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Field Tests on the Residual Effectiveness of Deposits of Malathion and Bayer 29493 against Resistant *Anopheles albimanus* in El Salvador *

H. F. SCHOOF,[1] WILLIS MATHIS [2] & J. R. AUSTIN [3]

The appearance of resistance to both dieldrin and DDT in several malaria vectors has intensified investigations on the potential of organophosphorus compounds for residual application. This report describes the final year's activities of a three-year study on malathion. Water-wettable formulations of malathion and of Bayer 29493 were evaluated against DDT/dieldrin-resistant Anopheles albimanus *in El Salvador.*

The results indicate that neither compound at a dosage of 0.5 g/m² offers any promise as a residual agent. At dosages of 1.0 g/m² or 2.0 g/m² the two toxicants gave effective kills (70%-100%) for periods of 2½-3 months, based on 1-hour exposure to the treated surfaces. Up to 3 months, both compounds gave similar levels of effectiveness on wood, thatch, and mud. On whitewash and plaster surfaces, Bayer 29493 was superior to malathion.

The findings indicate that each insecticide has considerable potential value for residual treatment in areas where the malaria vector cannot be killed effectively by either DDT or dieldrin. In such areas, further investigation into their utility as replacements for the chlorinated hydrocarbon insecticides is warranted.

In 1958, studies by the Pan American Sanitary Bureau in El Salvador showed that *Anopheles albimanus* was resistant to dieldrin in eight localities in different parts of the country (Schoof, 1959). The species was also resistant to DDT in some areas, particularly along the coast southeast of La Libertad. Since concurrent work at Savannah, Ga., and in Mississippi in the USA (Mathis & Schoof, 1958, 1959) on the potential of malathion as an alternative residual spray to DDT and dieldrin in malaria control had indicated that residues of malathion on wood, paper, or cardboard were highly effective against susceptible and dieldrin-resistant *Anopheles quadrimaculatus* for periods of 4-15 months, the detection of dieldrin/DDT-resistant populations of *A. albimanus* afforded an opportunity to carry out field tests of this compound on the types of surface encountered in tropical areas. To conduct those investigations, a co-operative project was established with the participation of the Savannah, Ga., Communicable Disease Center of the US Public Health Service, the Pan American Sanitary Bureau, the International Cooperation Administration,[4] and the Ministry of Health of El Salvador. This paper describes the studies made in 1959 in the Department of La Libertad, El Salvador, for the purpose of determining the residual activity of two organophosphorus compounds

* The opinions and conclusions presented in this article are those of the authors and may not necessarily be those of the Pan American Sanitary Bureau.

[1] Chief, Biology Section, Technical Development Laboratories, Technology Branch, Communicable Disease Center, Public Health Service, US Department of Health, Education, and Welfare, Savannah, Ga., USA.

[2] Medical Entomologist, Biology Section, Technical Development Laboratories, Technology Branch, Communicable Disease Center, Public Health Service, US Department of Health, Education, and Welfare, Savannah, Ga., USA.

[3] Entomologist, Pan American Sanitary Bureau, San Salvador, El Salvador.

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when applied to the different house surfaces present in that area.

EXPERIMENTAL AREA

The experimental area lies along the Pacific coast of El Salvador on either side of the port of La Libertad. It consists of seven cantons—Buenos Aires, Majahual, San Rafael, San Diego, San Dieguito, Melara, and Cangrejera—all of which are located on or adjacent to a single roadway (Carretera Littoral). The study area is at the western end of the cotton-growing zone, this crop being grown in the cantons of Cangrejera, Melara, and San Diego, but not in the others.

Considerable variation occurs in the types of material used in house construction in the La Libertad area. On the immediate coast, most houses are made with thatch on a wooden frame or with a thatch roof and mud walls (Fig. 1). Inland, many of the houses are built with walls of mud[1] (Fig. 2) or adobe brick walls and tile roofs; a few have plaster walls and tile roofs. Numerous houses have walls of several materials; in others, there are no walls, the structure being a V-shaped roof on supporting posts. In addition to the materials mentioned above, the following were also utilized: wooden slab, metal, brick, plaster, "cement", paper, and reeds (Fig. 3, 4, and 5).

Both *A. albimanus* and *A. pseudopunctipennis* are present in El Salvador, but the former has been considered the chief malaria vector. Except in Melara, *A. albimanus* was the species most frequently captured in the experimental zone.

In the coastal areas of El Salvador, rainfall occurs principally from May to October (18-35 cm per month), the period from November to early April being dry and warm.

METHODS AND MATERIALS

Three insecticides—malathion, Bayer 29493 (Baytex or S 1752)[2] and DDT—were used in the tests. Bayer 29493 had shown promise as a residual application in the Belgian Congo (Cerf & Lebrun, 1959), and DDT was employed to measure its efficacy against mosquitos partially resistant to it. The number of houses sprayed with each compound and the dosage used were as follows:

Toxicant	*g/m²*	*Number of houses*
Malathion	0.5	37
	1.0	58
	2.0	22
Malathion: DDT	0.25: 1.0	70
	0.5 : 1.0	83
DDT	1.0	53
	2.0	242
Bayer 29493	0.5	11
	1.0	23
	2.0	20
		619

The formulations were made from wettable powders containing 25 % malathion,[3] 40 % Bayer Compound 29493,[4] and 75 % DDT. Spraying teams from the malaria eradication programme of the El Salvador Ministry of Health made the applications, using conventional-type cylindrical hand-compression sprayers each equipped with an "8004" nozzle.[5] Although the crews were under closer supervision than is practised in routine spraying, the emphasis was placed on seeing that each house was sprayed with the proper formulation and dosage rather than on stressing the coverage obtained. The purpose of this was to ensure that the method of treatment would be the same as that normally followed in an operational programme.[6]

The first series of treatments were made during the period 10-19 March 1959. To obtain more information on certain types of surface and on Bayer 29493, a second series of houses was treated during the period from 29 June through 1 July, 1959. The untreated control dwellings were distributed among the treated houses.

[1] Usually rough in surface and spread over lattice work of saplings, commonly called *bajareque*.

[2] 0,0-Dimethyl 0-[4-(methylthio)-*m*-tolyl] phosphorothioate. Use of trade names is for identification purposes only and does not constitute endorsement by the US Public Health Service.

[3] Furnished through the courtesy of American Cyanamid Company, New York, USA.

[4] Furnished through the courtesy of Vero Beach Laboratories, Inc., Vero Beach, Fla., USA, and Farbenfabriken Bayer, San Salvador, El Salvador.

[5] Spraying Systems Company, Bellwood, Ill., USA.

[6] All crews were clothed according to the standard practices adhered to in applying DDT, no face masks or visors being employed. The usual practices of washing and avoiding contamination with spray drift were followed.

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FIG. 1
THATCHED-ROOF HOUSES IN CANTON SAN RAFAEL

FIG. 2
BAJAREQUE CONSTRUCTION ON FOUNDATION OF ADOBE

FIG. 3
WOODEN HOUSE WITH TILED ROOF

FIG. 4
HOUSE OF FIRED BRICK COVERED WITH PLASTER, CANTON SAN DIEGO

FIG. 5
HOUSE CONSTRUCTED OF POLES, THATCH, PAPER AND METAL, WITH TILED ROOF

To evaluate the treatments, chief reliance[1] was placed on the wall-cone method in which adult female mosquitos were confined in transparent plastic funnel-shaped cones[2] on the treated surfaces. The exposure period used during the first 8 weeks after treatment was 30 minutes, and 60 minutes thereafter. At 5-8 months after treatment, special tests were made in which the exposure times were 60, 120, and 240 minutes. After exposure, specimens were provided with water and held for 24 hours for mortality determination. Except for a few weeks in September and October, all mosquitos used were from a dieldrin/DDT-resistant colony[3] which was maintained at San Salvador.

The pattern of evaluation at the beginning of the study required tests at one week, one month, and at monthly intervals thereafter (operational difficulties caused irregularities in the inspection schedules during the July-November period). The number of houses inspected each time varied between 3 and 11 depending on the total number of houses treated with that dosage in each area (i.e., of the 58 houses treated with malathion (1.0 g/m^2) 15 were checked on each inspection; of 13 treated with Bayer 29493 (1.0 g/m^2), 5 were inspected). So far as possible, the same houses were inspected throughout the study. When a house could not be entered, another dwelling was selected from a list of alternate houses for that inspection. In each house, the tests were made on three types of surface, unpainted wood being employed as a standard site in all houses. As certain treatments failed, the time formerly spent on their inspection was devoted to testing additional sites or surfaces in the treatments still under surveillance.

To obtain a broad coverage of the surfaces in each house and to minimize the effects of possible variations in the amount of toxicant present thereon, each successive test was made on a different site. All sites tested were marked to prevent replication on the same spot.

TABLE 1

AVERAGE 24-HOUR PERCENTAGE MORTALITIES OF FEMALE DDT/DIELDRIN-RESISTANT *A. ALBIMANUS* EXPOSED[a] TO ALL TYPES OF SURFACES TREATED WITH MALATHION AT 0.5, 1.0, OR 2.0 g/m^2 IN EL SALVADOR

g/m^2	Percentage 24-hour mortality at week:					
	1	4	8	12	16	20
0.5	85	44	22	—	—	—
1.0	99	97	84	61	37	—
2.0	94	94	90	78	61	42

[a] 30 minutes' exposure at weeks 1, 4, and 8; 60 minutes' at weeks 12, 16, and 20.

RESULTS

Table 1 gives the average mortalities[4] obtained on all types of surfaces treated with malathion at 0.5, 1.0, and 2.0 g/m^2. A week after application each dosage gave high mortalities; the lowest was 85 % with 0.5 g/m^2. The 0.5 g/m^2 treatment yielded only 44 % mortality at week 4 as compared with kills of 94 % or above for the 1.0 g/m^2 and 2.0 g/m^2 treatments. On week 8, kills with the 1.0 g/m^2 and 2.0 g/m^2 dropped to 84 % and 90 % respectively, while those for 0.5 g/m^2 fell to 22 %. The mortalities from the two higher dosages continued to decline each month until, at week 16,

[1] It was originally planned to compare anopheline densities in treated and untreated houses but the numbers captured in untreated dwellings after the first month were too few to validate the use of this technique.

[2] Each cone was 8.5 cm. in diameter at the base and 5.5 cm high, and the stem of the funnel had an aperture 1.0 cm. in diameter. The latter was loosely plugged with cotton wool to prevent any loss of specimens. Furnished through the courtesy of the World Health Organization, Geneva, Switzerland.

[3] This colony was established by the El Salvador Department of Health at San Salvador from specimens collected at Santo Domingo, El Salvador, by Dr José Pedro Duret, Pan American Sanitary Bureau, late in 1958. Resistance levels to DDT in the colonized strain were checked in April, May, June, July, and October. A 1-hour exposure to 2.0% and 4.0% DDT-Risella oil papers gave mortalities in the ranges of 6%-14% and 17%-40% respectively. A similar exposure to dieldrin-Risella oil papers at concentrations of 0.8%, and 1.6% in April, May, June, and July yielded kills in the ranges of 9%-35% and 30%-36% respectively. The level of susceptibility to DDT of field specimens used in the biological tests in September-October was similar to that of the colony. Susceptibility of colony and field specimens to malathion was also checked with treated papers prepared by dipping in malathion-xylene solutions. Exposure of colony females for 15 minutes to papers dipped in concentrations of 0.012%, 0.025%, 0.05%, and 0.1% yielded mortalities of 67%, 83%, 100% and 100% respectively. Field-collected adults from Canton Melara gave average mortalities (6 replicates, April, May, and June) of 66%, 84%, 97%, and 100% for malathion concentrations of 0.012%, 0.025%, 0.05%, and 0.1%.

[4] These average mortalities are *used only to indicate the general trends in the decline of the biological effectiveness of the residues.* They are based on the percentage mortality of the total number of specimens used in all the tests for a single time period even though the relative number of specimens per type of surface may have been varied.

TABLE 2

PERCENTAGE MORTALITY OF FEMALE DDT/DIELDRIN-RESISTANT *A. ALBIMANUS* EXPOSED [a] TO VARIOUS SURFACES TREATED WITH MALATHION (1.0 g/m²) IN CANTON SAN RAFAEL

Week	Percentage 24-hour mortality [b]					
	Wood	Thatch	Paper	Mud	Cement	Average
1	100 (43)	100 (69)	100 (11)	100 (92)	—	100
4	98 (117)	100 (75)	100 (19)	90 (63)	58 (12)	95
8	86 (94)	88 (110)	100 (39)	37 (49)	17 (12)	78
12	82 (136)	77 (101)	95 (20)	31 (128)	80 (54)	66
16	78 (109)	47 (148)	4 (25)	11 (102)	30 (57)	41

[a] 30 minutes' exposure at weeks 1, 4, and 8; 60 minutes' at weeks 12 and 16.

[b] The number of specimens is shown in parentheses.

TABLE 3

PERCENTAGE MORTALITY OF FEMALE DDT/DIELDRIN-RESISTANT *A. ALBIMANUS* EXPOSED [a] TO VARIOUS SURFACES TREATED WITH MALATHION (2.0 g/m²) IN CANTON SAN RAFAEL

Week	Percentage 24-hour mortality [b]			
	Wood	Thatch	Mud	Average
1	100 (74)	100 (50)	81 (62)	94
4	100 (64)	100 (55)	79 (43)	94
8	92 (61)	100 (60)	61 (23)	90
12	87 (83)	86 (73)	68 (140)	78
16	100 (50)	56 (75)	50 (129)	61
20	83 (101)	43 (70)	14 (155)	42

[a] 30 minutes' exposure at weeks 1, 4, and 8; 60 minutes' at weeks 12, 16, and 20.

[b] The number of specimens is shown in parentheses

the 1.0 g/m² application gave 37 % mortality, and 2.0 g/m² gave 61 %.

Of the two towns treated with malathion (1.0 g/m²), the data for Canton San Rafael are more complete in relation to the number of tests on different surfaces. A résumé of these data is given in Table 2. Residues on wood, thatch, and paper gave effective kills [1] through week 12, with the over-all average mortality declining below 70 % because of the poor results obtained on mud surfaces. In contrast, mud surfaces in Canton San Diego yielded average mortalities of 97 %, 94 %, and 74 % at weeks 4, 8, and 12. Of the six tests made on mud in Canton San Diego at week 12, four gave kills above 83 %, and two had mortalities of 42 %. Plaster, a surface found only in Canton San Diego, yielded kills of 85 % and 20 % at weeks 1 and 12, while wood gave almost complete mortalities for 12 weeks and an 84 % kill at 16 weeks.

Malathion at 2.0 g/m² on wood gave from 83 % to 100 % mortality for 20 weeks ; on thatch, from 86% to 100% for 12 weeks ; on mud, from 79 % to 81 % for 4 weeks (Table 3). At weeks 8, 12, 16, and 20, the kills on mud were 61 %, 68 %, 50 %, and 14 % respectively. In the June treatments, the results for wood, thatch, and mud were similar to those obtained for the March treatments. Residues on plaster at 2, 9, and 15 weeks gave mortalities of 100 %, 65 %, and 13 % respectively. On whitewash at 2, 9, and 14 weeks, the kills were 61 %, 22 % and 19 % respectively.

Data for the two combination formulations of malathion and DDT are given in Tables 4 and 5. Malathion:DDT at 0.5:1.0 g/m² was slightly more effective than at 0.25:1.0 g/m². In comparison with malathion alone at 0.5 g/m², the combination malathion:DDT at 0.5:1.0 g/m² gave higher aver-

[1] A mortality of 70 % or above was considered an effective kill.

TABLE 4

PERCENTAGE MORTALITY OF FEMALE DDT/DIELDRIN-RESISTANT *A. ALBIMANUS* EXPOSED [a] TO VARIOUS SURFACES TREATED WITH MALATHION:DDT AT 0.25:1 0 g/m²

Canton	Week	Percentage 24-hour mortality [b]			
		Wood	Thatch	Mud	Plaster
San Dieguito	1	95 (38)	100 (21)	80 (60)	—
	5	62 (45)	28 (25)	51 (67)	—
	9	76 (49)	10 (20)	49 (99)	—
Buenos Aires	1	100 (51)	93 (85)	—	—
	5	14 (42)	17 (75)	—	—
	9	18 (50)	24 (86)	—	—

[a] 30 minutes' exposure at weeks 1 and 5; 60 minutes' at week 9.

[b] The number of specimens is shown in parentheses.

TABLE 5

PERCENTAGE MORTALITY OF FEMALE DDT/DIELDRIN-RESISTANT *A. ALBIMANUS* EXPOSED [a] TO VARIOUS SURFACES TREATED WITH MALATHION:DDT AT 0.5:1.0 g/m²

Canton	Week	Percentage 24-hour mortality [b]			
		Wood	Thatch	Mud	Plaster
Melara	3-4	91 (76)	94 (113)	77 (64)	—
	7	84 (129)	68 (119)	54 (52)	—
	11	79 (154)	45 (111)	39 (80)	—
	15	38 (162)	46 (117)	41 (76)	—
Cangrejera	1	93 (30)	—	90 (31)	87 (31)
	3	100 (32)	—	60 (20)	29 (21)
	7	68 (38)	—	54 (24)	24 (58)
	11	89 (57)	69 (83)	25 (67)	40 (97)
	15	44 (66)	73 (70)	38 (65)	25 (91)

[a] 30 minutes' exposure at weeks 3 and 7; 60 minutes' at weeks 11 and 15.
[b] The number of specimens is shown in parentheses.

age mortalities, but compared with malathion at 1.0 g/m² this combination was less effective on wood and thatch and apparently equal on mud.

The results for the application of Bayer 29493 in Canton San Diego at 0.5 g/m² and 1.0 g/m² (Tables 6 and 7) indicate that the 0.5 g/m² treatment gave effective average kills for only 4 weeks

TABLE 6

PERCENTAGE MORTALITY OF FEMALE DDT/DIELDRIN-RESISTANT *A. ALBIMANUS* EXPOSED [a] TO VARIOUS SURFACES TREATED WITH BAYER 29493 AT 0.5 g/m² IN CANTON SAN DIEGO

Week	Percentage 24-hour mortality [b]					
	Wood	Thatch	Mud	Plaster	Whitewash	Average
1	100 (40)	—	100 (24)	100 (21)	—	100
4	90 (91)	—	63 (19)	27 (11)	—	80
8	33 (86)	—	0 (21)	—	0 (21)	22
12	79 (82)	34 (64)	57 (65)	81 (75)	47 (47)	63
16	51 (75)	11 (62)	47 (64)	33 (73)	13 (44)	33

[a] 30 minutes' exposure at weeks 1, 4 and 8; 60 minutes' at weeks 12 and 16.
[b] The number of specimens is shown in parentheses.

TABLE 7

PERCENTAGE MORTALITY OF FEMALE DDT/DIELDRIN-RESISTANT *A. ALBIMANUS* EXPOSED [a] TO VARIOUS SURFACES TREATED WITH BAYER 29493 AT 1.0 g/m² IN CANTON SAN DIEGO

Week	Percentage 24-hour mortality [b]				
	Wood	Thatch	Mud	Plaster	Average
1	100 (63)	100 (51)	100 (22)	100 (20)	100
4	99 (95)	91 (11)	92 (49)	—	96
8	91 (66)	76 (17)	96 (67)	—	85
12	75 (67)	30 (64)	84 (73)	91 (64)	70
16	51 (63)	25 (69)	48 (61)	56 (73)	45
24	57 (63)	16 (88)	35 (83)	84 (74)	46

[a] 30 minutes' exposure at weeks 1, 4, and 8; 60 minutes' at weeks 12, 16, and 24.
[b] The number of specimens is shown in parentheses.

whereas the 1.0 g/m² dosage yielded mortalities at or above 70 % for 12 weeks. Although the lesser efficacy of the lower dosages is reflected markedly in the data for 30-minute exposures on wood and mud at weeks 4 and 8, the two dosages gave essentially equal levels of kill at 12 and 16 weeks.

TABLE 8

PERCENTAGE MORTALITY OF FEMALE DDT/DIELDRIN-RESISTANT *A. ALBIMANUS* EXPOSED [a] TO VARIOUS SURFACES TREATED WITH BAYER 29493 AT 1.0 g/m² IN CANTONS SAN DIEGO, MAJAHUAL, AND SAN RAFAEL

Week	Percentage 24-hour mortality [b]			
	Thatch	Mud	Whitewash	Average
2	100 (53)	100 (100)	100 (65)	100
9-12	43 (67) [c]	30 (142) [d]	56 (88) [e]	40
14-15	3 (59) [e]	16 (152) [f]	69 (106) [g]	31
18 [h]	19 (58)	14 (173)	56 (78)	28

[a] 30 minutes' exposure through week 12; 60 minutes' thereafter.
[b] The number of specimens is shown in parentheses.
[c] Week 9.
[d] Week 10.
[e] Week 12.
[f] Week 15.
[g] Week 14.
[h] On wood 98 % kill was obtained of 40 specimens tested.

TABLE 9

PERCENTAGE MORTALITY OF FEMALE DDT/DIELDRIN-RESISTANT *A. ALBIMANUS* EXPOSED [a] TO VARIOUS SURFACES TREATED WITH BAYER 29493 AT 2.0 g/m² IN CANTONS SAN DIEGO, MAJAHUAL, AND SAN RAFAEL

Week	Percentage 24-hour mortality [b]					
	Wood	Thatch	Mud	Plaster	Whitewash	Average
2	100 (33)	100 (72)	100 (202)	100 (76)	100 (79)	100
9	87 (39)	65 (88)	79 (135)	100 (76)	95 (135)	85
15	88 (24)	48 (89) [c]	62 (269) [d]	100 (69)	29 (77) [d]	61
21	79 (38)	36 (85)	38 (355)	49 (92)	17 (167)	37

[a] 30-minutes' exposure through week 12; 60 minutes' thereafter.
[b] The number of specimens is shown in parentheses.
[c] Week 14.
[b] Weeks 14 and 15 combined.

Direct comparison of the results of the June treatments of Bayer 29493 with those of the March applications is complicated by the fact that the site treatments in June were scattered over several cantons and operational difficulties prevented inspection at the same time intervals. However, the results for the June treatments of Bayer 29493 at 1.0 g/m² and 2.0 g/m² are comparable (Tables 8 and 9). At 9-12 weeks the treatment of 1.0 g/m² failed on the three surfaces tested (thatch, mud, and whitewash) even though 100 % kills were obtained at week 2. The dosage of 2.0 g/m² showed mortality levels on thatch and mud above those for the same surfaces at 1.0 g/m² at weeks 9 and 15. On an over-all average mortality basis, the 2.0 g/m² dosage was effective through 8-9 weeks, and the results for the March application (1.0 g/m²) were equal in effectiveness to those of the 2.0 g/m² treatment. Outstanding results with Bayer 29493 on mud were obtained in Canton Cangrejera, where six replicates in the same houses at weeks 2, 12, and 15 gave average mortalities of 100 %, 98 %, and 100 % respectively. High kills also were obtained on mud in individual houses in other cantons but companion dwellings showed much lower mortalities, thus suggesting possible overtreatment or the influence of household factors.

Comparative data for malathion and Bayer 29493 treatments in the same canton are given in Tables 10 and 11. Results of an application of the toxicants at a rate of 1.0 g/m² in Canton San Diego (Table 10) indicated that Bayer 29493 was slightly more effective on mud than malathion, while the reverse was true on wood. On plaster, malathion was inferior to Bayer 29493.

In the data for a treatment of 2.0 g/m² in one or two houses representative of each type of surface (Table 11), the findings for each surface concern tests in the same canton. Malathion appeared superior to Bayer 29493 on thatch, but the reverse was true on whitewash, plaster, and mud. The superiority of Bayer 29493 on mud was not as marked as it was on the other two surfaces.

Table 12 shows the results obtained with treatments of DDT at 1.0 g/m² and 2.0 g/m² on wood. The 1.0 g/m² application gave mortalities equivalent to those obtained with 2.0 g/m² at Cantons San Rafael and San Diego, but those at Canton Cangrejera (2.0 g/m²) were higher at all three inspections. On mud, the 1.0 g/m² dosage was less effective at 4 weeks than the 2.0 g/m² treatment at Canton Cangrejera, but at weeks 8 and 12 the kills for both dosages were between 40 % and 48 %. At Cantons San Rafael and San Diego, the number of tests on mud were too few for comparison. On plaster in Canton San Diego, the mortalities ranged between 65 % and 81 % for weeks 4-16. On whitewash, the results differed sharply in Canton San Diego and Canton San Rafael, the residues giving kills of 65 %-94 % through week 20 in the former and mortalities below 27 % for all inspections in the latter.

The greatest difference in DDT tests was in the mortalities obtained with the same dosage

TABLE 10

PERCENTAGE MORTALITY OF DDT/DIELDRIN-RESISTANT FEMALE *A. ALBIMANUS* EXPOSED [a] TO VARIOUS SURFACES TREATED WITH MALATHION OR BAYER 29493 AT 1.0 g/m² IN CANTON SAN DIEGO

Surface	Toxicant	Percentage 24-hour mortality [b] at weeks:				
		1	4	8	12	16
Wood	Malathion	100 (10)	100 (101)	99 (84)	100 (61)	84 (63)
	Bayer 29493	100 (63)	99 (95)	91 (66)	75 (67)	51 (63)
Thatch	Malathion	—	—	—	68 (38)	8 (40)
	Bayer 29493	100 (51)	91 (11)	76 (17)	30 (64)	25 (69)
Mud	Malathion	—	97 (36)	94 (47)	74 (65)	21 (70)
	Bayer 29493	100 (22)	92 (49)	96 (67)	84 (73)	48 (61)
Plaster	Malathion	85 (20)	—	—	20 (137)	16 (117)
	Bayer 29493	100 (20)	—	—	91 (64)	36 (73)

[a] 30-minutes' exposure at weeks 1, 4, and 8; 60 minutes' at weeks 12 and 16.
[b] The number of specimens is shown in parentheses.

TABLE 11

PERCENTAGE 24-HOUR MORTALITY OF DDT/DIELDRIN-RESISTANT FEMALE *A. ALBIMANUS* EXPOSED [a] TO VARIOUS SURFACES TREATED WITH MALATHION OR BAYER 29493 AT 2.0 g/m²

Surface	Toxicant	Percentage 24-hour mortality [b] at weeks:		
		2	9	14
Wood	Malathion	—	85 (26)	83 (24)
	Bayer 29493	—	75 (32)	100 (27)
Thatch	Malathion	100 (63)	100 (76)	67 (63)
	Bayer 29493	100 (72)	65 (88)	45 (89)
Mud	Malathion	100 (139)	70 (144)[c]	57 (135)[d]
	Bayer 29493	100 (139)	100 (69)	84 (147)
Plaster	Malathion	100 (130)	65 (141)	12 (144)[d]
	Bayer 29493	100 (76)	100 (76)	100 (69)
Whitewash	Malathion	61 (75)	22 (85)	19 (74)
	Bayer 29493	100 (71)	86 (90)	56 (73)

[a] 30 minutes' exposure at weeks 2, 9, and 10; 60 minutes' at weeks 14 and 15.
[b] The number of specimens is shown in parentheses.
[c] Week 10.
[d] Week 15.

(2.0 g/m²) in different cantons. The mortalities in Canton San Rafael for all surfaces averaged 28 %, 34 %, 40 %, 14 %, and 24 % for weeks 4, 8, 12, 16, and 20 respectively, while for the same intervals in Cantons San Diego/Cangrejera, the average percentage mortalities were 52/67, 70/58, 76/60; 76/80, and 53/71.

During the spraying operations and the surveillance periods, there were no indications or reports of adverse effects of any treatment upon spraying

TABLE 12

PERCENTAGE MORTALITY OF FEMALE DDT/DIELDRIN-RESISTANT *A. ALBIMANUS* EXPOSED [a] TO UNPAINTED WOOD TREATED WITH DDT AT 1.0 g/m² OR 2.0 g/m²

Week	Percentage 24-hour mortality [b]			
	1.0 g/m²	2.0 g/m²		
	Canton San Rafael	Canton San Rafael	Canton Cangrejera	Canton San Diego
4	38 (64)	27 (42)	73 (33)	35 (31)
8	62 (58)	47 (43)	74 (34)	66 (39)
12	45 (53)	34 (44)	63 (38)	69 (36)

[a] 30 minutes' exposure at weeks 4 and 8; 60 minutes' at week 12.
[b] The number of specimens is shown in parentheses.

personnel or inhabitants of the treated dwellings. Cholinesterase determinations were not made on any of the personnel during the experimental period.

DISCUSSION

The value of the foregoing data depends chiefly on their relationship to what could be expected with mosquitos normally entering these houses and resting on the wall or roof surfaces.[1] The data from wall cone tests are obviously influenced by the exposure period used; the 30-minute and 60-minute periods selected are much shorter periods of time than the periods during which *A. albimanus* normally rests on wall surfaces in El Salvador. Adults may be found in numbers in both the morning and afternoon hours, which indicates resting periods well in excess of 4-6 hours.

Another factor influencing the individual wall cone test is the site selected. Since the treatment was done under operational conditions, there was, as is true in all residual spraying, a variation in the amount of insecticide deposited on the interior surfaces of the huts. With fresh deposits such variations are concealed biologically since maximum kills prevail until, as the residues age, the differences in surface dosage are reflected in a greater spread in the range of mortalities obtained.

In these tests, the experimental data for the two compounds are comparable, since the same technique of appraisal was used for each. Further, as a means of minimizing the effect of variation, replicate tests were made on similar surfaces and in different houses and the results combined to give an average mortality for each surface.

The suitability of the wall cone technique for evaluating the biological activity of surface residues is shown by the fact that the results reflect the differences in dosage levels of the same compound and the influence of the age of the residue or the type of surface on the biological efficacy of the deposit. The data readily indicate the decline in effectiveness of each compound with time (Tables 1-11). In the early tests, when the deposits produced kills above 90 %, the results with individual cone tests were similar; as the efficacy declined, the range of kills on any one surface increased. This aspect is emphasized by data recorded on thatch for the same four houses over a period of 16 weeks (Table 13). Obviously, there was a difference in the efficacy of the treated surfaces of the four houses, but this difference did not become apparent until the residues aged. The basis of this difference is a matter of conjecture. It could have been due to a number of factors, such as differences in dosage applied or house usage. Similar variations were experienced on other surfaces. At 8 weeks with Bayer 29493 (1.0 g/m^2), mortalities on six sites on mud averaged 96 %, the lowest kill being 83 %. At 16 weeks the average kill on this surface was 48 %, two sites yielding 100 % kills, the remainder giving mortalities between 10 % and 60 %. On wood, Bayer 29493 (0.5 g/m^2) at seven of eight sites gave 100 % kill, the eighth only 55 % kill at 4 weeks. At 8 weeks, the average kill for the eight sites was 33 % (as compared with 90 % at 4 weeks); two of the sites gave no kills and one yielded 91 % mortality.

The toxicity of the residues with exposure periods of more than one hour was appraised using 2- and 4-hour periods with deposits of 5 and 7 months' age. In the initial 4-hour evaluations, the results (Table 14) showed that at 20 weeks malathion at 1.0 g/m^2 or 2.0 g/m^2 gave 100 % kills

TABLE 13

PERCENTAGE MORTALITY OF FEMALE DDT/DIELDRIN-RESISTANT *A. ALBIMANUS* EXPOSED [a] TO THATCH TREATED WITH MALATHION AT 1.0 g/m^2 IN FOUR HOUSES IN CANTON SAN RAFAEL

House No.	Percentage 24-hour mortality [b] at weeks:			
	4	8	12	16
71	100 (11)	40 (15)	13 (15)	7 (29)
83	100 (12)	100 (13)	27 (11)	10 (10)
95	100 (12)	100 (9)	100 (26)	24 (25)
104	100 (22)	100 (24)	100 (28)	100 (26)
Average mortality	100	88	74	39

[a] 30 minutes' exposure at weeks 4 and 8; 60 minutes' at weeks 12 and 16.

[b] The number of specimens is shown in parentheses.

[1] Studies on the residual activity of insecticides in themselves are not concerned with disease transmission rates and can and should be conducted independent thereof. Only in areas where the habits of the vector indicate intradomiciliary transmission is residual spraying of homes a logical and justifiable approach to the malaria problem. When residual deposits are effective in this sense, data on the relative efficacy of different toxicants can be considered in relation to disease transmission.

TABLE 14

PERCENTAGE MORTALITY OF FEMALE DDT/DIELDRIN-RESISTANT *A. ALBIMANUS* EXPOSED FOR 4 HOURS TO 5-MONTH-OLD RESIDUES OF MALATHION AND BAYER 29493 ON VARIOUS SURFACES

Toxicant	g/m²	Week	Percentage 24-hour mortality [a]					
			Wood	Thatch	Mud	Plaster	White-wash	Cement
Malathion [b]	1	20	100 (140)	47 (132)	20 (143)	25 (161) [c]	—	23 (171)
		33	58 (40)	0 (23)	17 (35)	7 (54) [d]	—	0 (42)
	2	20	100 (164)	46 (138)	20 (164)	—	—	—
		33	36 (33)	5 (43)	13 (31)	—	—	—
Bayer 29493	0.5	20	72 (141)	11 (105)	60 (139)	65 (192)	34 (96)	—
	1.0	20	100 (137)	24 (134)	91 (143)	97 (143)	—	—

[a] The number of specimens is shown in parentheses.
[b] Data for each time interval relate to tests in the same houses (Canton San Rafael).
[c] One series of tests from Canton San Diego, not included in this figure, gave 19 % kill with 140 specimens.
[d] Canton San Diego data.

TABLE 15

PERCENTAGE MORTALITY OF FEMALE DDT/DIELDRIN-RESISTANT *A. ALBIMANUS* EXPOSED FOR 1, 2, AND 4 HOURS TO MALATHION RESIDUES ON VARIOUS SURFACES

g/m²	Week	Hours of exposure	Percentage 24-hour mortality [a]					
			Wood	Thatch	Mud	Plaster	Cement	Average
1.0 [b]	33	1	0 (55)	0 (43)	0 (38)	0 (48)	0 (41)	0
		2	27 (51)	0 (44)	3 (37)	2 (48)	0 (35)	7
		4	74 (65)	3 (39)	17 (35)	7 (54)	0 (42)	25
2.0 [c]	33	1	46 (90)	3 (71)	2 (171)	—	—	—
		2	10 (40)	0 (43)	4 (28)	—	—	—
		4	36 (33)	5 (43)	13 (31)	—	—	—
2.0 [d]	22	1	100 (23)	68 (98)	24 (250)	10 (154)	—	32
		2	100 (24)	12 (42)	49 (79)	25 (40)	—	42
		4	100 (21)	36 (39)	56 (79)	14 (36)	—	48

[a] The number of specimens is shown in parentheses.
[b] Cantons San Rafael and San Diego.
[c] Canton San Rafael (Los Angeles).
[d] Cantons Buenos Aires, Majahual, San Rafael (Sta. Emilia), Cangrejera, and San Diego.

on wood but was ineffective on thatch, mud, plaster, and cement. At week 33, the mortalities on all surfaces showed a further decline. At 1.0 g/m² Bayer 29493 was equal in effectiveness to malathion on wood and yielded superior kills, of 91 % and 97 %, on mud and plaster respectively. On thatch, this toxicant gave lower kills than malathion. Bayer 29493 was less effective at 0.5 g/m² than at 1.0 g/m² on all surfaces.

In a second series of tests, exposures of 1, 2, and 4 hours were made in the same houses and on the same surfaces. These results are given in Table 15. With malathion at 2.0 g/m² at week 22, slightly increased kills occurred on mud with the

TABLE 16

PERCENTAGE MORTALITY OF FEMALE DDT/DIELDRIN-RESISTANT *A. ALBIMANUS* EXPOSED FOR 1, 2 AND 4 HOURS TO RESIDUES OF BAYER 29493 ON VARIOUS SURFACES

g/m²	Week	Hours of exposure	Percentage 24-hour mortality [a]					
			Wood	Thatch	Mud	Plaster	White-wash	Average
1.0	18	1	98 (40)	19 (58)	14 (173)	47 (32)	56 (78)	35
		2	100 (29)	14 (43)	17 (77)	64 (36)	93 (44)	47
		4	100 (41)	28 (46)	51 (82)	100 (37)	91 (35)	68
2.0	21	1	79 (38) [b]	36 (85)	38 (355)	17 (167)	49 (92)	37
		2	71 (34) [b]	35 (37)	50 (78)	73 (41)	51 (41)	55
		4	70 (43) [b]	33 (46)	72 (74)	100 (39)	40 (41)	63

[a] The number of specimens is shown in parentheses.
[b] Two of three houses gave 100 % kills.

increase in exposure time. On wood, the residues gave complete mortalities at all time intervals. On thatch and plaster, the 4-hour exposure did not produce an increase in kill. In a second area at week 33, the kills on wood, thatch, and mud treated with malathion (2.0 g/m²) were similar irrespective of exposure time. At a dosage of malathion of 1.0 g/m², similar results were obtained for 1-, 2-, and 4-hour exposures on all surfaces but wood. The latter showed an increased mortality with the lengthening of the exposure period, the kill being above 70 % at 4 hours.

With Bayer 29493 at 1.0 g/m² or 2.0 g/m², increased kills were obtained on mud and plaster at 2 and 4 hours ; but on wood and thatch, the mortalities were similar at the three exposure times (Table 16). On wood, two of the three tests at 1, 2, and 4 hours gave complete mortalities. At 1.0 g/m², the residues on whitewash showed higher mortalities at 2 and 4 hours, whereas no difference in kills was apparent at 2.0 g/m². On plaster, the mortalities for the 1.0 g/m² and 2.0 g/m² dosages were approximately the same, but on mud 1.0 g/m² gave 51 % kill as compared to 72 % for 2.0 g/m². In earlier tests of the 1.0 g/m² application, mortalities of 91 % were obtained on plaster (Table 14). Whether this difference or the higher kill obtained with a dosage of 1.0 g/m² on whitewash (Table 16) is significant is questionable, since the experiments involved treatments applied in different cantons.

These extended exposure tests indicate that with malathion residues the increase in exposure time apparently has little effect on the mortalities obtained. Bayer 29493 displayed a marked and greater response to an increase in exposure time on plaster and mud surfaces than did malathion. On thatch neither compound showed any response change regardless of exposure time.

In the DDT treatments the data for the 1.0 g/m² and 2.0 g/m² dosages were not adequate to permit any firm statements on the relative merits of the two application rates. The findings (Table 12) suggested that there is little difference in the relative biological action of the two dosages on wood up to 3 months. Similar uniformity in biological activity has been found at Savannah, Ga., where tests through 32 weeks in animal-baited huts showed that a dosage of 2.0 g/m² gave kills of *A. quadrimaculatus* females ranging from 73 % to 97 %, and that of 1.0 g/m² from 67 % to 90 %.

Extended exposure tests were also made on DDT-treated surfaces, but with the exception of those for Canton San Diego, the data were not clear-cut in evidencing an increase in mortality with an increase in exposure time. In Canton San Diego (weeks 28 and 31), the 4-hour exposure period produced higher mortalities (80 %) than exposures of 1 or 2 hours (38 % and 50 %) on wood, plaster, and whitewash.

As might be anticipated, the mortality levels of dieldrin/DDT-resistant females exposed to field residues derived from DDT suspensions were generally higher than those achieved by exposure of adults to the DDT-Risella-oil papers employed in the standard susceptibility tests. However, *com-*

parison of mortalities for these two types of exposure *is not valid*, since susceptibility tests merely measure the response of the insect to the chemical and cannot be considered to reflect its effectiveness in the field (Mathis et al., 1959). Similar results were obtained in studies in the USA with a dieldrin-resistant strain of *A. quadrimaculatus*, which gave an average of 5% mortality on 1.6% dieldrin-treated papers but showed a 40%-50% kill on overnight exposure to dieldrin-treated surfaces in animal-baited huts (Mathis & Schoof, 1959). Such findings again emphasize that resistance data alone cannot be considered as a means of measuring the field efficacy of a toxicant.

The results obtained with malathion on mud in El Salvador are contrary to those experienced in laboratory tests on mud blocks at Savannah, Ga., where deposits of 1.0 g/m² on blocks of Georgia mud failed to produce satisfactory kills of *A. quadrimaculatus* within 1 week of treatment. Previous studies also had shown that residues of neither DDT (2.0 g/m²) nor dieldrin (0.5 g/m²) on the same type of blocks produced effective kills for more than 3 weeks. In contrast residues of DDT and dieldrin have been reported to remain effective on mud for periods of more than 6 months in the field (McNeel, 1958). It is recognized that different types of mud will influence the durability of residues; nonetheless, the data strongly indicate that current laboratory techniques do not provide an accurate measure of the potential efficacy of these toxicants on mud surfaces. Consequently, negative laboratory data on mud surfaces in themselves are not sufficient to discount the possible usefulness of a toxicant in field treatment.

CONCLUSIONS

In considering the results obtained for malathion and Bayer 29493, these facts are evident:[1]

1. Dosages of 0.5 g/m² of either compound offer little promise.

2. At dosages of 1.0 g/m² and 2.0 g/m², both toxicants give effective average kills of adult *A. albimanus* for a period of 2½ to 3 months.

3. With *malathion*, residues of 1.0 g/m² were most effective on wood, thatch, and paper, producing good kills for 12 weeks. On mud, satisfactory kills occurred through 12 weeks in one canton; in a second poor results obtained within 8 weeks. At 2.0 g/m², malathion gave suitable mortalities on wood and thatch through week 12. On mud the mortalities were satisfactory to week 4 and slightly below that level for weeks 8 and 12. In limited tests unsatisfactory kills were obtained on whitewash in 2 weeks while on plaster the mortalities at 2 weeks were excellent. At 9 weeks the kills on plaster were slightly below the satisfactory level.

4. With *Bayer 29493*, residues of 1.0 g/m² were effective on wood, mud, plaster, and whitewash in one canton for 12 weeks; in a second canton, poor kills were obtained on mud in 10 weeks and unsatisfactory mortalities on whitewash in 12 weeks. This compound was least effective on thatch, satisfactory kills generally not being obtained after week 8. On plaster, mortalities of 91%-100% were obtained for 12 weeks. Results for 2.0 g/m² treatments in June were superior to those of the 1.0 g/m² application in June and approximately the same as those for the 1.0 g/m² in March.

5. Based on 4-hour exposures, excellent kills can be obtained for 20 weeks with malathion at 1.0 g/m² or 2.0 g/m² on wood, or with Bayer 29493 at 1.0 g/m² on wood, mud, and plaster. Both compounds failed on thatch, although slightly higher mortalities were obtained on that surface with malathion.

The results of these field tests indicate that either malathion or Bayer 29493 offers considerable promise for a residual treatment against anopheline mosquitos. Both require further field testing in various areas to determine the suitability of each against different vectors and under other environmental conditions. A dosage of 1.0 g of either toxicant per m² appears the application rate of choice at this time, both from an economic and from a toxicological standpoint. Based on the available toxicological data (Gaines, 1960) and the greater experience with its use, malathion offers the lesser hazard to humans at this time. Either of these organophosphorus toxicants is considerably more expensive than DDT or dieldrin at current prices.

In malaria eradication campaigns the use of either of these compounds should be resorted to only when it is obvious that the chlorinated hydrocarbon toxicants such as DDT and dieldrin no

[1] Based on 30- and 60-minute exposure periods for wall cone tests and a level of 70% as representing a satisfactory mortality.

longer provide the residual effectiveness required to interrupt malaria transmission. Such a change should be based on entomological and epidemiological data and not merely on the fact that susceptibility tests disclose a change in the response of the mosquito population.

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RÉSUMÉ

Des insecticides de remplacement, destinés à combattre *Anopheles albimanus* devenu résistant au DDT et à la dieldrine, ont été mis à l'essai dans les environs du port de La Libertad, au Salvador.

Les auteurs donnent les résultats obtenus au cours de la dernière de trois années d'étude, avec des poudres mouillables de malathion, de Bayer 29493 et de malathion-DDT, appliquées à 324 maisons.

A la dose de 0,5 g/m², aucun de ces insecticides n'a de pouvoir rémanent utile. A la dose de 1,0 ou 2,0 g/m², la malathion et le Bayer 29493 produisirent une mortalité de 70-100% pendant 2-3 mois, sur des moustiques exposés pendant 1 heure à leur action. Jusqu'à 3 mois, ces deux insecticides se montrèrent aussi efficaces sur des surfaces de bois, de chaume ou de boue séchée. Sur le plâtre ou les surfaces passées à la chaux, le Bayer 29493 était supérieur. Les observations indiquent que ces deux substances présentent un grand intérêt, là où le vecteur résiste au DDT et à la dieldrine. Il est conseillé de poursuivre leur étude comme insecticides de remplacement.

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