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SEVEN INSECTICIDES AS RESIDUAL SPRAYS IN BULIDINGS NATURALLY INFESTED WITH *ANOPHELES QUADRIMACULATUS*[1]

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Applications of insecticides that have long residual activity inside buildings have been used extensively throughout the world in programs for control of malaria. However, the resistance to DDT and dieldrin that has developed in mosquitoes has made it important to find alternate materials.

Since 1943, the Entomology Research Division has maintained a testing program at the Insects Affecting Man Investigations Laboratory, now at Gainesville, Florida for the evaluation of new insecticides as residual sprays against disease-carrying mosquitoes. To be useful in programs involving buildings occupied by people, the insecticides must have a favorable mammalian toxicity, remain effective for a considerable period, and be cheap. Fast knockdown also would be a highly desirable characteristic.

The present paper reports the results obtained in tests made in mosquito-infested buildings with a group of insecticides that have been highly effective in laboratory tests (Gahan *et al.* 1967; Wilson *et al.,* 1970) and that have an LD_{50}

[1] Mention of a pesticide or a proprietary product in this paper does not constitute a recommendation or an endorsement of this product by the USDA.

to rats higher than 100 mg/kg body weight. All the test chemicals were received from commercial sources; however, most of them were available only for experimental purposes, so nothing is known about their eventual cost. The designation, chemical name if no approved common name is available, and acute oral LD_{50} to rats (based on information received from the manufacturer) for the compounds evaluated are as follows:

used as water suspensions. All potential resting places inside each building were treated at the rate of 2 g/m^2, and special attention was given to areas under feed boxes and in dark corners. Most applications were made between June 12 and 27, and the treated buildings were checked once a week for 11–13 weeks before the rice fields were drained. However, Bay 38800 was received late and was applied July 16 so the treatment was observed for

Designation	Chemical Name	Acute oral LD_{50} in rats (mg/kg)
Bay 38800	*o*-2-cyclopenten-1-ylphenyl methylcarbamate	>500
Baygon®	*o*-isopropoxyphenyl methylcarbamate	95–104
Carbaryl		540
CIBA C-9491	*O*-(2,5-dichloro-4-iodophenyl) *O,O*-dimethyl phosphorothioate	2000
Montecatini L-561	ethyl mercaptophenylacetate *S*-ester with *O,O*-dimethyl phosphorodithioate	300
Dursban®	*O,O*-diethyl *O*-3,5,6-trichloro-2-pyridyl phosphorothioate	135–163
Hercules 14469	*m*-cumenyl (mercaptoacetyl)methylcarbamate *S*-ester with *O,O*-dimethyl phosphorodithioate	432

The study was conducted during the summer of 1968 in the vicinity of Stuttgart, Arkansas, one of the principal rice-growing areas of the United States. In this region, large numbers of fields are flooded from early May until September, and *Anopheles quadrimaculatus* Say from these fields enter the available buildings, particularly those that house animals or have animals nearby, to spend the day resting on the walls, ceilings, or spider webs.

Only small buildings such as chicken houses, barns, dog houses, pump houses, storage sheds, and garages that housed animals or had animals nearby were used. Also, the count of *A. quadrimaculatus* in all buildings selected had exceeded 150 on at least two occasions the week before treatment. Three buildings, each of which was located in a different area, were treated with each formulation. The sprays were applied with a 3-gallon compressed air sprayer equipped with a TeeJet nozzle that produced a flat, fan-shaped spray. Three compounds were applied as emulsions, five were used as wettable powders, and two formulations of carbaryl were

only 8 weeks. In addition, five buildings were designated as untreated checks and used to determine fluctuations in the populations of mosquitoes throughout the summer.

The effectiveness of a treatment was judged by comparing the pretreatment and posttreatment counts of adult *A. quadrimaculatus* in the buildings. These counts were always taken in the afternoon to allow the insecticide adequate time to kill the resting mosquitoes. However, on rainy or extremely cloudy days, some mosquitoes entered the buildings several hours later than normal and continued to fly instead of resting quietly on the walls. When that occurred, counts were not made until the next afternoon.

The effectiveness of the residual deposits was also evaluated by exposing 10 to 40 *A. quadrimaculatus* that had been collected in an untreated building to the walls of treated buildings for 60 minutes under half sections of petri dishes. One dish, held in place by rubber bands stretched between 2 staples driven into the wall, was used for each of 4 walls. The time required for 50 and 100 percent knockdown was recorded if it occurred during the exposure. Whenever less than 50 percent or 100 percent knockdown occurred in 1 hour, those particular readings were listed as >60 minutes in figuring the average. The dishes were removed from the wall by sliding stiff 4 x 5-inch cards under them to confine the insects. The mosquitoes then were slightly anaesthetized with carbon dioxide, transferred to clean cardboard cartons that had open mesh cloth lids, placed in an insulated box that contained 2 cans of coolant, and carried to an air conditioned room. A piece of cotton saturated with a 10 percent solution of sucrose and water was placed over the cover of each carton. Mortality counts were taken after the mosquitoes had been held for 24 hours.

The numbers of *Anopheles quadrimaculatus* counted in untreated buildings throughout the summer of 1968 are given in Table 1. They show mosquitoes were prevalent in the area throughout the entire time of the study. The density of adults gradually increased throughout June and reached a peak during July and August. A gradual decline started in the early part of September when the farmers began draining their rice fields but the average per building still was about as high between September 9 and 13 as it had been at the time all of the treatments except Bay 38800 were applied.

The average of the two pretreatment counts and the percentage reductions of free flying mosquitoes obtained by spraying are shown in Table 2 for each building. Baygon was the only insecticide that caused 100 percent reduction in all buildings throughout the entire test. Dursban was the next most effective compound and usually eliminated 99–100 percent of the mosquitoes; however, during the 13th and 14th weeks it gave only 97–98 percent reduction in one pump house, during the 5th week it gave only 93 percent reduction in the second pump house, and during the 10th week it gave only 98 percent reduction in the chicken house. Montecatini L-561 eliminated 99–100 percent of the mosquitoes for 11 weeks in two buildings and for 10 weeks in a third; however, during the last 2 weeks of the test, the residual activity in the pony barn and the chicken house showed considerable loss in toxicity. Hercules 14469 caused reductions of 99–100 percent in the storage shed for the entire 13 weeks, in the chicken house for 9 of 11 weeks, and in the pig shed for the first 9 weeks, but

TABLE 1.—Counts of *Anopheles quadrimaculatus* in untreated buildings.

	Number of mosquitoes counted in indicated type of building					
Date in 1968	Abandoned house	Animal barn	Animal barn	Chicken house	Goat shed	Total count
6/3–6/7	36	49		91	33	209
6/10–6/14	194	116	97	142	58	607
6/17–6/21	216	49	167	294	88	814
6/24–6/28	77	104	209	461	119	970
7/1–7/5	64	81	160	192	104	601
7/8–7/12	93	221	376	>1000	129	>1819
7/15–7/19	63	132	319	>1000	209	>1723
7/22–7/26	38	212	116	326	87	779
7/29–8/2	46	232	88	686	104	1156
8/5–8/9	42	110	121	640	116	1029
8/12–8/16	142	177	242	>1000	76	>1637
8/19–8/23	64	244	361	>1000	170	>1839
8/26–8/30	111	295	488	>1000	216	>2110
9/2–9/6	84	116	394	>1000	106	>1700
9/9–9/13	104	105	204	424	90	927

control dropped to 95–91 percent the 5th and 6th weeks (though it later increased to 100 percent) in the chicken house and varied from 76 to 81 percent in the pig shed after the 9th week. CIBA C-9491 and carbaryl were much less effective: however, with CIBA C-9491, the reduction frequently reached 100 percent; with carbaryl, it reached this level only once. Also the results obtained with carbaryl and CIBA C-9491 were quite erratic; heavy populations were found in one or more of the buildings treated with each compound within 1 to 2 weeks after spraying, and the control usually remained below 90 percent after the 9th to 11th weeks and sometimes stayed below that level after the 4th or 7th weeks. The wettable powder formulation of CIBA C-9491 appeared to be superior to the emulsion concentrate. Within 6–7 weeks after application, Bay 38800 showed considerable loss in effectiveness in the chicken house and in one dog house, and some loss in the other dog house.

Results of the wall exposure tests are presented in Table 3. This method of evaluation appeared to be much less sensitive than the counts of free-flying mosquitoes because the 24-hour mortalities were often so high and the knockdowns so slow that no loss in toxicity was apparent. However, Baygon, carbaryl, and Hercules 14469 consistently killed all the mosquitoes. CIBA C-9491, Dursban, and Montecatini L-561 usually caused 97–100 percent kill though some loss in toxicity appeared between the 2nd and 9th weeks in the dog house sprayed with the emulsion concentrate of CIBA C-9491 and in the chicken house sprayed with Dursban. The greatest loss in effectiveness occurred with Bay 38800; in all three buildings treated with this compound, the 24-hour mortality decreased from 91–100 percent the second week to 22–50 percent by the 6th-7th weeks.

Time to knockdown also showed some deterioration in the effectiveness of Baygon, Hercules 14469, Montecatini L-561, and Dursban because it increased between the 1st-2nd weeks and 10th-11th weeks. Baygon was always the fastest acting material tested. Considerable variation occurred from week to week with carbaryl, but no substantial loss in toxicity was apparent after 9–13 weeks of aging. In many tests, including some made with carbaryl and all made with CIBA C-9491 and Bay 38800, the knockdown was so slow that no conclusions could be drawn.

The discrepancies between the two methods of evaluation were most apparent in the results obtained with carbaryl and CIBA C-9491. In the exposure tests, both these compounds produced a high degree of mortality in 24 hours and appeared to be among the most effective tested; Baygon also was one of the most toxic and the fastest acting. However, when the density of the natural infestations in the buildings was evaluated, Baygon was the most effective, and carbaryl and CIBA C-9491 were two of the least effective. Obviously, carbaryl and CIBA C-9491 were more effective when the mosquitoes were forced to rest on the sprayed walls than when they were free to stay or leave.

The two methods of testing, thus, could lead to different interpretation of the effectiveness of insecticides. We believe the results obtained with natural infestations are of more value than those obtained when insects are forced to remain on treated surfaces as compounds that allow live mosquitoes to remain in treated buildings are likely to be inferior to those that eliminate them.

SUMMARY. Seven chemicals that had been highly effective in laboratory studies were evaluated as residual sprays applied at 2 g/m^2 in buildings naturally infested with adult *Anopheles quadrimaculatus*.

When the evaluation was made by counting the natural infestation of mosquitoes present, Baygon® (*o*-isopropoxyphenyl methylcarbamate) was the only insecticide that caused 100 percent reduction throughout the entire test. Dursban® (*O,O*-diethyl *O*-3,5,6-trichloro-2-pyridyl phosphorothioate) appeared to be the

TABLE 2.—Control of *Anopheles quadrimaculatus* in buildings treated with various insecticides applied as residual sprays at the rate of 2 g/m².

Type of building	Pre-treatment count	Percentage reduction at indicated weeks after treatment												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Baygon [a]														
Pump house	186	100	100	100	100	100	100	100	100	100	100	100	100	100
Chicken house	298	100	100	100	100	100	100	100	100	100	100	100	100	100
Storage shed	246	100	100	100	100	100	100	100	100	100	100	100	100	100
Dursban [a]														
Pump house	219	100	100	100	100	100	100	100	100	100	100	100	98	97
Pump house	207	100	100	100	100	93	100	100	100	100	100	99.5	99.5	
Chicken house	>1000	100	100	100	100	100	100	100	100	99.1	98	99.0		
Montecatini L-561 [b]														
Pony barn	329	100	99.0	100	100	100	100	100	100	100	100	100	74	64
Chicken house	246	100	100	99.6	100	100	100	100	99.6	99.0	100	93	89	
Garage	634	100	100	100	100	100	100	100	100	100	100	100		
Hercules 14469 [b]														
Storage shed	198	100	100	100	100	100	100	100	100	100	100	100	99.0	100
Pig shed	396	100	100	100	100	100	100	100	100	100	77	81	76	
Chicken house	187	100	100	100	100	95	91	100	100	100	100	100		
CIBA C-9491 [a]														
Pony barn	281	59	4	99.0	93	98	99.0	82	19	0	0	0	22	23
Cow barn	602	65	37	92	0	73	75 [c]							
Dog house	571	100	99.2	91	99.8	96	98	99.6	96	68	70	87		
CIBA C-9491 [b]														
Chicken house	423	99.3	57	100	100	100	100	99	99.1	98	98	81	76	61
Chicken house	294	79	89	99.0	99.6	95	94	59	55	97	85	58	68	
Chicken house	273	100	99.2	100	100	100	100	100	100	100	78	68		

TABLE 2.—Control of *Anopheles quadrimaculatus* in buildings treated with various insecticides applied as residual sprays at the rate of 2 g/m^2.

Type of building	Pre-treatment count	Percentage reduction at indicated weeks after treatment												
		1	2	3	4	5	6	7	8	9	10	11	12	13
							Carbaryl[d]							
Chicken house	727	98	71	90	98	99.0	99.8	99.2	99.7	99.4	99.3	86	69	70
Horse barn	536	90	85	98	96	98	99.0	94	99.1	88	67	90	89	
Chicken house	>1000	88	99.0	98	100	99.3	91	88	98	0	0	0		
							Carbaryl[e]							
Chicken house	733	89	2	78	88	97	97	98	99.0	99.0	97	77	34	81
Chicken house	344	92	92	97	98	98	93	84	42	91	58	45	38	
Chicken house	388	98	97	96	96	95	97	98	97	87	19	55		
							Bay 38800[b]							
Chicken house	485	100	100	100	99.8	97	43	59	71					
Dog house	276	100	100	99.6	100	99.6	22	34	62					
Dog house	361	100	100	100	100	100	100	95	94					

[a] Treatment applied as an emulsion concentrate.
[b] Treatment applied as a wettable powder formulation.
[c] Building was sprayed by owner.
[d] 53.68% carbaryl, 46.32% inert ingredients.
[e] 24% carbaryl, 38.5% petroleum distillate, 37.5% inert ingredients.

TABLE 3.—Averages of results obtained in petri dish tests on walls of 3 buildings treated with each insecticide.

Insecticide	Age of treatment in weeks	Time in minutes for knockdown of 50%	Time in minutes for knockdown of 100%	Percentage mortality in 24 hours
Baygon	1–2	6	10	100
	10–11	11	17	100
Carbaryl	1	>40	>54	100
	9–13	>42	>58	100
Hercules 14469	1	15	32	100
	9–11	>33	>48	100
CIBA C-9491 W. P.	2–3	>47	>60	100
	9–10	>60	>60	99
CIBA C-9491 E. C.	1	>50	>60	100
	9–12	>57	>60	91
Dursban	1	16	26	100
	9–11	>55	>60	80
Montecatini L-561	1–3	20	33	100
	9–10	>43	>49	99
Bay 38800	2	>36	>49	97
	6–7	>58	>60	40

next most effective compound since it produced 99–100 percent control on almost every occasion. Montecatini L-561 (ethyl mercaptophenylacetate *S*-ester with *O,O*-dimethyl phosphorodithioate (50 percent emulsifiable concentrate)) and Hercules 14469 (*m*-cumenyl (mercaptoacetyl) methylcarbamate *S*-ester with *O,O*-dimethyl phosphorodithioate) eliminated 99–100 percent of the mosquitoes for 9 to 13 weeks but showed considerable loss in toxicity in one or more buildings before the test was discontinued. CIBA C-9491 (*O*-(2,5-dichloro-4-iodophenyl) *O,O*-dimethyl phosphorothioate) and carbaryl were less effective and produced erratic results. Bay 38800 (*o*-2-cyclopenten-1-ylphenyl methylcarbamate) was the least effective compound tested.

Wall exposure tests in which the mosquitoes were confined close to treated surfaces under half sections of petri dishes appeared to be a much less sensitive measure of relative effectiveness than counts of free flying mosquitoes because the 24-hour mortalities were often so high and the knockdown so slow that no loss of toxicity was apparent.

Since the two methods of evaluation could lead to different interpretations of the effectiveness of insecticides, the results obtained with natural infestations would be of more value than those obtained with insects forced to remain on treated surfaces.

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