ULTRALOW VOLUME AERIAL SPRAYS OF MALATHION AND FENTHION FOR ANOPHELINE MOSQUITO CONTROL IN PANAMA CANAL ZONE JUNGLE[1]

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In 1967, a study was begun to evaluate ultralow volume (ULV; technical or highly concentrated material) applications of insecticides for the control of exophilic anopheline vectors of malaria in jungle areas. Preliminary studies made in the Panama Canal Zone with two insecticides, malathion and fenthion, showed that a dose 3 times that used for conventional application in the United States was required to achieve adequate control (Lofgren *et al.* 1968). However, more research was needed, and we particularly lacked information about the optimum droplet size for penetration of the jungle canopy. Consequently, additional tests were made during the fall of 1969 in the Canal Zone: (1) to further define the doses of insecticide needed to achieve satisfactory anopheline control under the jungle canopy, (2) to study the penetration of droplets of insecticide through the jungle canopy, (3) to correlate the reduction in natural populations of adult anophelines with the kill of caged anophelines, and (4) to evaluate the use of increased altitudes and wider swaths in the jungle.

The 1969 project was a combined effort of the Insects Affecting Man and Animals Research Laboratory, Gainesville, Florida, the Environmental Health Laboratory. U. S. Army Forces Southern Command, Fort Clayton, Canal Zone, and the Headquarters Special Operations Force Tactical Air Command, Eglin Air Force Base, Florida.

Materials and Methods. The tests were made in an area located between the Panama Canal railroad and the southeast border of the Canal Zone about 12 miles northwest of Gamboa. This area consists of mountainous terrain (peaks from 150 to 500 feet) covered almost entirely by a dense canopy which was from 50 to 100 feet above ground. The bioassays were made on a pipeline road that paralleled the railroad and was located near the center of the plot. The test plot was about 3 miles long and averaged 2 miles in width; however, only the upwind 1.6 miles of the plot were treated in each test; the remaining downwind area (1.4 miles across) was used to evaluate drift of the insecticide. All spray flights were made perpendicular to the road which was oriented from 315° west northwest to 135° east southeast. The swaths were marked with helium-filled weather balloons which supported bright orange paper panels.

The ULV sprays of malathion (95 percent) and fenthion (8 pounds active ingredient per gallon) were applied in the early evening, from 4:30 to 6:00 p.m., from an Air Force C-47 aircraft equipped with a fuselage-mounted spray boom system similar to that described by Glancey *et al.* (1970) and Lofgren *et al.* (1970). The malathion was dispersed through twelve 8008 TeeJet® nozzles with a boom pressure of 29 pounds per square inch. The fenthion was dispersed through

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twenty 8004 nozzles calibrated to deliver 6 gallons per minute with a boom pressure of 28 psi. All nozzles were positioned at a 45° angle forward to the thrust line of the aircraft which was flown at a speed of 150 miles per hour. The theoretical doses applied (based on the target area only) were 6 fluid ounces (0.456 pound) per acre of malathion and 1.2 fluid ounces (0.075 pound) per acre of fenthion.

Weather conditions (primarily wind velocity and direction at various altitudes) existing at the test site were determined by a combat weather team from Detachment 75, 5th Weather Wing, Hurlburt Air Force Base, Florida. Observations were made before, during, and about 30 minutes after each application.

The bioassays of the ULV aerial sprays included sampling of the natural adult mosquito population and the exposure in cups or cages of laboratory-reared larvae (fenthion tests only) and adult female *Anopheles albimanus* Wiedemann.

Sampling stations were spaced at 0.25-mile intervals along the pipeline road. The adult mosquitoes were collected with battery-powered aspirators by one man at each station for one hour during the evening from 6 to 7 p.m.; all these collections were returned to the Environmental Health Laboratory for identification and counting. Also, at each station, adult mosquitoes, 4- to 5-days old, were exposed in 16-mesh screen wire cages (25 per cage; 2 cages per station) which were suspended on 3.5-foot wooden stakes. One cage was located on the shoulder of the road, and one at about 100 feet from the road under the jungle canopy. Thus, we were able to make direct comparisons between the kill of caged mosquitoes and the reductions in the natural population; also, we could determine the effect of the jungle canopy by comparing the kills of mosquitoes under or outside the canopy. In all tests, the caged mosquitoes were exposed overnight (about 14 hr) in the jungle. When the larval *A. albimanus* were bioassayed in the tests with fenthion, they were exposed overnight in paper cups of water (25 larvae per cup) at the same sampling stations. Mortality of adults and larvae was recorded about 18 hours after the sprays were delivered.

Droplets collected in the open and under the dense jungle canopy were compared by "flooding" a small target area with malathion spray (five swaths at 50-foot intervals and at 75- to 100-foot altitude were made with the C-47 aircraft). Spray droplets were collected on silicone-treated glass microscope slides rotated in a vertical plane with a battery-operated spinning device at a speed of 5 mph to enhance impingement of the smaller spray droplets. A total of 200 droplets were sampled from each location, and the data were analyzed by the method of Yeomans (1949) for impinged droplets.

RESULTS AND DISCUSSION. The average pretreatment count of adult mosquitoes was 77 per man hour. Of these, 88 percent were *A. albimanus*, 7 percent other other anophelines, and 5 percent culicines. Table 1 shows the data obtained for the first test with 6 fluid ounces of technical malathion per acre. The 24-hour count of the natural population indicated that the highest reduction (99 percent) occurred 1.5 to 2 miles downwind from the last swath. However, the large increase in the check area (203 percent in 24 hours) indicated that the treatment area was reinfested very quickly; thus, overall mosquito control was poor. The data on kill of caged mosquitoes definitely showed that this poor control was not attributable to inadequate distribution of the insecticide; kill of mosquitoes in the treatment area was complete in cages along the road and ranged from 52 to 100 percent in cages under the jungle canopy.

In the second test with 6 fluid ounces per acre of malathion (Table 2), there was good correlation between the reduction (81–90 percent) in the natural population and the kill (62–100 percent) of the caged mosquitoes. In addition, kill of caged mosquitoes occurred as much as 1 mile downwind (100 percent along the road and 52 percent under the jungle canopy).

In the third test (Table 3), with 1.2

TABLE 1.—Control of anophelines in Panama Canal Zone jungle with 6 fluid ounces of 95 percent malathion per acre dispersed at 0.2 mile swath intervals and an altitude of 150 feet. The wind direction at the dispersal altitude was 135° at a speed of 3 mph.

	Percentage reduction or kill of anophelines at indicated distance (miles) from upwind side of plot[a]					
	Check upwind area	Treatment area			Downwind area	
Type of bioassay	(—)0.75–0	0–0.5	0.5–1	1–1.5	1.5–2	2–2.5
Natural adult population						
at 24 hr.	+203	+148	44	56	99	34
at 48 hr.	+537	50	49	+25	72	+43
Caged adult *Anopheles albimanus*						
on open road	13	100	100	100	86	60
under jungle canopy	9	52	98	100	58	8

[a] + indicates percentage increase.

fluid ounces of fenthion per acre, reductions of the natural population ranged from 13 to 84 percent in the treatment area; also, 84 to 99 percent reduction was obtained in the downwind area. Almost complete kill of caged mosquitoes was obtained on the road and under the jungle canopy in both the treatment and downwind areas. A high degree (92–100 percent) kill of larvae was also noted in the treatment area: in the downwind area, it ranged from 0 to 100 percent. In this test, 0.4 mile (or about 2000-foot) swaths were flown. The results indicated that adequate distribution of the fenthion was obtained.

The results of the fourth test (Table 4), 1.2 fluid ounces of fenthion per acre, did not appear as good as those of the third test. A 24-hour collection of the natural population could not be made because of heavy rains, but the 48-hour collection indicated reduction ranging from 18 to 84 percent. Caged adult mosquito kills ranged from 44 to 100 percent in both treatment and downwind areas. As in the previous test, larval kills were gen-

TABLE 2.—Control of anophelines in Panama Canal Zone jungle with 6 fluid ounces of 95 percent malathion per acre dispersed at 0.2 mile swath intervals and an altitude of 300 feet. The wind direction at the dispersal altitude was 300° at a speed of 3 mph.

	Percentage reduction or kill of anophelines at indicated distance (miles) from upwind side of plot[a]					
	Check upwind area	Treatment area			Downwind area	
Type of bioassay	(—)0.5–0	0–0.5	0.5–1	1–1.5	1.5–2	2–2.5
Natural adult population						
at 24 hr.	51	90	81	90	32	+37
at 48 hr.	+66	11	61	84	+13	+107
Caged adult *Anopheles albimanus*						
on open road	14	100	100	100	100	100
under jungle canopy	8	62	100	100	52	52

[a] + indicates percentage increase.

TABLE 3.—Control of anophelines in Panama Canal Zone jungle with 1.2 fluid ounces of fenthion (8 pounds active ingredient per gallon) and acre dispersed at 0.4-mile swath intervals at an altitude of 300 feet. The wind direction at the dispersal altitude was 320° at a speed of 3 mph.

	Percentage reduction or kill of anophelines at indicated distance (miles) from upwind side of plot[a]					
	Check upwind area	Treatment area			Downwind area	
Type of bioassay	(—)0.75–0	0–0.5	0.5–1	1–1.5	1.5–2	2–2.5
Natural adult population						
at 24 hr.	18	13	38	84	99	84
at 48 hr.	28	6	+116	+26	87	64
Caged adult *Anopheles albimanus*						
on open road	13	100	100	100	100	100
under jungle canopy	13	100	100	100	98	100
Larval *A. albimanus* in cups						
on open road	4	100	100	100	100	100
under jungle canopy	1	100	100	92	0	94

[a] + indicates percentage increase.

erally slightly less than adult kills at the same locations. In this test, the swaths were 0.8 mile wide (or about 4000 feet). Although the control obtained was not as good as in test 3, the data do not indicate that the reduced effectiveness should be attributed to the wide swaths.

The comparison of technical malathion droplets collected outside and under the jungle canopy showed that no droplets larger than 68 microns (μ) penetrated the jungle canopy, even though maximum droplet size was 152 μ (Table 5). This finding agrees closely with that of Hocking *et al.* (1953) who indicated that droplets over 80 μ did not penetrate into thickets. The mass median diameter of droplets collected under the jungle canopy was 30 μ; only 16 percent of the total spray volume was in droplets that were over 50 μ. This droplet spectrum agrees fairly well with the optimum droplet size for aerial applications suggested by Mount (1970).

Obviously, many problems are encountered in tests made in mountainous jungle terrain. A primary need is the development of techniques that will provide a thorough evaluation of the effects of the insecticidal sprays. In the present tests, counts of mosquitoes were made only along the roadside because movement into the jungle itself was impossible without first cutting trails. In addition, the female *A. albimanus* in these tests had a very short but definite biting period in the evening (about 1 hr beginning at dusk); no appreciable daytime activity was noted. However, this observation conflicts with observations during an earlier test (Lofgren *et al.* 1968) when collections were made in the jungle in the morning and afternoon. The difference may be associated with the fact that the earlier test plots were located very close to the breeding areas along the margins of Gatun Lake where densities were very high. Because of this lack of daytime biting and the crepuscular biting habits we were forced to limit our 12 collectors to one station each.

Another problem that was impossible to evaluate in these tests was the effect of the mountainous terrain on distribution of the insecticide and on mosquito kill. The test plot was characterized by differ-

TABLE 4.—Control of anophelines in Panama Canal Zone jungle with 1.2 fluid ounces of fenthion (8 pounds active ingredient per gallon) per acre dispersed at 0.8-mile swath intervals at an altitude of 500 feet. The wind direction at the dispersal altitude was 333° at a speed of 3 mph.

	Percentage reduction or kill of anophelines at indicated distance (miles) from upwind side of plot					
	Check upwind area	Treatment area			Downwind area	
Type of bioassay	(—)0.5–0	0–0.5	0.5–1	1–1.5	1.5–2	2–2.5
Natural adult population at 48 hr.	20	69	18	84	80	36
Caged adult *Anopheles albimanus*						
on open road	2	50	100	100	100	54
under jungle canopy	1	50	96	78	44	52
Larval *A. albimanus* in cups						
on open road	6	8	100	100	100	70
under jungle canopy	0	52	64	52	10	12

ence in elevation of as much as 300 feet; also, our observations of the movement of fog through the valleys suggested that wind currents over the jungle were not unidirectional and could cause an uneven distribution of the insecticide.

Also, little information was available concerning the migration of *A. albimanus* from the breeding areas. Some tests indicated that they migrated distances of three-fourths mile or more within 48 hours, and in one test, extensive reinfestation occurred within 24 hours. Because of this, it would have been desirable to take biting counts before 24 hours, but this proved logistically impossible in these tests.

Despite the problems just mentioned, we were able to gain insight into the problems associated with mosquito control in jungle areas, the effect of altitude on spray dispersal, and the size of droplets that penetrate jungle canopy. Because of the limited number of tests, we cannot draw absolute conclusions about the doses of malathion and fenthion nor the frequency of treatments needed to control anophelines. However, from the kill of caged mosquitoes, the doses used (6 fluid ounces per acre for malathion and 1.2 fluid ounces for fenthion) may be adequate in most instances if a large area is treated. (An important and unknown factor related to dose that should be resolved in future

TABLE 5.—Spray droplets collected on an open road and under jungle canopy in the Panama Canal Zone. Ultralow volume aerial spray of 95 percent malathion dispersed from an Air Force C-47 equipped with 8008 TeeJet flat-fan nozzles.

Percentage of total mass of droplets in indicated size range (μ)					Maximum diameter μ	Mass median diameter (μ)
<5–10	11–25	26–50	51–100	>100		
Open-road						
1	12	33	39	15	152	52
Jungle-canopy						
5	29	50	16	0	68	30

tests is the level of control needed to stop transmission of malaria.)

Our results do not indicate that we had any degree of residual control from the applications. Therefore, it may be that for residual control (24 hours or more) with these highly biodegradable chemicals, we may need doses that are too costly to be economically feasible or are not justifiable because of danger to nontarget organisms. One the other hand, contact and/or short-term residual control, that is, the elimination of mosquitoes present in the target area during or shortly after treatment, may be possible with lower doses than these we used. Mount *et al.* (1970a) showed that with ULV ground application it is possible to achieve contact control of adult mosquitoes with doses as low as 0.26 and 0.097 fluid ounces per acre of malathion or fenthion, respectively. This degree of efficiency may never be possible with aerial ULV application, but we do believe that increased efficiency is possible with more appropriate atomization. The atomization of technical malathion with a rotary-disc nozzle reported by Mount *et al.* (1970b) was very similar to the droplet spectrum collected under the jungle canopy in our tests. This comparison also suggested that better atomization would be one method of lowering insecticide doses needed for ULV aerial sprays, since the jungle canopy filters out the larger spray droplets produced by standard hydraulic nozzles.

The average mortality of the caged adult mosquitoes in all four tests indicated that a considerably higher degree of kill was obtained on the road than under the jungle canopy (93 vs. 75 percent). The same comparison of average larval kills in the two tests with fenthion also showed a similar difference (88 vs. 58 percent). This result compares favorably with data reported by Shepard and Gorman (1969) which showed 97 percent kill in medium vegetation versus 70 percent kill in heavy vegetation with ULV aerial sprays of naled. Based on our laboratory tests with these chemicals (unpublished data) the difference in kill noted between the open and covered areas represents about a twofold difference in the dose of insecticide. Furthermore, the droplet penetration study agrees with these findings since the droplet collection in the open showed that about 50 percent of the total spray volume did not penetrate the dense jungle canopy (droplets greater than 50 μ). Thus, if all the insecticide had been atomized into droplets of 50 μ or less, we might have been able to reduce insecticide dose by one-half while maintaining the same level of mosquito control.

The data obtained with the caged adults and the larvae confined in cups indicate that adequate coverage was obtained with swaths ranging from 0.2 to 0.8 mile wide. These wider swaths could represent a saving of 2 to 8 times in the amount of flying time needed to apply ULV aerial sprays compared with 500-foot swaths. However, the use of these wider swaths does require that the spray be applied into a crosswind which will drift the droplets various distances, depending on their size and density. Observations of wind velocity and direction should therefore be made at dispersal altitudes before applications are made. Mount *et al.* (1970c) demonstrated that a dispersal altitude of 150 feet was enough to drift malathion droplets as much as 3 miles when wind velocities were 5 mph. If calm winds prevail at this altitude, as happened in several of our tests in the Panama Canal Zone, the altitude had to be increased to a level where moderate winds were present. Our tests and those of Shepard and Gorman (1969) and Machado *et al.* (1969) suggest that dispersal altitudes of 300 to 1000 feet may be very useful for large-scale treatments.

SUMMARY AND CONCLUSIONS. Ultralow volume aerial sprays of malathion and fenthion were tested against anopheline mosquitoes in the Panama Canal Zone jungle. The sprays were applied with an Air Force C-47 aircraft equipped with a fuselage-mounted spray boom system. Theoretical doses of 6 and 1.2 fluid ounces per acre of malathion (95 percent) and fenthion (8 pounds active ingredient per gallon), respectively, gave fair to excellent

kills of caged adult *Anopheles albimanus* Wiedemann, but poor to good 24-hour reductions of natural populations of adult anophelines. Fair to excellent kills of larval *A. albimanus* were obtained in the tests with fenthion. The results indicated that a portion of the insecticides drifted for at least one mile which gave additional mosquito control downwind of the treatment area.

Swaths of 0.2 mile (malathion) and 0.4 to 0.8 mile (fenthion) provided adequate coverage. These greater intervals persent a 2- to 8-fold increase in efficiency of application over 500-foot swaths. Use of the wide swaths, however, is contingent on application of the spray into a crosswind. If surface winds are not sufficient to cause drift, applications at higher than normal altitudes may be necessary.

A comparison of the kill of caged adults and larvae of *A. albimanus* and the results of collections of malathion droplets indicated that only about 50 percent of the total spray volume penetrated the dense jungle canopy. No droplets over 68 μ were collected under the canopy though the maximum droplet size produced by the spray nozzles was 152 μ.

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