmosphere and the vegetation (Bosveld et al. 1999). This may lead to the phenomenon of decoupling of the upper air with the canopy. This can only happen if the canopy air temperature is lower than the air temperature above the canopy and usually occurs when wind speeds are low (Thistle 1996). When stability is classified according to Pasquill (Jensen 1973, Davies and Singh 1985), low-wind inversion conditions fit the category of very stable. When using this classification scheme, all of the nights of this study probably would fall under the category of very stable. Conditions classified as very stable should exhibit poor mixing with light meandering winds. The temperature lapses of April 21 and 22, as shown in Table 1, are smaller than those from the other nights; the lower values were due to improper sensor placement.

Vertical gusts were recorded on April 22 and May 12. If the decoupling of the air layers is not complete, even under stable conditions, then some mixing of canopy air with air above the vegetation will occur (Stull 1988, Bosveld et al. 1999). These vertical gusts show that some mixing of air layers occurred, thus bringing the aerosol close to the surface (Crabbe et al., 1994). Measurement of nocturnal meteorological variables is difficult when using slow-response sensors such as were used in these trials. Propeller anemometers with high thresholds can stall and wind vane inertia becomes critical in very humid conditions. Wind speed and direction at application height and several points between that and the canopy probably are necessary to make inputs to current models. The problem of applications at night is that nocturnal, stably stratified air layers are not well understood. Air movements are structured on a wide scale depending on canopy homogeneity and isotropy and are not well characterized by single point measurements (Bosveld et al. 1999, Nappo and Johansson 1999). Below the canopy, multiple, sensitive, fast-response sonic anemometers would be useful to measure very light wind and temperature fluxes (Kaimal and Finnigan 1994).

In conclusion, flat-fan systems have been shown to produce unacceptably high ground deposits and nontarget mortality. A high-pressure system with comparable if not better mosquito control efficacy proved to have no measurable negative effect on fiddler crabs. Therefore, this work advocates a change from the old flat-fan nozzle system to systems that produce a droplet size range similar to that studied here. Such droplet spectrums will reduce the environmental impact and also reduce the cost of mosquito control because comparable mosquito control was achieved with a reduced (75%) chemical load. Very careful attention must be paid to the prevailing atmospheric conditions at the time of pesticide application, and extreme inversion conditions should be avoided.

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