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GROUND DEPOSITION IMPACT OF AERIALLY APPLIED FENTHION ON THE FIDDLER CRABS, *UCA PUGILATOR*

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ABSTRACT. Caged fiddler crabs, *Uca pugilator,* were exposed to field ULV applications to measure the impact of fenthion. Two nozzle systems, conventional flat-fan nozzles (Tee Jet 8002SS) and high-pressure hydraulic nozzles (1/8 MIS), were compared using single spray swaths. Fenthion residues were detected throughout the 4.83-km test zone for both systems. Heavy ground deposits (650–1,670 μg/m²) of fenthion were found within 1 km using the flat-fan nozzle systems, which resulted in 80% fiddler crab mortality. Less than 100 μg/m² fenthion ground deposits were detected during the high-pressure nozzle trials. No fiddler crab mortality was observed within the first 1-km zone following 3 single swath applications repeated during 3 consecutive nights. We found also that when the fiddler crabs were exposed to 700–800 μg/m² fenthion, mortality occurred. Significant crab mortality (>50%) was observed when residues exceeded 1,000 μg/m².

KEY WORDS Organophosphate, Baytex, fiddler crab, ULV spray, fenthion deposition

INTRODUCTION

Aerial ultra-low volume (ULV) application of mosquito adulticides is one of the most effective techniques for controlling mosquitoes and preventing mosquito-borne diseases. Fenthion, an organophosphate insecticide, has been used frequently for control of adult mosquitoes. During application, large droplets of fenthion may be deposited onto tidal wetlands and wildlife areas, which often results in nontarget mortality, as in a recent case in the Rookery Bay National Estuary Research Reserve near Naples, FL (McKenney et al. 1997, Schoor et al. 2000). Invertebrates residing in the intertidal zone have been shown to be susceptible to fenthion exposure (McKenny et al. 1985; Clark et al. 1986, 1987). Fenthion ground deposition was associated with decreased populations of fiddler crabs, *Uca repax* (Smith) (McKenney et al. 1997). Also, 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).

Although insecticides often are distributed at uniform rates from the aircraft, downwind deposit onto ground surface depends on the volume (diameter) and specific gravity of the individual droplets of material being applied. Large aerosol droplets that deposit rapidly onto the ground surface are not available for control of adult flying mosquitoes and therefore are considered waste. Furthermore, large droplets may induce unfavorable environmental effects to nontarget species in areas of higher levels of deposit. Therefore, reduction of insecticide deposition to protect the natural environment becomes a priority in the selection or design of new spray systems. In addition, it is important to maintain the control efficacy against adult mosquitoes to protect the public health and welfare of residents and tourists.

Objectives of this study were to compare 1) the deposition profile of fenthion applied by two spray nozzle systems, a conventional flat-fan nozzle system and high-pressure hydraulic nozzles, and 2) the effects of fenthion residue deposition on caged fiddler crabs, *Uca pugilator* (Bosc).

MATERIALS AND METHODS

Research site

The experimental site was located at Golden Gate Estates east of Naples, FL. The site contained a vast network of paved roadways in a relatively uninhabited area, which permitted data collection for distances up to 11.24 km. For this study, we utilized 4.83 km on the eastern end. Collection stations for fenthion residue were established at 0.15-km intervals from 0–4.8 km adjacent to an east–west roadway. Stations for fiddler crabs were 0.44, 2.74, and 4.4 km downwind from the first spray swath line. A control station was set at approximately 3.2 km upwind. Weather data were collected by 3 Campbell Scientific weather stations. The stations were lined up at 0.8, 1.6, and 3.2 km downwind. The equipment monitored wind speed and direction at 2 and 10 m and temperature at 1.5-, 4.3-, and 7.9-m elevations at 3 locations and turbulence at 5.5 m of elevation at the primary station.

Aerial application of fenthion

Aerial ULV application of fenthion was conducted by Collier Mosquito Control District using a DC-3 airplane. The aircraft was equipped with a global positioning guidance system (GPS). Two nozzle systems for aerial application of fenthion were compared. The first system used conventional flat-fan nozzles (Tee Jet 8002SS) discharged at an

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air speed of 278 km/h (150 knots) and 414 KPa (60 psi) liquid pressure with a nozzle angle of 45° into the wind. The flat-fan nozzle system generated aerosol droplets within a 50–60-μm volume median diameter (VMD) range typically utilized by mosquito control. Currently, this application system is the most commonly used for aerial application of adulticides nationwide. A metering system recorded actual application volume for each test. The application rate was calculated to deliver 47.5 ml/ha (0.65 oz/acre) with 322-m (1,056-ft) flight centers and an aircraft speed of 241.4 k/h (150 mph). The second system used high-pressure hydraulic nozzles (1/8 MIS) with an air speed of 278 k/h and a liquid pressure of 20,684 K/a (3,000 psi). The high-pressure hydraulic spray system generates aerosol droplets within a 20–30-μm VMD range. Mosquito adulticide (fenthion) was applied at 35 ml/ha (0.48 oz/acre) with a DC-3 aircraft flying at an altitude of 91.44 m (300 ft). The 25% reduction from the intended flow rate (47.5 ml/ha) in the high-pressure system was due to loss of pressure caused by an increase in hose length (between the pump and tail boom) from the bench-tested model. During the aerial ULV spray, a single application swath (322 m) was flown over the most upwind station. Three replicate flights were conducted for each nozzle system under ideal wind conditions (16–24 km/h with a predominately west wind). Six trials of a single swath were conducted. Waiting time for sample collection posttreatment was 3 h, which allowed the residue downwind movement through the 4.8-km test area.

Field bioassay

The staff of the Rookery Bay National Estuarine Research Reserve (RBNERR) were responsible for the collection and maintenance of fiddler crabs and the design and setup of crab mesocosms. Caged fiddler crabs, collected from a pristine area outside the mosquito control application area, were used to determine impact of fenthion deposition on fiddler crabs. One inch of beach sand was placed in each of 12 dish-pan mesocosms, 30.5 cm × 40.5 cm, 24 h before the scheduled spray time. The sand was wetted with 35 parts per thousand (ppt) saltwater. Prior to the spray mission, 120 crabs were collected from the crab holding tanks. Each crab was sexed, weighed, and measured. Five males and 5 females were placed in each of the 12 dish-pan mesocosms. Three dish-pan mesocosms with 30 fiddler crabs were placed at each location. Mesocosms were covered with hardware cloth and secured by plastic cable ties and covered with damp towels until field deployment the same night. Three mesocosms were set at each of the 3 stations downwind and 1 control station upwind as indicated above.

Crabs were picked up within the first hour after sunrise following the application of fenthion. Mesocosms were covered with damp towels and crabs were returned to the laboratory at Rookery Bay. Crab mortality was recorded by the RBNERR staff in 12-h intervals following application for up to 120 h. In the event of mortality observed in control mesocosms during the 5-day observation period, the mortality was adjusted by Abbott's formula (Abbott 1925). All dead crabs were removed from the mesocosm, sexed, and measured (carapace in mm) and recorded. In the event that the mesocosms were to be deployed on consecutive nights, the sand in each mesocosm was kept moist with 35 ppt saltwater, and mesocosms were covered with damp towels to maintain moisture. At the end of the assay, the crabs were removed from each mesocosm. Remaining crabs were individually sexed, weighed, measured (carapace in mm), and recorded.

Fenthion residue collection

At each sampling station, 2 filter papers (24 cm in diameter; Whatman International Ltd., Maidstone, England) were placed side by side on a Styrofoam board, 40 × 80 cm, covered with aluminum foil. Filter papers were pinned on top of the aluminum foil and replaced after each test. Fenthion residue samples were collected approximately 3 h following application to allow spray droplets to settle. Each filter paper was removed from the styrofoam board, folded using 2 pairs of forceps, and placed into a screw-top 40-ml Pyrex® culture tube. Each tube was filled with 30 ml of hexane immediately after sample collection. All samples were placed in a cooler with "blue ice" and held at 4°C. Quality control of residue recovery in 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 Public Health Entomology Research and Education Center, Florida A&M University, Panama City, FL, for fenthion residue analysis. To ensure the analytical data quality, one of the paired filter-paper samples located at each sampling station was shipped to the U.S. Environmental Protection Agency Laboratory at Gulf Breeze, FL, for analysis.

Fenthion residue determination

A Varian 3400 gas chromatograph equipped with a thermionic specific detector and 8200 autosampler (Varian Analytical Instruments, Sugar Land, TX) was used in this study. Data were collected by a Dell Computer Work Station (Dell Computer Corporation, Round Rock, TX) equipped with data-handling software Star Chromatograph Version 4.51 (Varian Analytical Instruments). The injector was operated at 250°C in 10 to 1 split mode and the detector operated at 300°C. A DB-5 capillary column 30 m × 0.25 mm i.d. (film thickness = 0.1 μm) bonded with fused silica was also used. The column oven starting temperature was 130°C, with

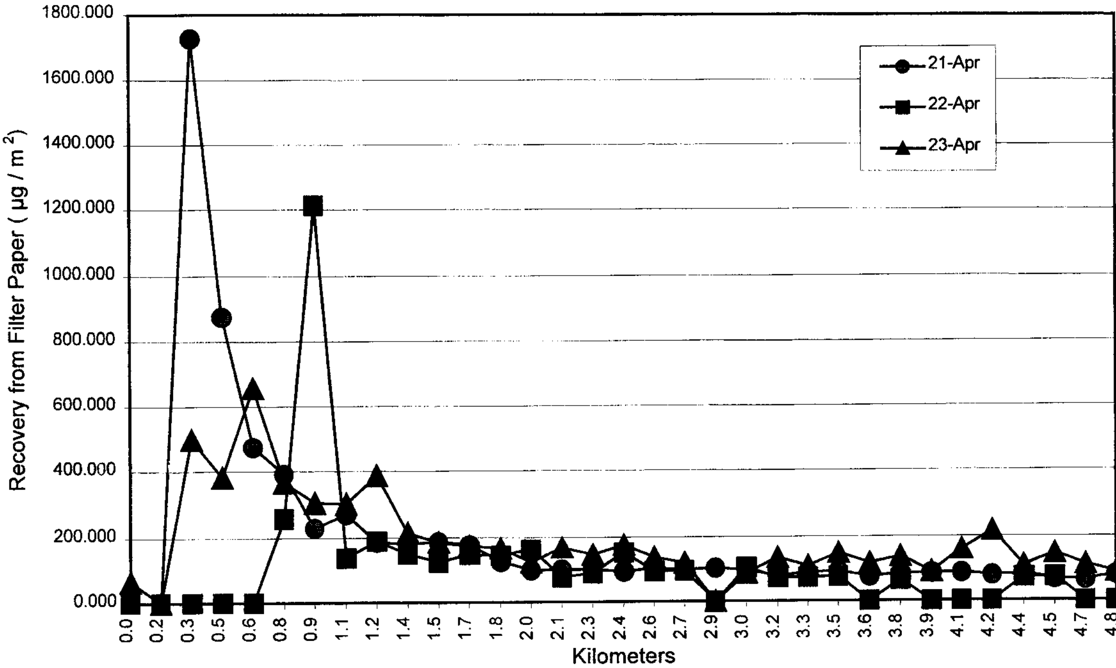

Fig. 1. Downwind drift and deposit of fenthion aerial ultra-low volume sprays via flat-fan spray nozzles for mosquito control at designated distances from one swath placement (applied at 47.5 ml/ha on April 21–23, 1998).

an increase at 15°C/min to 275°C, 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 µg/ml to 10 µg/ml with $R^2 \geq 0.995$. Continuous calibrations at the level of 2 µg/ml were conducted every 10 samples and were within the criteria of 100 ± 10% recovery limit at each time. Laboratory and field spikes from each sampling were within 100 ± 20% recovery limit. All blanks were clean from contaminants.

RESULTS

Light winds (0.43 m/sec) from the SW measured at 5.5 m by the Gill UVW anemometer for the first hour were highly variable in direction ($\sigma = 20.6$) on April 21, 1998. The anemometer recorded low to moderate steady wind (0.76 m/sec) for the first 1.5 h from the west on April 22, 1998. From the anemometer, very low wind speeds that started from the northeast were recorded. However, the wind direction was predominately west or west–southwest, with occasionally east and east–southeast winds on April 23, 1998. The anemometer measured average winds of 1.5–2.5 m/sec, mostly from the northwest, for the first 1.5 h on May 12, 1998. The east–west component of the wind as measured by the Gill UVW anemometer was mostly below the threshold, while the north–south component was very strong, 3.8–3.9 m/sec from the north, in the first 2 h. The wind speed dropped the last hour and was variable in direction, even blowing from the east at one point on May 13, 1998. The east–west component of the wind as measured by the Gill UVW anemometer was low, below the threshold, most of the night. The exception was about 20–25 min postspray, when an average wind of 0.48 m/sec from the west was measured. But compared with the average 1.48 m/sec wind from the south during this period, that amounts to a resultant of only 18° west of south. The north–south component was moderately strong and extremely steady at an average of 1.7 m/sec from the south for at least 2 h postspray on May 14, 1998.

Fenthion residue deposits on filter paper were detected throughout the 4.83-km test zone from both nozzle systems. The highest deposited residue on filter paper at each of the 3 single swaths was 1,729, 1,213, and 657 µg/m^2 on April 21, 22, and 23, 1998, respectively, for the flat-fan nozzle system, with an average droplet VMD of 70–80 µm (Fig. 1). The variation of peak location among the replicates reflected the changing of wind speeds or direction in each replication. The heavy deposit was within 1 km downwind for the flat-fan nozzle systems (Fig. 1). The deposition peaks shown in the flat-fan system were eliminated with the use of the high-pressure hydraulic nozzle system, with an average droplet VMD of 25–30 µm. There was an even distribution of low-level deposit downwind for each single swath of the high-pressure nozzle

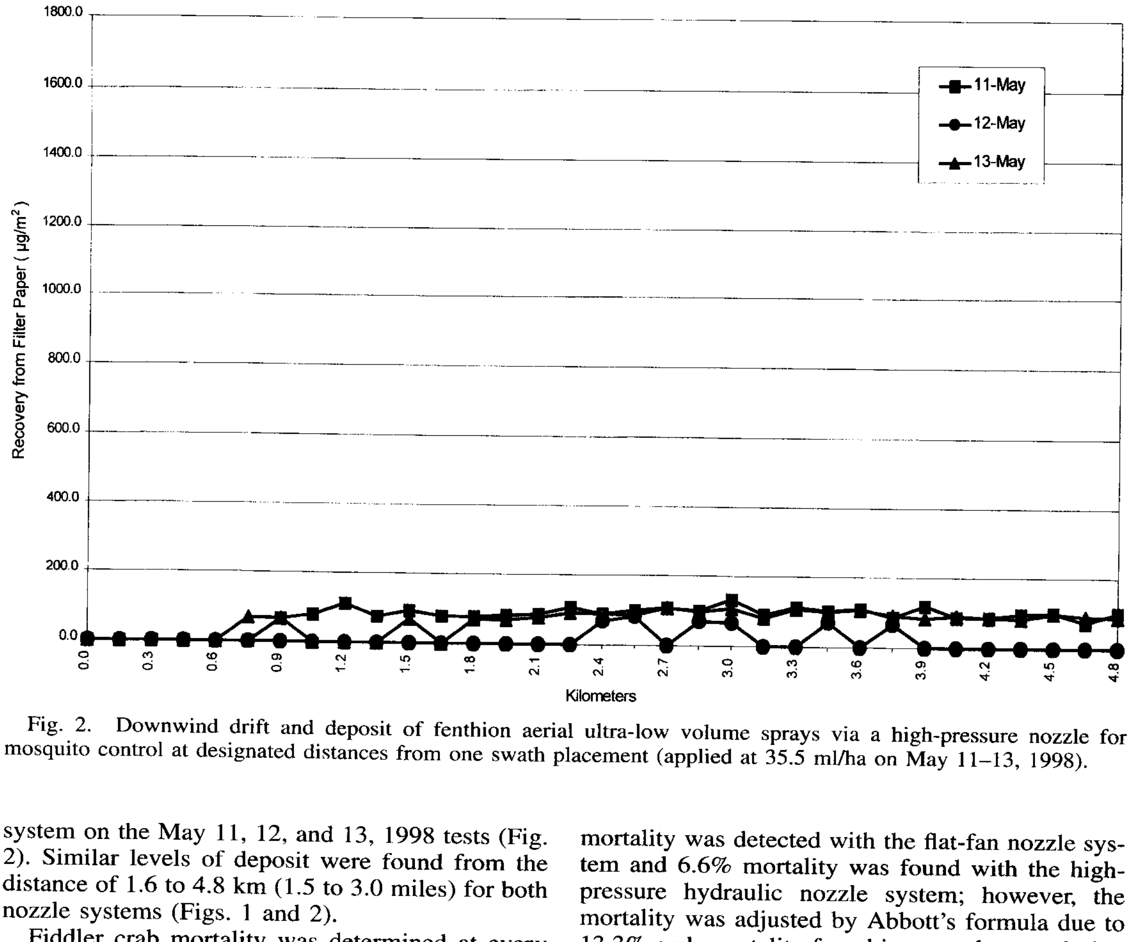

Fig. 2. Downwind drift and deposit of fenthion aerial ultra-low volume sprays via a high-pressure nozzle for mosquito control at designated distances from one swath placement (applied at 35.5 ml/ha on May 11–13, 1998).

system on the May 11, 12, and 13, 1998 tests (Fig. 2). Similar levels of deposit were found from the distance of 1.6 to 4.8 km (1.5 to 3.0 miles) for both nozzle systems (Figs. 1 and 2).

Fiddler crab mortality was determined at every 12-h interval and the total assay time was 120 h for each mesocosm following fenthion ULV applications. The flat-fan nozzle system elicited 80% accumulated mortality in fiddler crabs located at 0.44 km, which was within the heavy deposit zone (0.0–1.1 km). In the same deposit zone, no fiddler crab mortality was found following aerial ULV application of fenthion via the high-pressure hydraulic nozzle system. At 2.74 and 4.42 km, no fiddler crab mortality was detected with the flat-fan nozzle system and 6.6% mortality was found with the high-pressure hydraulic nozzle system; however, the mortality was adjusted by Abbott's formula due to 13.3% crab mortality found in control cages during a 120-h postspray observation (Table 1).

DISCUSSION

This study is not representative of operational mosquito control because only one swath was placed during each test. Multiple swaths are the normal practice for operational mosquito control and additive effects of fenthion deposition would

Table 1. Comparison of residue of fenthion deposited on filter paper and percentage mortality of the fiddler crab, *Uca pugilator*, at 120-h holding time following aerial ultra-low volume application of a single swath on 3 consecutive dates by 2 different nozzle systems.

Distance downwind (km)	Flat-fan nozzle system: Fenthion residue (µg/m²)	Flat-fan nozzle system: % mortality of fiddler crabs (30/cage/station)	High-pressure nozzle system: Fenthion residue (µg/m²)	High-pressure nozzle system: % mortality of fiddler crabs[1] (30/cage/station)
Control	ND[2]	0	ND	0
0.44	1,257.00	80	ND	0
2.74	308.75	0	212.37	0
4.42	295.67	0	171.17	0

[1] The % mortality adjusted by Abbott's formula (control mortality was 13.3%; the mortality of fiddler crab was 6.6% at the 2.74- and 4.42-km stations.

[2] ND, not detected.

be anticipated. Three single swaths were applied via each of 2 different spray systems to compare the ground deposition profile of fenthion residue. Deployment of fiddler crabs in conservative night was due to the fact that no fiddler crab mortality occurred in the first 24 h with the flat-fan nozzle system. Also, it was difficult to place the crab cages within the peak deposition area due to unpredicted wind speed and turbulence during each test. Multiple exposures were intended to clarify the toxicological response of fiddler crabs to residue deposition of ULV applied fenthion. Based on the fenthion residue recovery and field bioassay, mortality of fiddler crabs would occur following exposure to over 700–800 $\mu g/m^2$ residues of fenthion (Fig. 1). The 80% mortality (Table 1) was an additive effect of fenthion deposition from 2 tests (April 21, 875 $\mu g/m^2$; April 23, 382 $\mu g/m^2$) (Fig. 1). No fenthion deposition was found at the first crab station (0.44 km) on April 22 due to the stronger wind carrying the peak deposition further downwind (0.9 km) (Fig. 1). The residue deposition reached the maximum within 1.5 km following ULV application using the flat-fan nozzle system, which resulted in fiddler crab mortality. We observed crabs that shook, lost appendages, were paralyzed, and eventually died following exposure to fenthion. Due to the fenthion deposition within 1 km via the flat-fan nozzle system, a distance of spray offset is recommended to avoid environmentally sensitive areas. The high-pressure nozzle system minimized the nontarget impact by elimination of the peak of the residue deposit in the same region (Fig. 2). There was no major peak of fenthion deposition or mortality of the fiddler crabs beyond 1 km downwind for both spray systems (Figs. 1 and 2).

Control of adult mosquitoes may require the application of an insecticide in the form of aerosol droplets via airborne drift through areas where adult mosquitoes are flying. The application requires a delivery system (nozzle) capable of producing aerosol droplets. Flat-fan spray nozzles depend on wind shear passing over the nozzle to atomize the insecticide; therefore, aircraft speed is critical. To control flying mosquitoes effectively, pesticide droplets must stay in the air for the chance of contacting target insects. Droplets that are deposited on the ground are considered waste. The waste deposit may be toxic to nontarget species and cause environmental damage. Larger droplets influenced more by gravitational force deposit rapidly, while small droplets influenced by wind and turbulence stay aloft and may drift several kilometers. Reducing droplet size with application volume remaining constant drastically increases the number of droplets within a given airspace, thereby increasing the probability of impingement on target mosquitoes. Reduction in size of droplets also increases drift time and reduces deposit downwind, as demonstrated by the residue profile of the high-pressure nozzle system.

The aerosol drift dynamics from aerial mosquito adulticide operations depend on droplet size. Elimination of all or most aerosol droplets that are $\geq$30 μm in diameter would eliminate peak deposits in the area nearest the aircraft, as demonstrated by the high-pressure nozzle system in this study. The high-pressure nozzle system achieved reduction in the environmental contamination during our test. Large droplets (>50 μm) that fall rapidly to the ground and cause nontarget mortality become useless for impinging on flying adult mosquitoes, as we found in our study. The chance of contacting an adult mosquito increases as droplet size decreases. Mount et al. (1970) reported that droplets between 10 and 25 μm in diameter were most effective for impingement on flying mosquitoes. Reducing the waste that deposits on the ground while increasing the density of aerosol droplets passing through the target zone has several advantages: 1) reduction in nontarget effects (fiddler crabs), 2) increase in mosquito control efficacy, and 3) reducing labor cost, equipment, and pesticides. Our challenge in the future is to develop better spray nozzle systems with a deposit profile similar to the high-pressure hydraulic nozzles used in this study, which produced at least 80% of the spray volume with droplets smaller than 30 μm in diameter. This will then achieve the goal of reduction of environmental deposits and protection of nontargets while still providing effective adult mosquito control.

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