

OUTDOOR CONTROL OF ADULT MOSQUITOES WITH DDT OR PYRETHRUM APPLIED WITH GROUND EQUIPMENT¹

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Prior to recent developments in the use of DDT (1-trichloro-2, 2-bis [*p*-chlorophenyl] ethane) as an insecticide, the outdoor control of adult mosquitoes received little attention. Ginsburg (1935) reported the use of pyrethrum spray for the protection of public gatherings, and in 1943 Latta and Wilson investigated the use of pyrethrum aerosols and smokes against adult mosquitoes in the open (Stage 1945).

In 1943 and 1944 extensive tests were conducted at the Orlando, Fla., laboratory of the Bureau of Entomology and Plant Quarantine with dusts, sprays, and liquefied-gas aerosols containing DDT or pyrethrum against adult mosquitoes in their natural habitats. All treatments were applied with ground equipment. The purpose of these tests was to determine the possibility of obtaining immediate though temporary relief by the use of such methods, which, if effective, would be helpful to troops bivouacking in mosquito-infested jungles and other areas. Information gained from these studies also served as a basis for more extensive studies by this laboratory and various agencies using other types of ground equipment and aircraft. Studies on the prolonged effectiveness against adult mosquitoes of single applications of DDT to jungle vegetation are discussed in another paper (Madden *et al.* 1945).

The greater portion of the investigations discussed in this report were conducted under jungle conditions. Results were evaluated by counting the mosquitoes landing per minute on the front of the trousers.

Dust Treatments.—During August 1943, 18 field tests against adults of the salt-marsh mosquitoes *Aedes taeniorhynchus* (Wied.) and *A. sollicitans* (Walk.) were made in the daytime near Cocoa, Fla., with dusts consisting of various concentrations of DDT in talc. Treatments were applied with rotary hand dusters, to square plots from ¼ to 10 acres in size, by crossing and recrossing the plots in swaths approximately 20 feet wide. The plots were located under a high canopy of cabbage palmetto and oaks, with an undergrowth of thick, low-hammock vegetation mixed with dense clumps of saw palmetto.

Results are given in Table 1. The percentage control is based on counts made

TABLE 1. Control of adult salt-marsh mosquitoes with dusts consisting of various concentrations of DDT in talc. 1943.

Concentration of DDT	Amount of DDT per Acre	Size of Plot	Control after 3 to 4 Hours
Per Cent	Pounds	Acres	Per Cent
50	.4	¼	100
20	.1	1	90
		1	99
50	.5	1	83
		1	93
5	.25	1	93
		1	95
10	.23	10	97
20	.2	1	99
		1	93
10	.1	1	99
		1	91
5	.05	1	80
		1	92
1	.035	1	97
	.025	1	71
	.024	10	81
Check (talc 5 lb.)	0	1	1

3 to 4 hours after treatment. Observations indicated that the reduction in mosquitoes recorded at that time persisted throughout the remainder of the day, largely because the salt-marsh species do not move about

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to any great extent in daylight. The reduction of mosquitoes was highly satisfactory and ranged up to 100 per cent. Although residual effects were not expected, a few observations showed that the residue from higher dosages gave good control up to 10 days.

Since control with DDT dusts appeared impractical from a military standpoint, as it is difficult to prepare them in the field and to keep them in perfect physical condition for proper delivery, testing with the insecticide in this form was discontinued after the completion of these tests.

Spray Treatments.—Tests with finely atomized sprays against salt-marsh mosquitoes were conducted in the same area and under the same conditions as the tests with dusts. Solutions containing various concentrations of DDT were applied with a paint sprayer connected with a hand-power pressure tank. Treatments were applied in 20-foot swaths as in the dust tests. The nozzle was held about 4 feet above the ground and directed in such a way as to take advantage of any air movement in order to drift the spray as far as possible. The results are presented in Table 2. It will be noted that good reduc-

tion was obtained with as little as 5 grams of DDT per acre. No increase in effectiveness was obtained with dosages above 50 grams per acre. As was expected, little or no residual effect was demonstrated. Kerosene alone gave some control.

In the summer of 1944 tests were continued in the same area with treatments involving 10 to 20 per cent of DDT but much smaller amounts of total solution, since the 1943 tests had shown that the dispersion of even a liter per acre involved a great amount of pumping to provide the large quantity of air needed for atomization. Furthermore, if limited amounts of liquid could be used effectively, the supply problem, which is an important factor under military conditions, could be alleviated materially. In these tests (Table 2) excellent control was obtained with as little as 67 ml. of total solution per acre. Because of the higher concentrations, however, more DDT was applied in this small amount of liquid than with 240 ml. of a solution containing 5 per cent of DDT.

In a series of eight tests concentrated sprays containing either DDT or pyrethrum were compared. Each solution was

TABLE 2. Control of adult salt-marsh mosquitoes with finely atomized sprays containing various concentrations of DDT in different diluents.

Diluent	Concentration of DDT	Total Spray per Acre	Amount of DDT per Acre	Size of Plot	Control after—		
					1 Hour	3 to 4 Hours	24 Hours
	Per Cent	Milliliters	Grams	Acres	Per Cent	Per Cent	Per Cent
TESTS IN 1943							
Solutions:							
Cyclohexanone	50	500	250	1	....	99	....
Kerosene	5	1,000	50	1	....	99.7	61
			200	1/4	....	99.4	....
	.5	1,000	5	1	....	85	51
Aqueous emulsion ¹	5	1,000	200	1/4	....	96	....
Check (kerosene)	0	1,000	0	1	....	41	32
TESTS IN 1944							
<i>o</i> -Dichlorobenzene	10	240	24	1	97	....	....
		140	21	2/3	92	....	....
Cyclohexanone 20% } Motor oil 5% } Kerosene 55% }	20	67	14	2/3	93	....	....
No. 2 fuel oil	5	240	12	1	95	....	....

¹ Made from a concentrate containing 25% of DDT, 7% of Triton X-100 (an aralkyl polyether alcohol), and 68% of xylene.

tested four times on each of two 1-acre plots, the treatments being alternated between plots in order to eliminate any error due to possible physical differences in the plots. The DDT spray contained 10 per cent of DDT plus 10 per cent of cyclohexanone, and the pyrethrum spray 0.75 per cent of pyrethrins plus 5 per cent of motor oil (S.A.E. 30) in kerosene. Both solutions were applied at the rate of 240 ml. per acre. This dosage contained 24 grams of DDT and 1.8 grams of pyrethrins. The average control 1 hour after treatment was 94 per cent with both treatments. The pyrethrum spray gave control almost immediately after application, but the action of the DDT spray was somewhat slower, requiring about 20 minutes to produce the same results.

Satisfactory control over a large area with a limited amount of material is dependent not only on a high concentration of the insecticide but also, and perhaps to a greater degree, on the type of equipment used. For best results a nozzle must be used that will break the material into a large number of fine particles. A laboratory study of the particle size of the spray produced by the nozzle used in these tests showed an average diameter of 18 microns when a solution containing 5 per cent of DDT in kerosene was discharged at about 25 pounds per square inch pressure. This is somewhat larger than the particle size produced by certain nozzles now available, but it appears to have been satisfactory for all practical purposes. The optimum particle size for use under all types of conditions is still undetermined.

A limited number of exploratory tests were made with a power sprayer mounted on a jeep. This equipment was tested with and without an air blast behind the nozzle. The air blast was produced by a 24-inch wooden propeller rotating inside a sheet-metal collar 6 inches deep, which served to direct the air movement forward. Both the propeller and the compressor were operated by a 7-horsepower gasoline engine. The results indicate that a maximum effective swath width of about 100 yards is all that can be expected with such

equipment, either with or without the air blast. This does not appear sufficient to balance the difficulties involved in maneuvering such equipment through the jungle, although it may be useful in relatively open areas.

Aerosol Treatments.—The effectiveness of outdoor applications of liquefied-gas aerosols also was studied. Preliminary tests against salt-marsh mosquitoes were conducted in 1943 at Cocoa, in the same manner and under conditions identical with those in the dust and spray tests. Both DDT and pyrethrum aerosols, with *Freon-12* (dichlorodifluoromethane) as the propellant gas, were dispersed from standard 1-pound Army containers, or "bombs," carried on sticks about 8 inches from the ground and applied in 20-foot swaths. The results presented in Table 3

TABLE 3. Control of adult salt-marsh mosquitoes with liquefied-gas aerosols containing either pyrethrum or DDT, 1943.
(1-acre plots unless otherwise indicated.)

Aerosol	Total Amount of Aerosol Per Plot	Amount of Active Ingredient Per Acre	Control after 3 to 4 Hours
	Grams	Grams	Per Cent
Pyrethrum (0.4% pyrethrins) + sesame oil 8%	331	1.32	98
	500	2.0	97
	500	2.0	99
	2,461 ¹	1.56	95
	136	.54	95
DDT:			
5% + cyclohexanone 10%	450	22.5	91
	450	22.5	95
	450	22.5	99
	264	13.2	75
25% + dibutyl phthalate 25%	520 ²	130.0	100

¹ 6 $\frac{3}{4}$ acres treated.

² $\frac{1}{4}$ acre treated.

show that the contents of one of these bombs, whether pyrethrum or either DDT formula, gave from 91 to 100 per cent control over an acre of jungle. Biting stopped almost immediately with pyrethrum and within a few minutes with DDT. As in the dust and spray tests, treatments were

applied during the daytime and the plots remained practically free of mosquitoes until after dark.

A limited number of tests of pyrethrum and DDT-pyrethrum aerosols were conducted in the jungles of Panama in 1944. Applications were made in the same manner and at the same rate as in Florida, but at night. Complete control of *Mansonia* spp. and *Anopheles albimanus* Wied. was obtained for at least 1 hour.

During the summer of 1944 further tests were made of aerosols in 10- to 50-pound containers. The objective was to produce a large volume of aerosol at a fixed point and determine the control obtained as the cloud moved downwind. Methyl chloride was used as the propellant gas since it is safe toxicologically under outdoor conditions, is a better solvent for DDT, and is less expensive than *Freon-12*.

Preliminary tests were conducted on the open salt marshes near Cocoa. Applications were made early in the morning while the ground was still cool and the air movement was horizontal. The aerosols were discharged with a nozzle consisting of a $\frac{1}{4}$ -inch copper tube about 18 inches long having 15 holes on one side, each 0.017 inch in diameter. When 1,464 grams of an aerosol containing 2 per cent of pyrethrins, 15 per cent of motor oil (S.A.E. 30), and 25 per cent of kerosene was discharged over a 90-foot front, complete control of mosquitoes for 600 feet of the marsh and an additional 200 feet into the jungle was obtained within 10 minutes. Comparable tests were made over about 15 acres of marsh with two formulas—(1) 20 per cent of DDT, 10 per cent of cyclohexanone, 5 per cent of motor oil (S.A.E. 30), and 65 per cent of methyl chloride; and (2) 20 per cent of DDT, 10 per cent of cyclohexanone, 30 per cent of kerosene, 5 per cent of motor oil (S.A.E. 30), and 35 per cent of methyl chloride. In each case 6,000 grams of aerosol was discharged over a 400-foot front. Formula (1) gave a reduction of approximately 75 per cent of mosquitoes up to the edge of the jungle, a distance of 1,200 feet, in less than 10 minutes. At

the end of $1\frac{1}{4}$ hours there was 90 to 95 per cent control over the entire area. Formula (2) produced a coarse spray instead of an aerosol, and no control was obtained even 100 feet from the point of discharge as late as 40 minutes after treatment.

Formula (1) was tested again by discharging 15,890 grams of the aerosol from a boat, along a 1,000-foot front at the edge of a square mile of open marsh. The nozzle consisted of 10 copper tubes, 1 inch long and 0.040 inch inside diameter, fastened at right angles to a $\frac{1}{4}$ -inch copper tube. Complete control of mosquitoes was obtained up to 1,500 feet downwind. Two additional tests were made with the same formula to determine the relative efficiency of two different nozzles. In each test 6,000 grams of total aerosol was discharged along a 400-foot front. In one test the $\frac{1}{4}$ -inch tube with the 15 holes, previously described, was used, and in the other test a $\frac{1}{4}$ -inch tube with 10 capillary tubes $\frac{3}{4}$ -inch long and 0.017 inch in diameter attached to one side. The 15-hole nozzle gave an over-all control of 78 per cent up to 1,200 feet, whereas the capillary-tube nozzle gave 75 per cent control for only 100 feet. These results indicate that the type of nozzle plays an important part in the results obtained.

Further tests with aerosols were made on rice-stubble field near Stuttgart, Ark., against adults of *Psorophora* spp. Satisfactory kill was obtained for only 175 to 400 feet. The poor drift is attributed to the type of nozzle used, which consisted of a $\frac{3}{8}$ -inch copper tube with a series of holes 0.030 inch in diameter drilled in one side.

Although rather outstanding control was obtained in a number of the tests in Florida, the use of aerosols in the open has given in general rather erratic results. Apparently, as with the sprays and dusts, the best results can be obtained under jungle cover or similar sheltered places, when the air movement is not strong enough to remove the treatment before it has a chance to kill. Advantages obtained by greater drift over open areas are uncertain. It is probable that the con-

dition of the atmosphere and characteristics of the terrain were important factors in some of the tests.

Discussion.—In general, the results of the investigations with DDT and pyrethrum applied with ground equipment were very striking. Although the use of hand equipment requires a great amount of labor, it is a practical means of protecting personnel in bivouac or other restricted areas from mosquitoes. The application of DDT and pyrethrum sprays and aerosols in this manner was recommended to the armed forces as early as 1943. The use of power sprayers mounted on ground vehicles may be practical under conditions where terrain will permit.

The information gained from these experiments has also served as a basis for more extensive studies utilizing other equipment, such as airplanes. The results demonstrated that very small amounts of either DDT or pyrethrum were required to control adult mosquitoes. It was encouraging and highly significant that over 90 per cent reduction of adult salt-marsh mosquitoes was obtained at dosages as low as 0.05 and 0.025 pound per acre. Since it was known that adult mosquitoes could be controlled with very low dosages, studies with aircraft were considered essentially a problem of developing suitable equipment and methods of controlling the spray so that it would reach the mosquitoes.

Summary.—Outdoor tests with dusts, sprays, and aerosols containing DDT or pyrethrum as a method of temporary control of adult mosquitoes were conducted in 1943 and 1944. Dusts applied at rates from 0.035 to 4 pounds of DDT per acre gave good control of adult salt-marsh mosquitoes (*Aedes taeniorhynchus* [Wied.] and *A. sollicitans* [Walk.]), but for practical use they are considered less satisfac-

tory than sprays. Sprays applied at the small dosage of 12 grams of DDT (0.025 pound) per acre, with a concentration requiring only about 240 ml. of liquid or less, gave nearly complete reduction of mosquitoes when atomized properly with a paint-sprayer nozzle and applied in 20-foot swaths. Similar results were obtained with sprays containing 0.75 per cent of pyrethrins applied at the rate of 1.8 grams of pyrethrins (0.004 pound) per acre. Limited tests indicated that heavy power equipment was not sufficiently better than hand equipment to warrant its use in jungle areas. The contents of a standard 1-pound aerosol container applied in the same manner as the dusts and sprays, with the container held about 8 inches from the ground, was found to be sufficient to give 91 to 100 per cent control over an acre of jungle. The aerosols were also effective against *Mansonia* spp. and *Anopheles albimanus* Wied. in Panama. DDT and pyrethrum aerosols were about equally effective. Pyrethrum gave almost immediate control in both sprays and aerosols, while DDT was somewhat slower, producing the same results in about 20 minutes. Large amounts of aerosol discharged at one point and drifted downwind gave conflicting results in open areas.

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