RESIDUAL SPRAYS FOR THE CONTROL OF *ANOPHELES QUADRIMACULATUS* IN BUILDINGS

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Spraying the interior of buildings with insecticides to kill the adults of *Anopheles* mosquitoes has been widely used as a malaria control measure since the end of World War II. In recent years there have been many reports that serious resistance has developed to DDT and other chlorinated hydrocarbons. Brown (1958) in his review of the literature on this problem presents evidence that physiological or behavioristic resistance to one or more of these insecticides has become widespread throughout the world. Other and more effective insecticides are therefore needed to insure an effective, continuing campaign to eradicate malaria.

Laboratory tests conducted by LaBrecque *et al.* (1958) and Gahan *et al.* (1959) indicated that malathion, Diazinon, dicapthon, ronnel (Korlan, Dow ET-57), barthrin, and 2,4-dimethylbenzyl chrysanthemumate had sufficient residual durability and toxicity to serve as substitutes for the chlorinated hydrocarbons. To obtain more information on these materials under conditions of practical use, a series of tests was conducted in the vicinity of Stuttgart, Arkansas, during the summer of 1958 in buildings naturally infested with adults of *Anopheles quadrimaculatus* Say. DDT was included as a standard.

Stuttgart is in one of the principal rice-growing areas in the United States, and there are many large fields flooded with water from May until September. *Anopheles* breeding starts early in the growing season and reaches a peak during the latter part of August or early in September. Adult mosquitoes are prevalent throughout the summer in buildings that house animals or are close to their pasturages, but are usually not numerous on farms without livestock.

Only small buildings on farms having livestock were used in this study. Most of them were chicken houses or barns that housed animals each night, but some pump houses, sheds, garages, and privies close to areas where cattle or chickens fed regularly were also used. All were constructed of wood, and several had a portion of the inside surface covered with tarred paper. Since spider webs provide resting places for *Anopheles* adults and the spray did not adhere to them as well as to the wood, those that could be removed easily were eliminated before spraying. In some buildings the spiders built new webs after the insecticides had been applied, and mosquitoes were sometimes found resting on them.

Emulsion sprays were applied on the interior walls, ceilings, and any pieces of equipment that were present. The exterior surfaces and areas under the eaves were left untreated. Applications were made with a compression sprayer that had an adjustable nozzle with a flat fan cap. All but two of the sprays were prepared from concentrates containing 25 percent of the toxicant, 65 percent of xylene, and 10 percent of Triton X-100 (an aralkyl polyether alcohol). The others were commercial preparations containing 25 percent of Diazinon or 50 percent of malathion. Just enough material was placed in the sprayer to treat a single building at the desired dosage. Between July 14 and 23 each material was applied to three or four buildings at the rate of 200 mg. per square foot. These sprays contained 2.5 percent of toxicant. Between August 4 and 7 barthrin and 2,4-dimethylbenzyl chrysanthemumate were applied to two additional buildings at 200 mg. and to three or four others at 400 mg. per square foot. These sprays contained 5 percent of toxicant. On August 11 Diazinon and malathion were

TABLE 1.—Effect of insecticide residues on mosquito densities in buildings during the afternoon

Dosage (mg./sq. ft.)	Type of Building	Pretreatment Count	Percent Reduction at Indicated Intervals after Treatment Weeks						
			1	2	3	4	5	7–8	10–11
Malathion									
50	Shed	373	98	89	—	92	—	99.4	—
		496	99.8	99	—	96	—	99.3	—
	Chicken house	276	99.6	97	—	91	—	63	—
200	Chicken house	677	100	100	100	100	100	97	99
		329	100	100	100	100	100	95	98
	Garage	612	100	100	100	99.7	99	100	99
Diazinon									
50	Horse stable	975	100	98	—	36	—	—	—
		537	100	86	—	6	—	—	—
	Chicken house	354	100	97	—	8	—	—	—
200	Garage	1100	100	100	—	100	100	96	99.9
		299	100	100	100	100	99.3	3	—
	Chicken house	675	100	100	100	99.7	99.7	61	—
DDT									
200	Chicken house	177	100	100	97	97	95	93	59
		629	100	99.7	99	97	94	79	91
	Cow barn	1570	98	72	79	76	44	—	—
Dicapthon									
200	Chicken house	620	100	99.5	98	99.6	88	0	—
	Privy	207	100	99.5	86	99	96	0	—
	Pump house	136	100	100	100	99.3	97	7	—
Ronnel									
200	Cow barn	5250	99.9	99.9	62	0	—	—	—
	Sheep fold	1445	100	100	84	48	24	—	—
	Horse stable	451	100	100	99.6	98	91	49	—
2,4-Dimethylbenzyl chrysanthemumate									
200	Pigsty	407	85	98	49	0	—	—	—
	Chicken house	248	100	99.6	80	63	0	—	—
		328	99.1	75	10	—	—	—	—
		1125	99.6	95	68	—	34	—	—
	Shed	396	99.7	99.5	73	59	10	—	—
	Pump house	192	100	97	97	—	88	96	—
400	Chicken house	237	100	98	90	—	61	—	—
		212	100	97	86	—	27	—	—
		412	100	99	92	—	84	97	—
	Dog house	345	100	99.7	100	—	98	99	—
Earthrin									
200	Chicken house	182	91	90	0	0	—	—	—
	Cow barn	1537	98	97	90	11	—	—	—
		910	97	83	0	—	—	—	—
	Shed	305	99	55	48	—	—	—	—
	Pump house	225	100	98	—	91	88	93	100
400	Chicken house	725	99.7	98	83	—	97	95	—
		348	100	98	83	—	74	95	—
	Pigsty	945	100	99	95	—	91	99.4	—

applied in 1 percent emulsions to three buildings at 50 mg. per square foot.

The effectiveness of these treatments was determined by making pre- and post-treatment counts of the *Anopheles* adults seen in the buildings. Before a building was selected two afternoon observations were made. If the infestation exceeded 100 *Anopheles* both times, the building was used in the test. In buildings where the number exceeded 500 it was impossible to obtain an accurate count, for mosquitoes moving from one spot to another disturbed those in the vicinity; therefore, 50 or 100 were counted to assist in making estimates of the total number present. Most of the post-treatment observations were also made during the afternoon, to allow the insecticide time to affect the mosquitoes. Between August 4 and 20 all the buildings that were free of mosquitoes in the afternoon were visited on 1 or 2 days within an hour after sunrise to ascertain if *Anopheles* were entering the buildings and resting on the treated surfaces. Repeat visits were made the same day at hourly intervals until all mosquitoes left or it became obvious that some of them would remain until the afternoon. All the interior surfaces were examined with the aid of a flashlight. Particular attention was paid to the corners of the room, the inside and under side of chicken nests, the inside of empty boxes or feeding troughs, and other places where the light intensity was low, as they were the favored resting areas. On hot days most of the mosquitoes were on the lower part of the wall and none on the ceiling, but on cool days they preferred the ceiling and upper part of the wall. Most of the mosquitoes in these buildings were *Anopheles quadrimaculatus*. An occasional *Psorophora* was seen, but it was never included in the counts. The percent reduction was determined from the number of mosquitoes observed before and at various intervals after treatment.

During the latter part of September the rice fields were drained. The nights became sufficiently cool so that the mosquitoes encountered were sluggish. Low counts were obtained on September 29 in many of the sprayed and unsprayed buildings, showing the end of the mosquito season was approaching rather than an increase in effectiveness of the residues. The experiment was discontinued on that date. By that time the age of the treatments ranged from 7 to 11 weeks.

The results are given in Table 1. The most effective materials were malathion and Diazinon. Not a single mosquito was found during the afternoon throughout the first 3 weeks in any of the buildings sprayed with these materials at 200 mg. per square foot and only a few were found the fourth and fifth weeks. The malathion continued to show 95–99 percent reduction throughout the 10–11 week observation period, but by the seventh or eighth week the protection had disappeared in one of the buildings sprayed with Diazinon and decreased to 61 percent in another. Observations made within 1 hour after sunrise demonstrated that neither of these chemicals was highly repellent. More than 50 and as many as several hundred mosquitoes that landed readily on the treated surfaces were seen in each of the buildings. As early as the third and fourth weeks malathion appeared to be the faster acting material, because it cleared the buildings of mosquitoes by 8–9 a.m. A few mosquitoes were still present at that time in the buildings sprayed with Diazinon, but they disappeared by 10–10:30 a.m. Neither of these compounds was as satisfactory at a dosage of 50 mg. per square foot as at 200 mg. Some *Anopheles* adults were found in the afternoons of the first week in the buildings treated with malathion and the second week in those sprayed with both compounds. Counts were so high by the fourth week in the three buildings treated with Diazinon that no further observations were made, but reductions above 90 percent were maintained in two of those treated with malathion throughout the 7-week period.

In contrast to the results with malathion and Diazinon, mosquitoes were found as early as the third week in all the buildings sprayed with DDT at 200 mg. per square foot. The reduction in one cow barn was less than 100 percent the day after treatment and less than 80 percent by the second week. Although the other two treatments were considerably more effective, on one occasion between the eighth and eleventh weeks the protection dropped to 79 percent in one of the buildings and 50 percent in the other. After the fifth week it was never above 95 percent in any building.

Dicapthon and ronnel also were highly effective in all buildings for at least 2 weeks. Two of the ronnel treatments then lost their toxicity rapidly, but the residue in the horse stable gave at least 98 percent protection for 4 weeks. This building was about half a mile from the closest rice field, which reduced considerably the population pressure. Mosquitoes were entering the stable during this period, however, for about 100 were seen one morning within an hour after sunrise, over half of which were on treated surfaces. By the seventh week this treatment had lost about 50 percent of its effectiveness. The privy sprayed with dicapthon contained 28 mosquitoes in the third week, but most of them were on a recently constructed spider web. By the fifth week two of the dicapthon treatments were losing their toxicity rapidly and by the seventh week all three were ineffective.

Barthrin and 2,4-dimethylbenzyl chrysanthemumate were the least durable. At 200 mg. per square foot both failed to give complete protection during the afternoon for 2 weeks in any of the buildings, and most of the treatments were less than 90 percent effective within 3 weeks. Increasing the dosage to 400 mg. per square foot improved the protection obtained, but the two materials still lost their effectiveness faster than the 200-mg. deposits of Diazinon or malathion. While it remained effective, 2,4-dimethylbenzyl chrysanthemumate, which laboratory tests have shown to be particularly quick in knockdown, did reduce annoyance more than at least four of the other compounds. Two weeks after application the number of *Anopheles* mosquitoes found within an hour after sunrise in buildings sprayed with this insecticide at 400 mg. per square foot ranged between 2 and 12, as compared with more than 75 in those sprayed with barthrin at 400 mg., 150 in those with malathion at 200 mg., and 250 in those with Diazinon and DDT at 200 mg. Early-morning counts were not made in the buildings treated with ronnel and dicapthon. Counts made soon after sunrise should indicate the maximum densities that will be present at any one time, as *Anopheles* adults seek their daytime resting places at that time.

Although malathion was superior to DDT in these tests, it may not be more effective against other species. A comparison of the results obtained with DDT in this experiment and the one conducted in 1944 (Gahan and Lindquist 1945) shows that the present treatments were considerably less effective. In 1944 deposits that averaged 208 mg. per square foot reduced the infestation more than 99 percent for 3½ to 4½ months, whereas none of the present treatments produced this degree of protection after the third week. Possibly the practice by many farmers of scattering dusts containing a combination of DDT and BHC on lawns and around barnyards to obtain relief from mosquitoes has caused some resistance to develop.

SUMMARY.—Malathion and Diazinon were the most effective of seven chemicals applied as residual treatments to buildings containing natural infestations of *Anopheles quadrimaculatus* Say. At 200 mg. per square foot both compounds gave 100 percent reduction for 3 weeks and malathion gave 95 percent to 99 percent reduction throughout the remainder of the 10- to 11-week observation period, but by the seventh or eighth week Diazinon had

lost considerable effectiveness. Observations made within one hour after sunrise demonstrated neither chemical was highly repellent. The DDT standard gave less than 95 percent reduction after the fifth week. Dicapthon and ronnel (Dow ET-57, Korlan) were highly effective for at least 2 weeks and partially effective for 4 to 5 weeks. Barthrin and 2,4-dimethylbenzyl chrysanthemumate were the least durable of the group, but while it remained effective, the latter compound acted very quickly.

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