DRIP APPLICATION OF THREE ORGANOPHOSPHORUS INSECTICIDES FOR MOSQUITO CONTROL[1]

R. D. SJOGREN[2] AND M. S. MULLA[3]

The calibrated drip method of applying insecticides to flowing and impounded waters for mosquito control has been used intermittently for the past 20 years. Recent availability of new organophosphorus compounds, which have improved stability and safety attributes under a wide range of field conditions, has given renewed interest to the practical application of this technique in mosquito control programs.

Knowles and Fisk (1945), Wisecup *et el.* (1946), Geib and Smith (1949) and Smith and Geib (1949) reported the results of early work with DDT emulsions introduced into flowing water to control mosquitoes in rice fields and irrigated pastures. Gahan and Mulhern (1955) tested several materials using an automatic applicator developed by Gahan *et al.* (1955). Gahan and Noe (1955) successfully controlled mosquitoes in Arkansas rice fields by the introduction of water-soluble phosphorus insecticides into the irrigation water as it flowed into the fields. In 1957 Gahan obtained control for distances up to ⅜ mile using parathion in California pastures. Lancaster (1964, 1965) tested six insecticides for rice field mosquito control. Ethyl parathion was subsequently employed in a large scale program in which farmers dripped the material into irrigation water under the direction of Extension Service personnel. The equipment used by the above authors to apply dilute or concentrate emulsifiable formulations employed either a siphon or constant head principle.

Recently, Mulla and Darwazeh (1968) made detailed studies on the efficacy of several organophosphate mosquito larvicides for *Aedes* in pastures where insecticidal concentrates were dripped into flowing water. The results of their studies were highly promising, which led to the use of the same technique in the present study. This paper reports the results of field experiments conducted from July through October, 1967, on the efficacy of fenthion (*O,O*-dimethyl *O*-[4-(methylthio)-*m*-tolyl] phosphorothioate), Dursban® (*O,O*-diethyl *O*-3,5,6-trichloro-2-pyridyl phosphorothioate), and Abate® (*O,O,O',O'*-tetramethyl *O,O'-thiodi-p*-phenylene phosphorothioate) applied by the calibrated drip method to flowing waters in ditches and ponds. Emphasis was placed on determining the dispersal and biological effectiveness of each material at specific rates of application and their respective residual capability.

Methods and Materials. Field larval populations of *Culex pipiens quinquefasciatus* (Say), *C. tarsalis* Coquillett, and *C. peus* Speiser were employed for bio-assay purposes. No significant levels of resistance to the three materials tested are on record for the species in the locality in which the tests were performed. Effectiveness of the treatments was determined by dipping for larvae. Pretreatment and post-treatment samples were taken at established sampling stations. When possible, untreated plots were designated for comparison purposes. Post-treatment control evaluations were made 24 hours after application in the flowing water experiments, and 48 or 72 hours in the impounded water tests. To determine the residual control capability in the latter experiments, weekly post-treatment sampling was conducted until second or third instar larvae were collected.

The rates of flow in the ditch experiments were determined in cubic feet/second using a Price Current Meter or by

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[2] Manager-Entomologist, Northwest Mosquito Abatement District, Riverside, California.

[3] Associate Professor, Department of Entomology, University of California, Riverside, California.

area x velocity calculations. To determine the duration of treatment and rate of application in p.p.m. required by each source for optimum control, field water and larval samples were collected and tested in the laboratory to determine baseline dosage rates. Rates of application (lbs./acre) for impounded water were determined by total surface area in acres over which the water was spread. Emulsifiable concentrate formulations were applied to the flowing and impounded waters by dripping either at the head of the ditch or inlet to the pond. Equipment used was of simple construction utilizing constant head pressure (Mulla and Darwazeh, 1968). As reported by other authors using insecticide concentrate solutions, several failures in obtaining even discharge rates were encountered in preliminary experiments.

Two experiments were conducted in the Santa Ana River bottom, near Riverside, California. In both experiments, fenthion was evaluated for the control of mosquito breeding under conditions of heavy marginal vegetation in an irrigation ditch sustaining a flow of 23.2 $ft.^3$/sec. (10,440 gal./min.). The water flowing in this ditch contained approximately 50 percent sewage effluent. The rate of application was held constant at 0.20 p.p.m. with the duration of the drip 240 and 100 minutes.

In another experiment, fenthion was evaluated for mosquito control in a duck club (Hidden Valley Gun Club, Riverside, California). Fenthion was applied to a duck pond at the inlet on two occasions at the rate of 0.15 and 0.20 lbs./acre. The water used to fill the ponds was also composed of approximately 50 percent sewage effluent, originating from the Santa Ana River. The high level of organic material produced recurrent *Culex* mosquito breeding in marginal vegetation.

Dursban was applied to a raw sewage line prior to its discharge into two permanent lagoons operated by the Cucamonga County Water District, Cucamonga, California. The effluent from the initial lagoons connected in series, subsequently passed into four percolation ponds connected in parallel. The latter ponds were periodically rotated. The most distant point from the inlet was 930 feet. One gallon of insecticide containing 4 pounds of actual Dursban was released over a 24-hour period to give a rate of 0.47 lb./acre. This rate is based on the surface area of ponds flooded at the time of treatment. During the period of study the ponds received an average dilution of one million gallons of water per day. Pretreatment larval populations of *C. peus* and *C. tarsalis* in the four ponds averaged 97/dip.

On three separate occasions, Dursban, Abate and fenthion emulsifiable concentrates were dripped at 0.23 lb./acre into the inlet of 17 acres of percolation ponds and adjacent pasture which received four million gallons per day of sewage effluent from the City of Ontario Sewage Treatment Plant, Ontario, California. One gallon of 4 lb./gallon of each of the above materials was released over an approximate period of 24 hours on August 17, October 6, and October 25, 1967 respectively. The assessment of efficacy was continued until mosquito breeding became apparent in the treated area.

Results and Discussion. In the flowing water experiments in which fenthion was dripped for 240 and 100 minutes at the rate of 0.2 p.p.m., excellent control of larvae was obtained over the first 2 miles of irrigation ditch, (Table 1). Complete mortality occurred over the entire ditch, except at the end where it entered a reservoir. Here either the duration of the drip, lack of sufficient time for mortality, or dilution may have been factors contributing to reduced mortality. Mulla (1961) showed the 24-hour LC_{90} of susceptible 4th instar *C. p. quinquefasciatus* larvae to fenthion to be .0150 p.p.m. In laboratory tests using field water samples of moderate organic content, *C. quinquefasciatus* larvae were subjected to serial dilutions of fenthion to determine the dosage rate required to obtain complete kill of larvae within 4 hours. This time interval was chosen as an aid to determine the minimum dosage rate and shortest

Table 1.—Mosquito control with 0.20 p.p.m. fenthion drip applied to the Hidden Valley Gun Club main irrigation ditch.

Application period and date	Distance (miles)	Av. no. of larvae/dip Pre-treat.	Post-treat. (24 hr.)	% Control
240 min. (9-10-67)	0.25	4	0	100
	0.5	16	0	100
	0.75	250	0	100
	1.0	25	0	100
	1.5	25	0	100
	2.0	25	0	100
	3.0	70	3[a]	96
100 min. (10-24-67)	0.25	1	0	100
	0.5	3	0	100
	0.75	40	0	100
	1.0	25	0	100
	1.5	25	0	100
	2.0	75	0	100
	3.0	10	6[a]	40

[a] Terminal site was in inlet to a 4-acre irrigation reservoir.

treatment period required to obtain desired control. The lowest rate effective was .10 p.p.m. which gave 80 percent kill of test larvae within 1 hour and 100 percent within 4 hours.

In the duck pond experiments using fenthion at the rate of 0.15 lb./acre (Table 2), very good control of mosquito larvae was obtained on several occasions. The degree of control obtained by dripping the material into the pond inlet over a two to three-hour period proved very promising in view of the fact that the ponds were essentially static. It was determined that post-treatment evaluation could be performed best between 48 and 72 hours thus providing optimum time for distribution of the material throughout the pond. Field results appear to substantiate the laboratory data obtained by Mulla (1963) on the persistence of fenthion in water.

When Dursban was applied by the drip method at the rate of 0.47 lb./acre to raw sewage ponds (Table 3), 100 percent larval mortality resulted in all ponds within 48 hours after the initiation of treatment. Weekly post-treatment inspections detected the first larvae, larger than 1st instar, on October 3, 1967—57 days after treatment. These larvae were found in low numbers in one of the percolation ponds. Weekly inspections were continued until the adult mosquito populations declined in the area on approximately November 1. While breeding re-established

Table 2.—Mosquito control with fenthion drip applied to the Hidden Valley Gun Club duck ponds.

Date	Area (acres)	Rate (lb./acre)	Av. no. larvae/dip Pre-treat.	Post-treat. (48 hr.)	% Control
9-16-67	7	0.15	100	0.5	99
10-6-67	7	0.15	38	1.5	96
9-24-67	7	0.20[a]	120	0.0	100
9-24-67	10	0.20[a]	25	0.0[b]	100

[a] Material was applied to inlet of first pond, treated water then flowed through weir into second pond.
[b] Inspection performed 72 hours post-treatment.

TABLE 3.—Mosquito control with Dursban® drip applied to the Cucamonga County Water District raw sewage ponds.

			Av. no. larvae/dip										
				Post-treatment (days)									
Pond no.	Area (acre)	Rate (lb./acre)	Pre-treat.	2	8	15	22	29	36	43	50	57	64
1	2.4	0.47	84	0[a]	0	0	0[a]	0	0	0[a]	0	0	0
2	2.6	0.47	86	0[a]	0	0	0	0	0	0[a]	0	0	0
3	1.3	....	dry	..	..	..	..	0	0	0[a]	0	0	0
4	1.3	0.47	85	0[a]	0	0	0[a]	0[a]	0[a]	0[a]	0[a]	0	1
5	2.5	....	dry	..	..	..	..	..	..	..	..	..	..
6	2.3	0.47	133	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	1	3
	12.4												

[a] Egg rafts recovered in the process of dipping for larvae.

in low numbers in all percolation ponds, no larvae were taken from the two initial stabilization ponds.

Composite samples of treated water were collected 16 and 36 days post-treatment. Serial dilutions of treated and tap water were bio-assayed with 30 4th-instar *C. peus* larvae in the laboratory. Complete larval mortality in 24 hours was produced by 40 percent treated, 60 percent tap water on both occasions.

Steelman *et al.* (1967) related that Dursban provided residual control of mosquito larvae for 144 days when it was applied at the rate of 1 p.p.m. to livestock waste disposal lagoons. Lewis *et al.* (1966) reported effective residual control for 23 days with Dursban at 0.1 lb./acre when applied to log ponds in Oregon. Work by Ludwig and McNeill (1966) showed Dursban when applied at 0.05 lb./acre gave residual control of *Aedes sollicitans* larvae for 4 weeks. Dursban granules applied at 2.0 lbs. active ingredient per acre gave complete control of *A. sollicitans* up to 11 weeks, even though test plots were flooded intermittently by high tides.

The results obtained in the comparative evaluation of Dursban, Abate and fenthion when applied at 0.23 lb./acre by the drip method are presented in Table 4. The sewage effluent passed through two

TABLE 4.—Mosquito control with Dursban®, Abate® and fenthion applied by drip at the rate of 0.23 lb./acre to effluent from the Ontario City Sewage Treatment Plant.

				Av. no. of larvae/dip								
					Post-treat. (days)							
Date	Material	Pond no.	Area (acres)	Pre-treat.	3	6	13	20	27	34	41	48
8–17–67	Dursban	1	0.8	64	0	0[a]	0	0	0	0	0	2
		2	1.7	0	0	0[a]	0	0	0	0	0	5
		3	14.5	119	0	0	0	0	0	0	0	35
10– 6–67	Abate	1	0.8	5	0	0	0	4	..	..	..	..
		2	1.7	8	0	0	0	3	..	..	..	..
		3	14.5	50	0	0	0	14	..	..	..	..
10–26–67	Fenthion	1	0.8	4	0	0	0	0[b]	..	..	..	..
		2	1.7	3	0	0	0	0[b]	..	..	..	..
		3	14.5	14	0	0	2	2[b]	..	..	..	..

[a] Water level of two initial percolation ponds was lowered for three weeks subsequent to this date.
[b] Field adult mosquito population was on decline in area, as evidenced by adjacent untreated plots.

percolation ponds to reach an abandoned pasture where it subsequently ponded in dense vegetation over 14.5 acres. Each of the materials gave 100 percent larval control within 48 hours over the entire 17 acre area, the most distant point being one-half mile from the treatment site. The first post-treatment larval populations in the Dursban, Abate and fenthion treated plots became established in 43, 15, and 12 days respectively. The duration of residual activity was well defined with Dursban and Abate. In the last test using fenthion, the larval population re-established in much lower numbers than after the other two tests. This was believed to be due to a concurrent reduction of field populations, as populations in adjacent untreated sources were also on the decline.

The data obtained with Dursban, Abate and fenthion applied to flowing and impounded waters by the drip method indicate that effective larval control under conditions of heavy vegetation and high organic pollution can be achieved. While the rates of application employed with this technique are greater than those used when the materials are applied by conventional methods, considerable operational savings in time, labor and materials are possible. Recent studies by Patterson and von Windeguth (1964), von Windeguth and Patterson (1966), Ferguson *et al.* (1966), Mulla (1961) and Keith and Mulla (1966), show the relative safety and hazards of these three insecticides to non-target organisms. Under appropriate circumstances increased rates of application of certain of these materials may be used without serious detriment to the balance of the aquatic ecosystem. In waste waters with high levels of suspended organic material, increased dosage rates, particularly of Dursban, can result in extended residual larval control.

Summary. Field studies were conducted during the summer of 1967, in Southern California, to evaluate Dursban®, fenthion and Abate® emulsifiable concentrates applied by the drip method for larval mosquito control. Fenthion was applied to flowing water at 0.2 p.p.m. for 240 and 100 minute periods. Good larval control was achieved over the entire 3-mile length of ditch at the longer interval; the control level decreased beyond the 2-mile point at the shorter treatment period. Fenthion applied at 0.15 and 0.20 lb./acre to the inlet of duck ponds gave good larval control within 48 to 72 hours post-treatment.

Dursban applied (at 0.47 lb./acre) to 8.6 acres of raw sewage lagoons receiving 1 million gallons/day dilution, achieved 100 percent larval control in all ponds within 48 hours post-treatment. The first larvae, larger than first instar, were collected 57 days after treatment, with partial control existing for an additional 30 days.

In a comparative evaluation of Dursban, Abate and fenthion applied at 0.23 lb./acre on three separate occasions to 17 acres of ponded sewage effluent receiving approximately 4 million gallons/day dilution, 100 percent control resulted in the initial application of each material. The residual control duration of each material was 43, 15, and 12 days respectively.

The experimental results indicate that effective and economical control of mosquito larvae in flowing and quiescent waters can be achieved by the application of insecticide concentrates at 0.2 p.p.m. and 0.15–0.25 lb./acre respectively.

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