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Experimental Field Treatments with Larvicides for Control of *Anopheles, Aedes,* and *Culex* Mosquitoes[1,2]

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ABSTRACT

Grassy plots were treated with granular, wettable powder, and emulsifiable-concentrate formulations of 22 different insecticides to determine their residual life as larvicides. Larvae of *Anopheles albimanus* Wiedemann, *Aedes taeniorhynchus* Wiedemann, and *Culex pipiens quinquefasciatus* Say were used as test insects. Thirteen of the compounds gave satisfactory results for 6 or more weeks against at least one of the test species. Dursban® (*O,O*-diethyl *O*-(3,5,6-trichloro-2-pyridyl) phosphorothioate) at 1 lb/acre was the most effective compound; fenthion at 2 lb/acre and Abate® (*O,O*-dimethyl phosphorothioate *O,O*-diester with 4,4'-thiodiphenol) and Mobam® (benzo[*b*]thien-4-yl methylcarbamate at 4 lb/acre gave comparable results. At 0.5 lb/acre Dursban gave 6 and >12 weeks of 90% kills of *A. taeniorhynchus* and *A. albimanus*. Carbamates, such as propoxur, carbaryl, and Mobam were effective against one or more of the 3 species for >12 weeks when applied at rates of 2 to 4 lb/acre. Residual activity varied markedly with the dosage rate and species tested.

To evaluate the effectiveness of candidate insecticides against *Anopheles, Aedes,* and *Culex* larvae, field plots were set up at Fort Stewart, Ga. During the period 1966–69, 22 insecticides, made up as granular, wettable powder, and/or emulsifiable concentrate formulations, were evaluated to determine their residual life.

The type of treatment was similar to "prehatch or preflood larviciding," a procedure that has been used successfully against floodwater *Aedes* (Vannote 1952, Carpenter and Kunan 1952).

MATERIALS AND METHODS.—The 22 insecticides were bromophos, carbaryl, chlorphoxim, dichlorvos, fen-

[1] Diptera: Culicidae.

[2] Use of trade names is for identification purposes only and does not constitute endorsement by the Public Health Service or the U. S. Department of Health, Education, and Welfare. Received for publication Oct. 22, 1970.

thion, phoxim, propoxur, tetramethrin, and the following compounds without approved common names:

Abate®: *O,O*-dimethyl phosphorothioate *O,O*-diester with 4,4'-thiodiphenol

Akton®: *O*-[2-chloro-1-(2,5-dichlorophenyl) vinyl] *O,O*-diethyl phosphorothioate

Bay 38799: *o*-cyclopentylphenyl methylcarbamate

Ciba-8874: *O*-(2,5-dichloro-4-iodophenyl) *O,O*-diethyl phosphorothioate

Ciba-9491: *O*-(2,5-dichloro-4-iodophenyl) *O,O*-dimethyl phosphorothioate

Cidial®: ethyl mercaptophenylacetate *S*-ester with *O,O*-dimethyl phosphorodithioate

Dursban®: *O,O*-diethyl *O*-(3,5,6-trichloro-2-pyridyl) phosphorothioate

Dursban methyl analogue: *O,O*-dimethyl *O*-(3,5,6-trichloro-2-pyridyl) phosphorothioate

fenitrothion: *O,O*-dimethyl *O*-(4-nitro-*m*-tolyl) phosphorothioate

Gardona®: 2-chloro-1-(2,4,5-trichlorophenyl) vinyl dimethyl phosphate

Hercules 14469: *m*-cumenyl (mercaptoacetyl) methylcarbamate *S*-ester with *O,O*-dimethyl phosphorodithioate

Landrin®: 3,4,5-trimethylphenyl methylcarbamate, 75%; 2,3,5-trimethylphenyl methylcarbamate, 18%

Mobam®: benzo[b]thien-4-yl methylcarbamate

NRDC-104: (5-benzyl-3-furyl) methyl 2,2-dimethyl-3-(2-methylpropenyl) cyclopropanecarboxylate (approx 70% trans, 30% cis isomers)

The test plots were 300 ft², and the soil was a sandy loam type with clays beginning from 18 to 22 in. down. Each was covered with plant growth, principally grass. All treatments were made to damp but not flooded plots. Materials generally were applied at rates of 1, 2, and 4 lb AI/acre. Dursban was also applied at 0.5 lb/acre. Granules were hand broadcast, and wettable powders and emulsions were applied with a 3-gal compressed-air sprayer (40 psi, 8002 nozzle).

One and 2 weeks after treatment and biweekly thereafter through week 12, 3 sod samples (1/12 ft² × 3 in. deep, each) for each dosage and each mosquito species to be tested were taken at random from the treated plots. Samples were placed in battery jars (3/jar) and flooded 72 hr prior to introduction of 25 third-stage larvae jar. The larvae were placed inside wire mesh baskets (2×2×2½ in.) which were lowered into the upper surface of the water; *Anopheles albimanus* Wiedemann, *Aedes taeniorhynchus* Wiedemann, and *Culex pipiens quinquefasciatus* Say larvae were used routinely. Food was given and mortality observations were made 18 hr after the larvae were placed in jars. Each sample remained flooded for 10 days, then a 2nd series of caged larvae was introduced into the jars, and the mortality was assessed after 48 hr.

At the field site area, the average weekly rainfall was from 0.25 to 3.75 in. Air temperatures and relative humidity at the plot site were 60–90°F and 70–100%, respectively. The samples taken, however, were flooded and held at a water temperature of 76–82°F.

RESULTS AND DISCUSSION.—In the 3-day flooded soil samples, 13 of the compounds tested gave 6 or more weeks of residual kills against at least one of the species tested (Table 1). Dursban at 1 lb/acre was the most effective compound in all formulations against all 3 species; all formulations gave more than 12 weeks of 90% kill except the granular one, which gave 10 weeks against *A. taeniorhynchus*. When tested at 0.5 lb/acre, Dursban granules were effective for 6 weeks against *A. taeniorhynchus* and >12 weeks against *A. albimanus* (not tested against *C. p. quinquefasciatus*). Abate WP and EC at 4 lb/acre were also quite effective; they gave greater than 12 weeks of residual kills against all 3 species. Abate formulations at an application rate of 2 lb/acre did not give satisfactory residual kills of any of the test species. Fenthion EC at 2 lb/acre gave 10 weeks of residual kills of *A. taeniorhynchus* and 8 weeks of *A. albimanus* and *C. p. quinquefasciatus*, but was not effective for more than 2 weeks as a wettable powder. Both formulations of Akton at 2 lb/acre were effective for 12 weeks against *A. taeniorhynchus* and *A. albimanus*, but proved ineffective against *C. p. quinquefasciatus*. Carbaryl WP at 4 lb/acre was also effective for 12 weeks against *A. taeniorhynchus* and *A. albimanus*; at 2 lb/acre it was ineffective. Cidial and bromophos EC were effective for 6–10 weeks against *C. p. quinquefasciatus* and *A. albimanus* but were ineffective against *A. taeniorhynchus*.

At 4 lb/acre, Mobam G were effective for 10–12 weeks against the 3 species, but at 2 lb/acre this formulation was ineffective at 2 weeks. The wettable powder formulation was not highly effective even at 4 lb/acre. C-8874 WP was effective for 6 weeks against all 3 species at 4 lb/acre. At 2 lb/acre fenitrothion WP and propoxur EC were effective against *A. albimanus* for 6 and 12 weeks, respectively, but each performed poorly against the other species. At 2 lb/acre, chlorphoxim gave 6 weeks residual action against *A. taeniorhynchus* but only as an emulsion. Hercules 14469 G and Landrin WP were effective 6 weeks against *C. p. quinquefasciatus*. Bay 38799, C-9491, and tetramethrin at 4 lb/acre and dichlorvos, Dowco 214, Gardona, phoxim, and NRDC-104 at 2 lb/acre were not effective against the test species.

Soil samples which remained flooded for 10 days showed that granules of propoxur, Dursban, and fenitrothion were more effective than after the initial flooding; this increase indicates a slow release of the toxicant from granular preparations. Other formulations such as emulsions or suspensions of Bay 38799, chlorphoxim, Gardona, and phoxim were ineffective on the 1st test after being flooded 10 days. Other compounds, such as Abate, Akton, carbaryl, Cidial, C-8874, C-9491, Dursban, fenthion, and Mobam gave essentially the same level of effectiveness after the 10-day flooding as they did at the 3-day testing.

The residual effectiveness of Abate, propoxur, carbaryl, Cidial, fenthion, and Mobam was influenced by the formulations and by the test species used. Where differences were related to formulation, the emulsions and suspensions were superior to the granular preparations of all these compounds except Mobam.

Compounds such as Akton, propoxur, and carbaryl were more effective against *A. taeniorhynchus*, whereas bromophos, Cidial, fenthion, Hercules 14469, and Landrin were more effective against *C. p. quinquefasciatus*. All of these compounds were satisfactory against *A. albimanus*.

The data from these tests emphasized the marked differences in species response to certain compounds such as Akton, bromophos, and Cidial. However,

Table 1.—Weeks of 90% kill based on 48-hr exposure of 3rd-stage larvae in 3-day and in 10-day (in parentheses) flooded soil samples.

Insecticide	Formulation	AI lb/acre	*Ae. taen.*	*A. alb.*	*C. quin.*
Abate	1.0% G	2	1 (<1)	1 (<1)	1 (<1)
	50.0% WP	2	1 (<1)	1 (1)	3 (3)
	43.5% EC	2	3 (3)	5 (5)	4 (4)
	1.0% G	4	6 (4)	4 (4)	—
	50.0% WP	4	10 (10)	>12 (>12)	>12 (>12)
	43.5% EC	4	>12 (12)	>12 (12)	>12 (12)
Akton	1.0% G	2	>12 (>12)	>12 (8)	2 (<2)
	25.0% EC	2	>12 (>12)	>12 (12)	2 (<2)
Bay 38799	75.0% WP	4	2 (<2)	4 (<2)	2 (<2)
	25.0% EC	4	2 (<2)	—	2 (<2)
Bromophos	25.0% EC	2	2 (<2)	6 (6)	6 (6)
Carbaryl	5.0% G	2	1 (<1)	1 (<1)	1 (<1)
	50.0% WP	2	1 (<1)	1 (<1)	1 (<1)
	50.0% WP	4	>12 (>12)	>12 (>12)	— (—)
Chlorphoxim	2.5% G	2	2 (<2)	4 (<2)	2 (<2)
	50.0% WP	2	6 (<2)	—	2 (<2)
	25.0% EC	2	2 (<2)	2 (<2)	2 (<2)
Ciba-8874	50.0% WP	4	6 (6)	6 (6)	6 (6)
Ciba-9491	10.0% G	4	2 (<2)	2 (<2)	2 (4)
	50.0% WP	4	2 (2)	4 (4)	2 (2)
Cidial	2.0% G	2	2 (<2)	4 (<2)	2 (<2)
	40.0% WP	2	2 (<2)	2 (<2)	2 (<2)
	50.0% EC	2	2 (12)	>10 (12)	>10 (12)
Dichlorvos	20.0% pellet	2	<2 (<2)	<2 (<2)	— (—)
Dursban	5.0% G	0.5	6 (8)	>12 (>12)	—
	5.0% G	1	10 (>12)	>12 (>12)	>12 (>12)
	25.0% WP	1	>12 (>12)	>12 (>12)	>12 (>12)
	22.5% EC	1	>12 (>12)	>12 (>12)	>12 (>12)
Dursban methyl analogue	1.0% G	2	2 (<2)	2 (<2)	2 (<2)
Fenitrothion	1.0% G	2	<2 (2)	4 (8)	<2 (<2)
	40.0% WP	2	<2 (<2)	6 (<2)	<2 (<2)
	25.0% EC	2	<2 (<2)	4 (4)	<2 (<2)
Fenthion	5.0% G	2	2 (<2)	2 (<2)	2 (<2)
	46.0% EC	2	10 (12)	8 (6)	8 (6)
Gardona	75.0% WP	2	2 (<2)	<2 (<2)	<2 (<2)
	25.0% EC	2	5 (<2)	<2 (<2)	<2 (<2)
Hercules 14469	5.0% G	2	2 (2)	2 (2)	6 (2)
	25.0% WP	2	2 (2)	<2 (<2)	2 (2)
Landrin	50.0% WP	2	<2 (<2)	<2 (<2)	6 (<2)
Mobam	10.0% G	2	2 (<1)	2 (<1)	<1 (<1)
	50.0% WP	2	<1 (<1)	<1 (<1)	<1 (<1)
	10.0% G	4	10 (10)	>12 (12)	>12 (10)
	50.0% WP	4	2 (2)	4 (4)	2 (2)
NRDC-104	25.0% EC	2	<1 (<1)	<1 (<1)	<1 (<1)
Phoxim	10.0% G	2	1 (<1)	1 (1)	1 (<1)
	40.0% WP	2	2 (<2)	2 (<2)	2 (<2)
	50.0% EC	2	2 (<2)	2 (<2)	2 (2)
Propoxur	5.0% G	2	1 (6)	2 (>12)	1 (—)
	50.0% WP	2	3 (2)	2 (4)	2 (—)
	13.5% EC	2	2 (2)	>12 (2)	2 (2)
Tetramethrin	50.0% WP	4	<2 (<2)	<2 (<2)	<2 (<2)
	25.0% EC	4	<2 (<2)	<2 (<2)	<2 (<2)

other chemicals such as Abate, Durbsan, and fenthion apparently have a broad spectrum of activity because they were effective against all 3 species. Differences between species were sometimes obscured by the dosage applied, as revealed by the data for the Dursban granules at 0.5 lb/acre vs. those at 1.0 lb/acre.

Although carbamates generally are considered poor candidates for larvicides because of their higher LC_{50} values, the response of certain species to higher dosages (i.e., 2 to 4 lb/acre) indicates that compounds such as propoxur, carbaryl, and Mobam might be quite useful as larvicides. Whether such dosages would be feasible would depend in part upon their effect on nontarget organisms as well as on economic considerations.

Of interest is the variation in efficacy shown in these trials between Abate and Dursban, 2 compounds that have similar LC_{50} values of ca. 0.001 ppm against the test species involved. Application of Abate to soil as done in the studies apparently destroys its high level of activity, and dosages 8 times higher than that for Dursban are required before a similar level of effectiveness can be achieved. Both Abate and Dursban are labeled for control of mosquito larvae, but the maximum dosage rates stated are 0.1 and 0.05 lb/acre, respectively. Such levels are for use in mosquito-infested waters as a temporary control measure. Each compound is considered harmful to fish and crustaceans and should not be used when these nontarget animals are of value. Consequently, consideration of the much higher dosages required for preflood treatments must be limited to situations where hazard to valuable nontaget organisms is improbable. Toxicity studies by Ferguson et al. (1966) showed 0.02–0.6 ppm Dursban to be the median tolerated limits for shiner, mosquito fish, and green sun fish after a 36-hr exposure in static water conditions. Von Windeguth and Patterson (1966) reported that at 2.0 ppm Abate gave an LD_{90} of shrimp in laboratory tests, but at 0.1 ppm no effect was observed on shrimp, fish, and other aquatic organisms. Ludwig et al. (1968) indicated that Dursban in field studies against salt marsh mosquitoes caused no obvious effects on caged and free shrimp, minnows, crabs, fish, and birds at a dosage of 0.025 lb/acre. At 0.05 lb/acre, however, a reduction in numbers of brown shrimp, small fish, and minnows was observed.

The continued effectiveness of many of these materials after extended exposure under dry and flooded conditions indicates they have a potential for use as larvicides in areas where application at infrequent intervals is the only practical and economic approach to larval control. This approach would be particularly desirable against mosquito vectors in areas where adulticiding treatments had not been successful in curbing mosquito densities and/or disease transmission.

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