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Field Performance of Dieldrin/Resin Wettable Powders on Sorptive Mud Surface

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Recent field experiments on the relative performance of dieldrin and dieldrin/resin wettable powders on sorptive mud surface have not confirmed the promising results obtained with the latter products in earlier laboratory tests. In view of this a renewed investigation into the possible factors governing the performance of such products was considered desirable, and further laboratory and field experiments were carried out in co-operation with the Colonial Pesticides Research Unit at Arusha, Tanganyika.

The results of these experiments have given a better understanding of the factors involved, and a coherent interpretation of the differences in performance shown by various products under different conditions. The main factors to be taken into account appear to be : mobility of the insects during exposure, as influenced by insect species and exposure conditions ; inherent toxicity of the dieldrin/resin particles ; and the average relative humidity inside the experimental huts.

The sorption phenomenon can be demonstrated in the field, but in view of the humidity conditions it does not seem likely that it will interfere seriously with practical mosquito control. A potential critical condition might be prevalent only in areas where the presence of sorptive mud is coupled with long periods of low humidity inside the huts, but further experimental data are necessary to confirm this.

INTRODUCTION

The problem of insecticide sorption in soils has been the subject of many investigations since the phenomenon was first discovered in laboratory experiments by Hadaway & Barlow (1951) in Great Britain and by Downs, Bordas & Navarro (1951) in Mexico. Considerable importance was attached to further studies on this subject, particularly because of the potential implications in the field. Sorptive soils are in common use as building and plastering material for the construction of mud houses in many tropical and subtropical countries where residual spraying with insecticides against anopheline mosquitos is carried out at regular intervals, and there was reason to assume that sorption of insecticides on mud walls could well interfere with the residual effectivenesses of the toxicant. With the change from malaria control to malaria eradication the problem became more urgent still.

No attempt will be made to give a complete account of the literature dealing with insecticide sorption; extensive basic studies have been published by Hadaway & Barlow (1952) and Barlow & Hadaway (1955, 1956, 1958a, 1958b), and more recently the subject has been reviewed by Bertagna (1959). Most of the experimental work was concerned, however, with the sorption phenomenon as observed under laboratory conditions, and only limited data referring to a possible correlation between sorption and field performance are available. Pal & Sharma (1952) reported an unexpectedly short residual effect of DDT in India and they related their observations to sorption. Deterioration of DDT deposits on mud surface under field conditions was also shown by Singh, Pal & Sharma (1951) and by Viswanathan (1952). Langbridge [2] demonstrated by the chemical analysis of wall scrapings that sorption of DDT, BHC and dieldrin took place on mud walls under field conditions, and he found a rapid loss of insecticide from the surface half-millimetre during the first two weeks after spraying.

[1] Shell Research Ltd., Woodstock Agricultural Research Centre, Sittingbourne, Kent, England.

[2] Langbridge, D. M. (1956) In: Nigeria, Federal Malaria Service, *Western Sokoto Malaria Control Pilot Project, Insecticide Chemistry Laboratory, Annual report 1955-56*, Yaba-Lagos (mimeographed document).

On the other hand, general experience has indicated that these insecticides, when applied in normal practice, have a residual effect far in excess of that which could be expected if the process of sorption did in fact render the residue inactive at the same rate. The experiments carried out by Davidson (1953) and by Burnett (1957) led to the same conclusion. Further evidence of the adequate residual effect of insecticides on sorptive mud surface was obtained in the Taveta-Pare malaria control project (East Africa), in which a nine-months spraying cycle for dieldrin was successfully adopted.

From these results it became clear that the persistence of a particulate surface deposit of insecticide need not necessarily be a prerequisite for satisfactory residual effect in the field, and that the insecticide can be active in the sorbed state. However, to what extent the residual effect would have been better if sorption had not occurred at all still remained an open question.

Further field observations on mosquito mortalities in treated experimental huts revealed some other interesting aspects. Bordas, Downs & Navarro (1953) found a marked increase in mortality of mosquitos naturally entering treated huts after the onset of the rainy season: the average kill of *Anopheles pseudopunctipennis*, which had fallen to only 5% nine months after spraying with DDT at a rate of 2 g/m^2 in experimental huts at Acatlipa, Mexico, increased to between 70% and 90% in the wet season. Similar results were obtained by these investigators in laboratory experiments using treated soil panels stored at different relative humidities, and this confirmed the earlier laboratory observations made by Hadaway & Barlow (1952), who showed considerably higher effectiveness of DDT residues in panel exposure tests with *Aëdes aegypti* if the panels were stored at a higher relative humidity. Further evidence of the influence of humidity on the field performance of insecticide residues on sorptive mud surface was provided by Burnett (1956), who carried out extensive hut experiments in Kenya on the residual effect of DDT, BHC and dieldrin against *Anopheles gambiae* and *funestus*. He noticed a seasonal variation in mortalities related to humidity. BHC and dieldrin in particular became more effective as the relative humidity increased during the rainy season; a similar response with DDT, however, was not observed.

The effect of humidity on the entire process of insecticide sorption has since been thoroughly investigated and a more detailed analysis of the various factors involved was given by the work of Barlow & Hadaway (1956, 1958b) and Gerolt.[1] The effect of humidity was shown to be threefold. An increase in relative humidity reduces the rate of initial sorption, i.e., the disappearance of the particulate residue. However, once the insecticide is in the sorbed state its further inward migration is accelerated at higher humidity, but the effect this has on the residual effectiveness is to a large extent compensated by the increased availability of the toxicant to the insects.

The above conclusions were the result of experiments in the laboratory, but it would seem difficult to visualize exactly the implications of these various factors under uncontrolled conditions in the field, particularly with other variables such as type of insecticide, dosage, mud surface, date of spraying, and intervals between applications. It is beyond doubt, however, that the increase in humidity during the rainy season in general would have a favourable effect on residual toxicity; in other words, the performance of the insecticide is to a large degree dependent on external conditions. In principle this could present a problem in malaria eradication programmes, as it is by no means certain that conditions will always be favourable; and, particularly in areas where the relative humidity may fall below the critical limit, sorption could well lead to inadequate residual effect.

For this reason investigations were initiated at the Woodstock Agricultural Research Centre with the purpose of finding ways and means to reduce sorption by altering the insecticide formulation. After preliminary attempts Gerolt (1957)[1] succeeded in preparing a new type of wettable powder based on ground solidified melts of dieldrin and an adjuvant, such as coumarone resin, chlorinated polyphenyl resin (Aroclor 5460 — a synthetic resin of Monsanto Chemicals Ltd.), colophony, gilsonite (a natural asphaltite), or sulfur. Greatly extended persistence on a sorptive mud surface was achieved in bio-assay tests under laboratory conditions, and 100% mortality in panel exposure tests with *Musca domestica* was maintained for a period of over ten months with dieldrin/coumarone resin, as compared with less than two days for a standard dieldrin wettable powder under similar conditions. Promising laboratory results were also obtained with the other adjuvants.

These encouraging findings have subsequently led to extensive field experiments, mainly in Tanganyika

[1] See the article by P. Gerolt on page 577 of this issue.

by the Colonial Pesticides Research Unit at Arusha, and in Mexico jointly by the Pan-American Sanitary Bureau, the Mexican Government and the Shell Companies, using a wettable powder based on dieldrin and gilsonite. The results of these experiments have been surprising in two ways. Firstly, the standard dieldrin wettable powder proved to have a much greater persistence than in the laboratory tests on sorptive mud panels. Secondly, the dieldrin/gilsonite formulation was not significantly different in performance from the wettable powder containing dieldrin alone.

The experiments by the Colonial Pesticides Research Unit[1] were carried out with experimental huts located at Magugu, Tanganyika, and included dieldrin and dieldrin/gilsonite wettable powders on both sorptive and non-sorptive mud surface (dosage 0.15-0.2 g dieldrin/m^2). Residual effectiveness was examined by wall exposure tests and by assessment of mortalities of female *Anopheles gambiae* naturally entering and resting in the huts. There was a gradual decrease in residual toxicity with time, but virtually no differences between the two products could be observed. However, toxicity was markedly higher on non-sorptive than on sorptive mud.

The trials in Mexico were conducted in various areas, using both dieldrin and dieldrin/gilsonite, and were part of the normal malaria eradication programme in that country. The trials were on a village scale and included the normal type of mud house. The results, as reported by McNeel (1958), showed that the standard dieldrin wettable powder at the rate of 25 mg dieldrin/square foot (0.25 g/m^2) was quite effective against *Anopheles pseudopunctipennis* for a period of over 300 days, and that the dieldrin/gilsonite gave a residual toxicity of the same order. Bordas (unpublished) in experimental hut tests at Acatlipa, Mexico, also found that dieldrin/gilsonite had no advantage over dieldrin alone.

Similar negative results were obtained by Sharma, Bami & Krishnamurthy (1957) in field trials in India against *Culex fatigans*, but mortalities were very low owing to the natural tolerance of this species and the apparently insufficient effect of dieldrin in the sorbed state.

Finally, dieldrin and dieldrin/gilsonite wettable powders have been applied in practice as part of the World Health Organization's malaria eradication campaign in Zanzibar.

[1] Unpublished Progress Reports Nos. 20 and 21 (1957) of the Colonial Pesticides Research Unit.

Judging from the evidence obtained in the field, there seemed to be unexpected discrepancies between laboratory and field results for which no inmediate answer could be given. It could well be that a number of factors (external conditions, mechanical disturbance of the residues in the huts, composition of the mud walls, exposure technique, resting habits of the insects, etc.), which are strictly controlled in the laboratory, might interfere in the field and affect adversely the performance of the dieldrin/gilsonite residues. The question also arose to what extent the sorption of the dieldrin from a standard wettable powder was a real problem of biological importance in the field or was merely a laboratory phenomenon. Finally, some doubt existed as to the value of certain laboratory testing techniques as a preliminary stage to field trials.

In view of this, laboratory and field experiments were carried out from March until December 1958, in co-operation with the Colonial Pesticides Research Unit at Arusha, Tanganyika. The main objectives of this work were the following:

(*a*) To obtain information on the possible causes of the discrepancies found between laboratory and field results regarding the relative performance of dieldrin and dieldrin/gilsonite on a sorptive mud surface.

(*b*) To examine the laboratory and field performance of wettable powders based on dieldrin and adjuvants other than gilsonite.

LABORATORY EXPERIMENTS

The main purpose of the laboratory experiments was to examine the multitude of factors which could conceivably be responsible for the discrepancies between laboratory and field results regarding the relative performance of dieldrin and dieldrin/gilsonite on sorptive mud. To this end a series of exposure tests was conducted in which conditions changed step-wise from artificial laboratory conditions to natural field conditions. The following factors were taken into account: composition of the substrate; spraying technique; storage position; storage condition, with particular reference to humidity; exposure position; exposure time; exposure technique; and type of adjuvant used in the experimental product.

The bio-assay techniques employed included panel exposure and wall exposure, with *Anopheles gambiae* as the test insect. The panel exposure tests in the laboratory were done under carefully cleaned glass funnels, on flat circular mud panels (diameter 10 cm, thickness 1 cm), with about 15 laboratory-bred female mosquitos (usually 2-4 days old; mixed unfed and blood-fed) per exposure. After the test the mosquitos were transferred to clean cages and kept for 24 hours, after which mortality counts were made. For the wall exposure tests use was made of the standard WHO technique with plastic funnels, attached to the wall by means of adhesive tape. Further experimental procedure was similar to that in the panel exposure tests.

In the series of panel exposure tests the factors mentioned above were varied in the following way:

1. *Substrate.* For some of the tests the panels were made of pure mud (from Babati, Tanganyika), which was known to possess a high sorptive capacity. For other tests mud/sand panels were used, having the same composition as the mixture employed for plastering huts (volume proportion mud : sand about 15:11).

2. *Spraying technique.* Spraying was done either with the De Vilbiss laboratory hand sprayer, as was the practice in previous laboratory experiments at the Woodstock Agricultural Research Centre, or with the Oxford field sprayer. In the latter case, the panels were suspended against the mud wall and sprayed together with the walls in the hut.

3. *Storage position.* After spraying, the panels were mostly stored horizontally. In a number of tests, however, vertical storage was included by suspending the panels against the mud wall in the hut, thus imitating the conditions to which the mud itself was also exposed.

4. *Storage conditions.* The following storage conditions were included in the tests:

(*a*) dry; the panels were stored in a desiccator over concentrated sulfuric acid (relative humidity about 3%).

(*b*) humid; the panels were stored in a desiccator over a saturated sodium sulfate solution in water (relative humidity over 90%).

(*c*) laboratory; the panels were stored free in the laboratory, but protected from dust (relative humidity about 70%).

(*d*) laboratory hut; the panels were stored horizontally and vertically in an aluminium hut near the laboratory (relative humidity varying between about 70% and 85%).

(*e*) field hut; the panels were stored vertically, suspended against the mud wall of the experimental hut during the dry season (for relative humidity see Fig. 4).

5. *Exposure position.* The exposure tests were usually done on panels in a horizontal position. A few vertical exposures were carried out as well, but as the results did not seem to be essentially altered by the exposure position, the horizontal exposure was taken as the normal procedure.

6. *Exposure time.* The initial exposure time immediately after spraying was half an hour. Subsequent exposures at several intervals after treatment were adjusted for each test so as to obtain mortalities below 100% for the less effective residues, thus making possible a comparison between the persistence of the various products. The usual exposure times were ¼, ½, 1 and 2 hours.

7. *Adjuvant.* All products included in the test were 50% dieldrin wettable powders with or without adjuvant. The adjuvant, which was melted together with the dieldrin before formulation, amounted to 25% of the final product. The products were the following: dieldrin wettable powder; dieldrin/gilsonite wettable powder; dieldrin/colophony wettable powder; dieldrin/Aroclor wettable powder. The dosage applied onto the panels amounted to approximately 20 mg dieldrin per square foot (0.2 g/m²).

The exposure tests on each individual panel were repeated at various intervals of time after spraying, in order to obtain data on the relative performance of the four products over an extended length of time (up to 7-11 weeks). In all, 51 test series have been carried out. However, the 13 initial test series will be disregarded, as mortalities amounted to 100% in most cases.

In order to create conditions between those in the laboratory and in the field, an aluminium hut was erected near the laboratory. A semicircular brick wall was constructed inside the hut, and plastered with a 1-inch (2.5 cm) layer of sorptive Babati mud (mud/sand ratio 15 : 11). The mud wall was divided into four sections of 23 square feet, measuring 4 feet wide and 5¾ feet high (2.1 m²; 1.2 m wide, 1.7 m high). The four sections were sprayed with dieldrin, dieldrin/gilsonite, dieldrin/colophony, and dieldrin/Aroclor respectively, provision being made during the spraying to avoid contamination of other parts of the wall. Spraying was done with the Oxford field sprayer. The dosage aimed at was 20 mg dieldrin/square foot (0.2 g/m²), but in fact the walls

TABLE 1. RELATIVE PERFORMANCE OF DIELDRIN AND DIELDRIN/RESIN IN EXPOSURE TESTS UNDER VARIOUS CONDITIONS, EXPRESSED AS PERCENTAGE 24-HOUR MORTALITY OF FEMALE *ANOPHELES GAMBIAE*

Substrate	Sprayer	Storage position	Storage condition	Exposure position	Exposure time (hours)	Age of residue	Product [a] d	d/g	d/c	d/A	C
			Panel exposure tests in laboratory								
Mud	De Vilbiss lab. sprayer	Horizontal	Dry (3% RH)	Horizontal	1	7 weeks	12	15	29	92	9
"	"	"	Humid (90% RH)	"	½	7 "	88	94	64	94	9
"	"	"	In lab. (about 70% RH)	"	2	7 "	7	44	50	93	0
Mud/sand	"	"	"	"	2	7 "	60	65	93	100	0
"	"	"	In lab. hut (about 70%-85% RH)	"	1	7 "	56	13	53	89	0
"	"	Vertical	"	"	1	7 "	27	20	47	81	0
"	Oxford field sprayer	"	"	"	1	9 "	13	0	13	25	0
"	"	"	In field hut (dry season)	"	2	7 "	0	0	—	83	2
			Wall exposure tests in laboratory hut								
Mud/sand	Oxford field sprayer	Vertical	In lab. hut (about 70%-85% RH)	Vertical	½	12 days	33	10	40	100	0
"	"	"	"	"	2	37 "	69	93	50	93	0
"	"	"	"	"	2	61 "	29	31	56	50	0
"	"	"	"	"	4	102 "	19	25	7	97	0
"	"	"	"	"	4	132 "	48	20	70	100	0
"	"	"	"	"	4	167 "	48	18	70	100	—
"	"	"	"	"	4	196 "	38	37	56	100	14

[a] d=dieldrin; d/g=dieldrin/gilsonite; d/c=dieldrin/colophony; d/A=dieldrin/Aroclor; C=control

received about 15 mg. The deposits immediately after spraying were determined by total chlorine analysis of sample paper strips attached to the wall during spraying (three replicates for each treatment). The analytical results showed that the average deposits amounted to 15.2, 15.1, 13.2 and 14.5 mg dieldrin/square foot for the above-mentioned products respectively.

The conditions in the hut were approximately similar to those in the field hut except that in this case the residues on the wall were kept undisturbed and free from mechanical abrasion such as is likely to occur in huts occupied every night.

For the tests in the laboratory hut the exposure method was changed, and use was made of the standard WHO equipment for wall exposure tests on a vertical surface. Exposures were done at various intervals of time up to about half a year after spraying.

Table 1 gives a summary of the results obtained in the tests carried out in the laboratory and in the laboratory hut, as expressed in terms of 24-hour mortality of female *Anopheles gambiae*. For practical reasons the complete series of panel exposure tests has not been included in the table, and a selection was made of representative tests for each of the conditions included in the experiment. However, the full set of results is covered by Table 2, which gives a simplified picture of the relative performance of the four products, based on the number of tests in which each dieldrin/resin product gave a lower, equal or higher mortality as compared with dieldrin alone. A more or less arbitrary standard had to be adopted for this comparison, and mortalities differing by less than 10% were considered equal.

TABLE 2

RELATIVE PERFORMANCE OF DIELDRIN/RESIN PRODUCTS, EXPRESSED AS NUMBER OF TESTS SHOWING LOWER, EQUAL OR HIGHER MORTALITIES AS COMPARED WITH DIELDRIN

Product	Mortalities compared with dieldrin: Lower	Equal	Higher	Total number of tests
Dieldrin/gilsonite	12	22	10	44
Dieldrin/colophony	11	17	14	42
Dieldrin/Aroclor	2	11	32	45

Two conclusions can be drawn from the experiments:

1. Dieldrin/Aroclor gave a considerably better performance than dieldrin alone in the majority of the tests. It is interesting to note that tests (see Table 1) carried out on panels, sprayed together with the walls in field huts and stored vertically against the walls for periods up to 7 weeks during the dry season, also showed the superior performance of dieldrin/Aroclor as compared with dieldrin alone.

2. Dieldrin/gilsonite and dieldrin/colophony did not give a noticeable improvement in performance over dieldrin alone in exposure tests with *Anopheles gambiae* under the given experimental conditions. There are indications, particularly in the wall exposure tests, that dieldrin/colophony tended to be slightly more persistent than dieldrin/gilsonite, but the differences are small.

In general it can be said that the results of the tests did not seem to be influenced to any great extent in these experiments by the varied factors, except for humidity and type of adjuvant. From Table 1 it can be seen that in the tests with panels stored under conditions of extremely low and high humidity, the high humidity markedly masked the differences in performance between dieldrin/Aroclor and dieldrin alone. This can be explained by higher activity of the sorbed dieldrin, which is in line with results previously obtained by other investigators.

The absence of any significant effect with dieldrin/gilsonite and dieldrin/colophony was rather unexpected in view of previous laboratory experiments at the Woodstock Agricultural Research Centre.[1] The interesting aspect, however, is that there are obviously no discrepancies as regards relative performance of dieldrin/gilsonite and dieldrin between the present laboratory results and the field results obtained by the Colonial Pesticides Research Unit in 1957. There are, on the other hand, discrepancies between the present results obtained in the laboratory at Arusha and those obtained at Woodstock, and some explanation is called for.

To this end it is necessary to consider more closely the factors which are likely to influence the effectiveness of particulate and sorbed dieldrin under the given test conditions. From the over-all picture obtained during the course of the investigation on the sorption problem, it would seem that the following factors are of importance in this connexion:

1. Mobility of the insects during exposure. This will depend on: (*a*) insect species, and (*b*) exposure conditions.

2. Inherent toxicity of the dieldrin/resin particles.

It is generally known that insecticide in the sorbed state can have a considerably toxic effect on insects, but relatively long exposure periods (at least half an hour) are necessary, and the effect is very much dependent on humidity. In the case of particulate surface residues, such as exist with the dieldrin/resin products, toxicity greatly depends on the pick-up of particles, and the extent to which particles are picked up is very likely influenced by the mobility of the insect in contact with the surface.

In previous laboratory tests *Musca domestica* and *Aëdes aegypti* have been used, and it was observed that under the given exposure conditions both insect species showed a considerable degree of mobility, which no doubt facilitates the pick-up of particles. As storage conditions of the panels had been adjusted so as to minimize the effectiveness of sorbed dieldrin (relative humidity less than 40%), the particulate residues of all dieldrin/resin products clearly showed an improved persistence.[1] *Anopheles gambiae*, however, prefers the resting state during exposure. Under these conditions a particulate residue is not necessarily of advantage, because toxicity does not depend so much on the pick-up of particles as on the uptake of dieldrin from material in the sorbed state or on a direct uptake of dieldrin from the dieldrin/resin particles.

Mobility of the insects is also greatly influenced by the exposure technique used. In experiments at Woodstock with the method developed at the US Public Health Service Laboratories at Savannah, Ga., it was observed that in the relatively large exposure chambers *Aëdes aegypti* prefers the resting state too. The results of these experiments showed that under these conditions dieldrin/gilsonite did not give a performance different from that of dieldrin alone. Only dieldrin/Aroclor was decidedly superior in persistence. Dieldrin/colophony gave an intermediate performance, although it did not differ very much from dieldrin/gilsonite.[1] These results are completely in line with the present results obtained with *Anopheles gambiae*.

Summarizing, it can be stated that there is a close agreement between the results of all tests with

[1] See the article by P. Gerolt on page 577 of this issue.

TABLE 3

INITIAL AND RESIDUAL EFFECTIVENESS OF VARIOUS DIELDRIN/RESIN PRODUCTS AGAINST *AËDES AEGYPTI*

Product	Age of residue	Exposure time	Dosage of dieldrin (mg/square foot) [a]	Percentage 24-hour mortality
Dieldrin/ gilsonite	2 hours	5 min.	9	0
	2 weeks	6 hours	2.5	22
	2 "	6 "	0.9	0
	2 "	6 "	0.25	0
Dieldrin/ colophony	2 hours	5 min.	9	17
	2 weeks	6 hours	2.5	100
	2 "	6 "	0.9	0
	2 "	6 "	0.25	0
Dieldrin/ Aroclor	2 hours	5 min.	9	47
	2 weeks	6 hours	2.5	100
	2 "	6 "	0.9	100
	2 "	6 "	0.25	15
Control		6 hours	—	0

[a] 100 mg/square foot = 1 g/m².

insects in the resting state, and it is obvious that under these conditions the differences in performance between dieldrin/resin and dieldrin alone tend to disappear, with the exception, however, of dieldrin/Aroclor.

The high activity of dieldrin/Aroclor could be further demonstrated in panel exposure tests dealing with inherent toxicity and persistence of various dieldrin/resin products. The tests involved the exposure of female *Aëdes aegypti* mosquitos (20-25 per replicate) to dieldrin/resin residues on mud panels at a series of low dosages, immediately after and 2 weeks after spraying. From the results as shown in Table 3, it was clear that the performance both in initial and in residual tests was least with dieldrin/gilsonite, and best with dieldrin/Aroclor, dieldrin/colophony being intermediate. It was possible to arrive at an approximate quantitative assessment of the relative residual toxicities in terms of dosages. Dieldrin/gilsonite at 1/10th of the usual dosage (25 mg/square foot, or 0.25 g/m²) was inadequate (22% mortality), whereas it was completely effective with dieldrin/colophony and dieldrin/Aroclor (100% mortality in both cases). At 1/30th of the usual dosage both dieldrin/gilsonite and dieldrin/colophony were ineffective (no mortality), but dieldrin/Aroclor was still fully active (100% mortality). At 1/100th of the usual dosage the mortality with dieldrin/Aroclor fell to a low level (15%), corresponding approximately to that obtained with dieldrin/gilsonite at 1/10th of the usual dosage (22%). These data indicate that under the given test conditions the toxicity of the dieldrin/Aroclor residues was about ten times higher than that of the dieldrin/gilsonite residues, dieldrin/colophony being intermediate.

The cause of this higher activity of Aroclor is not known, and no investigation into this question has been carried out. It may well be, however, that different solubility of the resinous adjuvants in the insect cuticle is one of the factors involved.

From the results so far obtained in the laboratory it is not surprising that dieldrin/gilsonite did not show a better performance than dieldrin under field conditions in the experiments conducted by the Colonial Pesticides Research Unit in 1957. It would appear that the same applies to dieldrin/colophony, although it may be slightly more effective than dieldrin/gilsonite. Dieldrin/Aroclor has so far given the best results. However, field experiments are necessary to find out whether its high effectiveness and long persistence can be demonstrated under natural conditions as well.

FIELD EXPERIMENTS

Experimental set-up

The main object of the field experiments was to examine the performance of dieldrin and dieldrin/resin wettable powders under field conditions, with particular reference to the relative persistence of dieldrin/gilsonite as compared with dieldrin in combination with other resins. The experiments were carried out at Magugu, about 140 km south of Arusha, an area where there is substantial mosquito breeding during the rainy seasons.

Use was made of experimental huts of the type employed by the Colonial Pesticides Research Unit for mosquito experiments. These test huts were constructed of ordinary bricks, the inside walls being plastered with a 1-inch (2.5-cm) layer of mud/sand mixture (volume proportions mud : sand about 20:12 for the non-sorptive Magugu mud, and about 15:11 for the sorptive Babati mud). The roofs were made of thatch, and the floors consisted of sheets of hardboard supported by wood, the hardboard being painted white in order to facilitate floor catching of dead mosquitos. The four walls each measured about 8 feet (2.4 m) long and 6 feet (1.8 m) high, the total mud surface was about 200 square feet (18.5 m^2), and the total roof surface was about 100 square feet (9.3 m^2). The huts were provided with one door and one window (1 × 1 foot, or 30 × 30 cm) into which a window exit trap could be fitted. The huts were occupied during the night, so that mosquitos were attracted. Window traps were put on from 4 p.m. to 7 p.m. (evening window trap) and from 7 p.m. to 8 a.m. (morning window trap); at other times the windows were kept closed by means of a wooden window shutter. The doors were kept closed throughout the day. Entry of mosquitos took place mainly through the eaves, which were loosely covered on the inside by hessian cloth in order to reduce light intensity, thus reducing the chance of mosquitos leaving the hut in another way than through the window traps. The huts were supported by four concrete structures, each surrounded by a water channel in order to prevent the entry of ants.

Two successive field experiments have been carried out. The first one, starting at the beginning of the rainy season, included six huts; the second one, starting at the beginning of the dry season, included three huts (the control hut being the same as in the first experiment). The following gives an outline of the treatments and the type of surface used in the respective huts:

1. Control	non-sorptive Magugu mud	
2. Dieldrin	" "	1st field experiment
3. Dieldrin	sorptive Babati mud	
4. Dieldrin/gilsonite	"	
5. Dieldrin/colophony	"	
6. Dieldrin/Aroclor	"	
7. Dieldrin	"	2nd field experiment
8. Dieldrin/gilsonite	"	
9. Dieldrin/Aroclor	"	

All products were 50% dieldrin wettable powders, with adjuvants at 25% of total formulation weight.

The spraying was done with the Oxford precision sprayer (emission rate of nozzle 2 litres in 135 seconds, pressure 30 p.s.i. or 9.1 atm., distance from nozzle to wall about 12-18 inches, or 30-45 cm), and the total amount of insecticide dilution was applied on the surface in two spraying runs, in order to avoid unevenness in deposit. The wall dosage intended was 20 mg dieldrin/square foot (0.2 g/m^2), i.e., about 60% of nozzle dosage. The determination of spray deposits was done in two ways: by the sample paper method, and by the wall scraping method. Sample papers (18½ × 1½ inches, or 47 × 3.8 cm) were attached to the lower part of the roof, and to the top and bottom part of the wall (three replicates in each case) before spraying. Wall scrapings (eight and six replicates per hut in the first and second experiment respectively) were done immediately after spraying with the aid of a special device, enabling the removal of a layer of mud approximately 1 mm thick from a circular surface area of about 38½ cm^2. The deposits were analysed by the total chlorine method, allowance being made for the chlorine present in the Aroclor. The analytical results showed that the average deposits on the wall as measured by the sample paper method amounted to 19.7, 19.1, 21.8, 19.7 and 13.2 mg dieldrin per square foot for treatments 2 to 6 respectively, and to 26.3, 22.7 and 20.1 mg dieldrin per square foot for treatments 7 to 9 respectively.[1] In general the analyses showed that the average deposits on the walls were according to expectation. Only the dieldrin/Aroclor hut in the first experiment received too low a dosage, and the dieldrin hut in the second experiment received too high a dosage. The results obtained with the wall scraping method were usually lower than those obtained with the sample paper method, which is understandable, as in the process of removing the scrapings from the wall a fraction of the mud is sometimes lost.

Pre-spraying counts of mosquitos in the huts were started a fortnight prior to treatment. Subsequent entomological evaluation of the residual effect of the various treatments was made in two ways:

1. By wall exposure tests,

2. By daily assessment of the 24-hour mortality among female mosquitos (*Anopheles gambiae* and culicines) naturally entering the huts.

During the full period of the experiments (15 March to 31 December 1958) daily records were taken of rainfall, maximum and minimum relative humidity, relative humidity at fixed hours (9 a.m. and 3 p.m.), and maximum and minimum temperature. Recording of humidity and temperature was done both outside and inside the hut.

Wall exposure texts

Technique. In order to obtain information on the residual effect of the various products under more

[1] 100 mg/square foot = 1 g/m^2.

or less controlled conditions, wall exposure tests were carried out in all the huts at regular intervals.

The technique consisted of an exposure for a fixed period of female *Anopheles gambiae* under Petri dishes held against the treated walls. After exposure the mosquitos were transferred to clean cages and held for 24 hours, after which mortality counts were made. Usually wild-caught mosquitos were used in the tests, but as the dry season advanced the mosquito population became too low and laboratory-bred mosquitos had to be transported from Arusha in order to continue the tests. About 15-25 mosquitos were used per replicate. The number of replicates was two or three depending on the availability of insects, and occasionally only one replicate could be done. The exposure time varied from 5 minutes to 4 hours depending on the age of the residue. In general the exposure time was adjusted so as to obtain mortalities below 100% in order to enable comparative conclusions to be made.

In total 39 test series were carried out in the first field experiment and 21 in the second field experiment. For a further analysis of the results the first six test series in the first field experiment will be disregarded, as mortalities all amounted to 95%-100%, owing to too long an exposure. Fig. 1, 2 and 3 give an over-all picture of the results obtained in 29 test series of the first field experiment. All mortality figures have been corrected according to Abbott's formula. It will be noticed that the exposure time was gradually increased with the ageing of the residues.

TABLE 4

RELATIVE PERFORMANCE OF DIELDRIN ON NON-SORPTIVE AND SORPTIVE MUD, EXPRESSED AS NUMBER OF TESTS SHOWING LOWER, EQUAL OR HIGHER MORTALITIES

Condition of test	Comparative mortalities			Total number of tests
	Lower on sorptive mud	Equal	Higher on sorptive mud	
Wet season	2	4	1	7
Dry season	18	4	2	24

Influence of sorption on effectiveness of dieldrin. The first question regarding the performance of the various products on sorptive and non-sorptive mud concerned the influence of sorption on the effectiveness of dieldrin in the wall exposure tests. In this connexion it should be mentioned that the main rainy season at Magugu ended between the 45-day and the 50-day test, whereas the short rains started between the 245-day and the 266-day test of the first field experiment.

In view of the influence of humidity on the effectiveness of dieldrin in the sorbed state, it is logical to distinguish between the wet and the dry season as far as the relative performance of dieldrin on the two types of mud is concerned. Table 4 gives a comparison based on the number of tests in which dieldrin on sorptive mud gave lower, equal or higher

FIG. 1

RELATIVE PERFORMANCE OF DIELDRIN ON NON-SORPTIVE AND SORPTIVE MUD

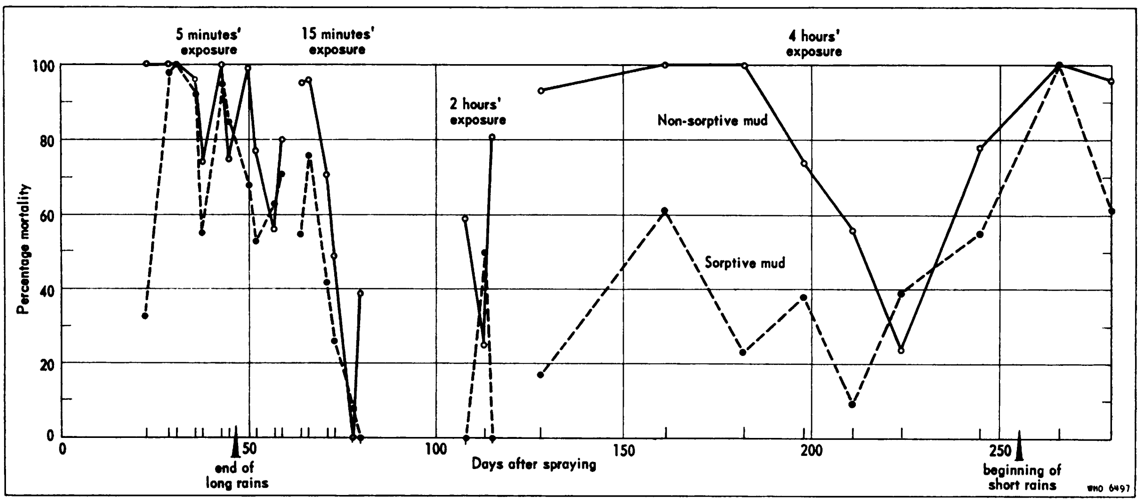


FIG. 2
RELATIVE PERFORMANCE OF DIELDRIN AND DIELDRIN/GILSONITE ON SORPTIVE MUD

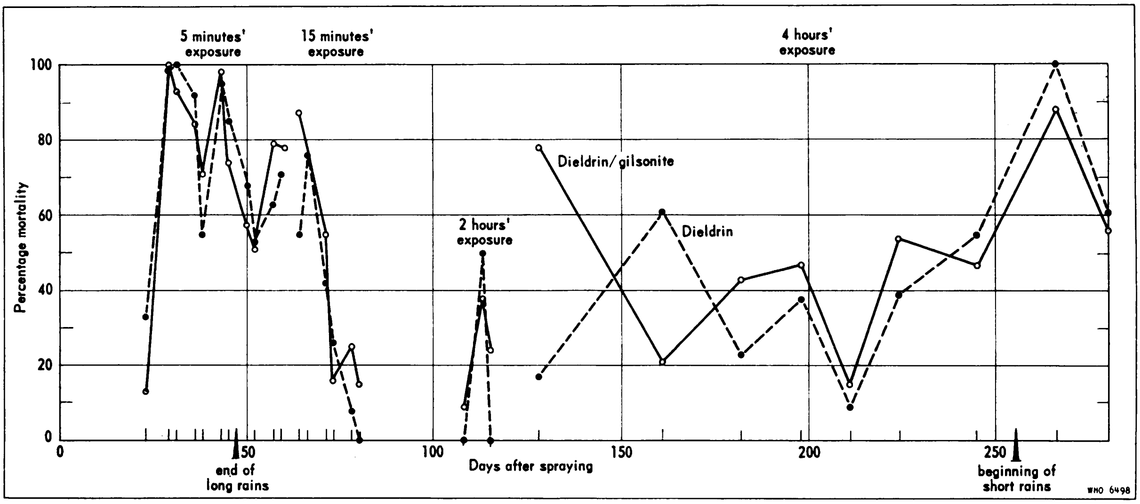
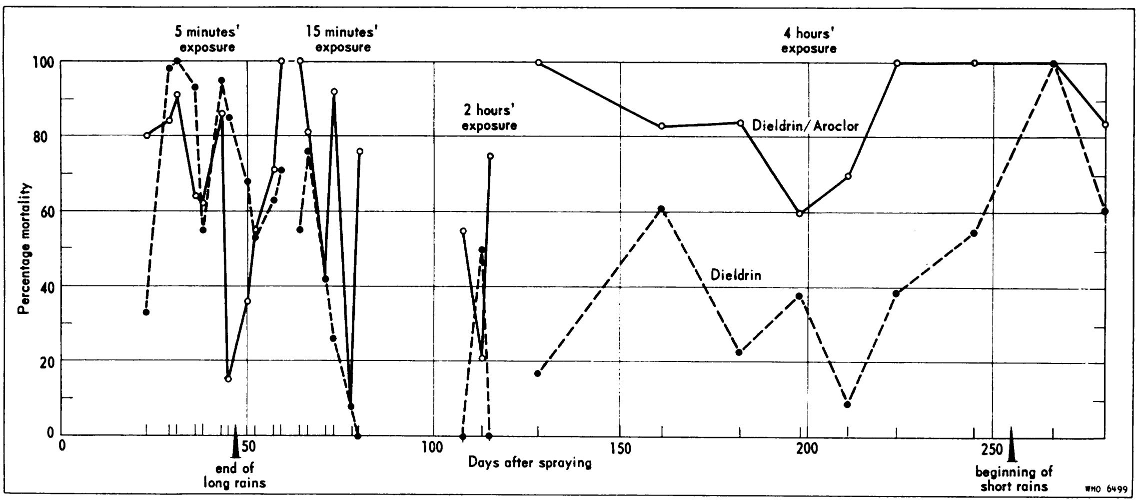


FIG. 3
RELATIVE PERFORMANCE OF DIELDRIN AND DIELDRIN/AROCLOR ON SORPTIVE MUD



mortalities as compared with dieldrin on non-sorptive mud.

It is obvious that during the wet season the influence of sorption was not well marked, and it is likely that because of the high average relative humidity the dieldrin in the sorbed state still had a high degree of effectiveness. During the dry season the picture was entirely different. In 18 out of the 24 tests, dieldrin on sorptive mud was less effective than on non-sorptive mud, and this shows that the influence of sorption under field conditions can be demonstrated by biological methods. Similar results were obtained by the Colonial Pesticides Research Unit at Arusha in their 1957 experiments. Fig. 1 shows that the differences in performance of dieldrin on the two types of mud was most noticeable during the second part of the dry season; and according to the humidity readings this is the period when the relative humidity is at its lowest. There was a marked tendency, however, for comparatively

TABLE 5

RELATIVE PERFORMANCE OF DIELDRIN AND DIELDRIN/RESIN ON SORPTIVE MUD, EXPRESSED AS NUMBER OF TESTS SHOWING LOWER, EQUAL OR HIGHER MORTALITIES AS COMPARED WITH DIELDRIN

Condition of test	Product	Mortalities compared with dieldrin on sorptive mud			Total number of tests
		Lower	Equal	Higher	
Wet season (1st field experiment)	Dieldrin/ gilsonite	2	4	1	7
	Dieldrin/ colophony	5	1	1	7
	Dieldrin/ Aroclor	3	3	1	7
Dry season (1st field experiment)	Dieldrin/ gilsonite	6	8	10	24
	Dieldrin/ colophony	3	8	13	24
	Dieldrin/ Aroclor	2	7	15	24
Dry season (2nd field experiment)	Dieldrin/ gilsonite	9	7	2	18
	Dieldrin/ Aroclor	4	5	9	18

lower mortalities with dieldrin on non-sorptive mud towards the end of the dry season, and this may well be an indication that the so-called non-sorptive mud was still sorbing a certain amount of dieldrin, which would become inactive under dry conditions. With the beginning of the short rains it seems that effectiveness increased again, and that the differences in performance of dieldrin on the two types of mud became less conspicuous, but more tests would be necessary to confirm this.

Relative performance of dieldrin and dieldrin/resin. In view of the similar results obtained with dieldrin on both non-sorptive and sorptive mud during the wet season it could not be expected that the addition of resin to the dieldrin wettable powder would improve the performance under these conditions. This has in fact been borne out by the results of the wall exposure tests. Table 5 shows that none of the three dieldrin/resin products gave any improvement in effectiveness, and if there was any difference it would be even in favour of the standard dieldrin wettable powder.

However, during the dry season the relative merits of the dieldrin/resin products can be differentiated more clearly. In general, of all products tested dieldrin/Aroclor gave the best performance in the wall exposure tests. Pooling the results of the two field experiments for the dry season, it can be seen that dieldrin/Aroclor gave a higher kill than dieldrin alone in 24 out of 42 tests, against only 12 for dieldrin/gilsonite. From the first experiment it seems that dieldrin/colophony was intermediate in performance.

TABLE 6

RELATIVE PERFORMANCE OF DIELDRIN ON NON-SORPTIVE MUD AND DIELDRIN/RESIN ON SORPTIVE MUD, EXPRESSED AS NUMBER OF TESTS SHOWING LOWER, EQUAL OR HIGHER MORTALITIES AS COMPARED WITH DIELDRIN

Condition of test	Product (on sorptive mud)	Mortalities compared with dieldrin on non-sorptive mud			Total number of tests
		Lower	Equal	Higher	
Dry season (1st field experiment)	Dieldrin/ gilsonite	18	2	4	24
	Dieldrin/ colophony	12	7	5	24
	Dieldrin/ Aroclor	7	10	7	24

The over-all results are supported when a comparison is made between the performance of the dieldrin/resin products on sorptive mud in the first experiment with that of dieldrin alone on non-sorptive mud. As could be expected, dieldrin/Aroclor equalled dieldrin on non-sorptive mud, whereas dieldrin/gilsonite was decidedly less effective, dieldrin/colophony being intermediate (Table 6).

One may wonder why the favourable results with dieldrin/Aroclor were not more consistent and why it gave a better performance in no more than 24 out of 42 tests. This becomes clearer if conditions under which the successive tests were carried out are taken into consideration. When the total period of the first field experiment until the beginning of the short rains (250 days) is divided into five periods of 50 days, the number of tests in which dieldrin/Aroclor gave higher mortalities than dieldrin alone showed the following trend:

1st 50 days	wet season	1 out of 7 tests
2nd „	dry season	6 „ 13 „
3rd „	„	3 „ 5 „
4th „	„	3 „ 3 „
5th „	„	3 „ 3 „

As may be seen there was a progressively improving relative performance of dieldrin/Aroclor with the advance of the dry season. This was not the case with dieldrin/gilsonite. A similar tendency could be noticed in the results of the wall exposure tests in the second field experiment. It seems likely that this is linked with the influence of the gradual decrease in relative humidity, under which conditions the sorption of dieldrin influences more and more the effectiveness of the insecticide alone. It is interesting to note that the period in which dieldrin/Aroclor gave consistently better results than dieldrin alone (150-250 days after spraying) coincides with the period of maximum difference in performance of dieldrin on non-sorptive and sorptive mud (see Fig. 1 and 3).

Fig. 2 and 3 give a more comprehensive picture of the relative performance of dieldrin/gilsonite and dieldrin/Aroclor as compared with dieldrin alone throughout the experimental period. They show when and to what extent differences could be observed. It can be seen that with the onset of the short rains the differences between dieldrin/Aroclor and dieldrin showed a tendency to disappear. Further tests, however, would be necessary to confirm this.

The interesting outcome of the wall exposure tests is that the results are generally in line with those obtained by the Colonial Pesticides Research Unit in the 1957 field experiments as well as with those obtained in the present panel exposure tests in the laboratory and the wall exposure tests in the laboratory hut. In all cases dieldrin/gilsonite has not given evidence of improved performance on sorptive mud with *Anopheles gambiae* as test insect under the given experimental conditions. Furthermore, the influence of sorption can be demonstrated in the field by wall exposure tests, but only during the dry season.

Dieldrin/Aroclor has given the best over-all results of all products tested, dieldrin/colophony being intermdeiate. It should, however, be noted that the superiority of dieldrin/Aroclor over dieldrin alone is noticeable during the dry season only, and is, generally speaking, less marked under field conditions than in the panel exposure tests in the laboratory or in the wall exposure tests in the laboratory hut. This suggests that factors are operating in the field which tend to reduce the differences in performance, and from an analysis of results obtained during five successive periods of 50 days it seems likely that humidity is at least a major factor involved.

Mortality assessment of mosquitos in the huts

Assessment of the mortalities among mosquitos present in the huts was done on a daily routine basis. For this purpose exit traps (1×1×1 foot, or 30×30×30 cm) were fitted in the windows twice a day: from 4 p.m. to 7 p.m. (evening window trap) and from 7 p.m. to 8. a.m. (morning window trap). After the window traps had been taken off, the mosquitos were transferred to clean cages and kept for 24 hours, after which the mortality counts were done. In addition, twice a day (in the morning and in the afternoon) dead mosquitos were recovered from the floor. No hand catching in the hut was done in order to allow the maximum period of resting on the wall. During the dry season, when the mosquito population density became low, mosquitos were released from cages in the huts from time to time (about 60-100 per hut). These release tests were always carried out at 7 p.m. in order to avoid mosquitos being attracted by the daylight and leaving the huts through the window traps too soon. However, the recovery of mosquitos in the release tests has been disappointing in general, and the results will not be reported separately but will be included in those obtained with mosquitos naturally entering the huts.

Table 7 gives a summary of the corrected mortality figures for the first and the second field experiments. Apart from the counts done two weeks before spraying, the first experiment covers a period of 40 weeks and the second a period of 30 weeks. The figures refer to mortalities for separate periods of 10 weeks, and are given for female *Anopheles gambiae*.

The interesting feature of these results is that there did not seem to be important differences in over-all performance between the various products. In the first experiment all mortalities were at the 95%-100% level during the first 10 weeks, and at the 80%-95% level during the next 10 weeks. Subsequently there were more indications of decline in effectiveness, and mortalities fell to the 40%-60% level during the last 10 weeks. In the second experiment there was 100% mortality during the first 10 weeks, about 65%-85% during the following 10 weeks, and about 55%-80% during the last 10 weeks.

The over-all picture for culicines (mainly *Culex fatigans*) is very similar, but mortalities were in general lower, as could be expected. Only during the first 10 weeks after spraying was an appreciable mortality obtained (> 50%). After that mortalities rapidly fell to the 30% level and below. No con-

TABLE 7

ASSESSMENT OF 24-HOUR MORTALITIES (%) AMONG FEMALE *ANOPHELES GAMBIAE* NATURALLY ENTERING EXPERIMENTAL HUTS

Product	Substrate	1st field experiment					2nd field experiment			
		Before spraying	After spraying				Before spraying	After spraying		
		1-2 weeks	1-10 weeks	11-20 weeks	21-30 weeks	31-40 weeks	1-2 weeks	1-10 weeks	11-20 weeks	21-30 weeks
Dieldrin	Non-sorptive mud	8	99	82	100	62				
Dieldrin	Sorptive mud	14	97	90	83	53	19	100	76	79
Dieldrin/gilsonite	Sorptive mud	0	99	90	100	39	10	100	66	56
Dieldrin/colophony	Sorptive mud	6	96	75	78	55				
Dieldrin/Aroclor	Sorptive mud	2	99	97	63	61	17	100	87	54

sistent differences in performance between the various products could be observed.

It should be mentioned that the interpretation of these field data was difficult in view of the low number of mosquitos caught in the huts during the 1958 season. Moreover, the mosquito catches in the various huts showed considerable differences, which may be attributed to the position of the huts in the field and to the fact that one sleeping person may attract more mosquitos than another. Therefore significance should be attached only to those differences in mortality which are fairly large and show a consistent trend.

The absence of obvious differences in performance between the various products can be further illustrated by taking the corrected over-all mortalities over the complete experimental period, as listed in Table 8. In spite of the relatively low number of mosquitos, there was a close agreement between the mortalities assessed in all treated huts, both for *Anopheles gambiae* and for culicines.

The results mentioned above tally fairly well with those obtained in the experiments carried out in 1957 by the Colonial Pesticides Research Unit (CPRU), in that dieldrin/gilsonite did not perform any better than dieldrin alone. It should be mentioned that the CPRU found somewhat lower mortalities among mosquitos in the huts lined with sorptive mud than in the huts with non-sorptive mud. This has not been confirmed, but the CPRU had used a somewhat lower dosage of dieldrin, and it may well be that similar differences would have been observed in the present experiments if observations had been extended over a still longer period.

The most interesting aspect, however, is that dieldrin/Aroclor, although having given a distinctly better performance than dieldrin in the wall exposure tests during the dry season, did not show any improvement as regards the mortalities among mosquitos naturally entering and resting in the huts.

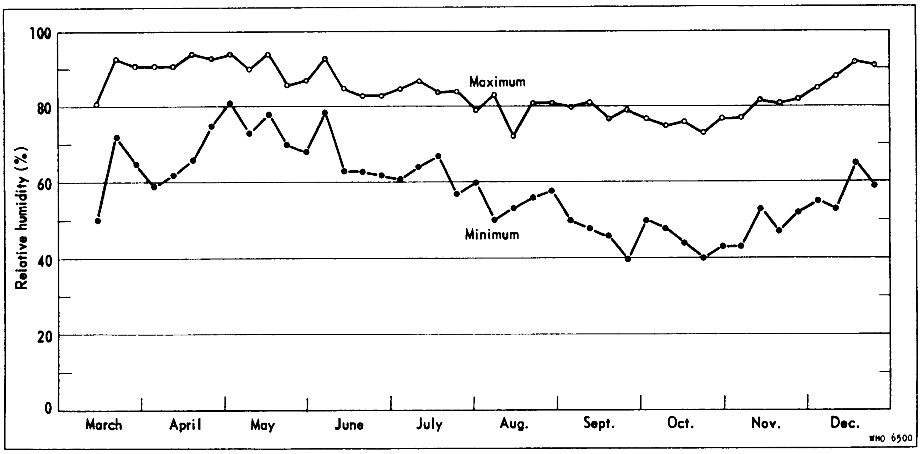
TABLE 8

OVER-ALL MORTALITIES AMONG MOSQUITOS NATURALLY ENTERING EXPERIMENTAL HUTS

Test	Product	Substrate	Percentage mortality	
			Anopheles gambiae	Culicines
1st field experiment	Dieldrin	Non-sorptive mud	85	35
	Dieldrin	Sorptive mud	89	45
	Dieldrin/gilsonite	,,	88	34
	Dieldrin/colophony	,,	78	35
	Dieldrin/Aroclor	,,	93	39
2nd field experiment	Dieldrin	Sorptive mud	88	62
	Dieldrin/gilsonite	,,	74	53
	Dieldrin/Aroclor	,,	86	57

FIG. 4

WEEKLY AVERAGE MAXIMUM AND MINIMUM RELATIVE HUMIDITIES INSIDE EXPERIMENTAL HUTS AT MAGUGU, TANGANYIKA



For a further explanation of this observation attention should be drawn to the relative humidity figures inside the huts. Daily recording has shown that the minimum relative humidity values for the months of April, May, June, July and August did not fall below 50% (except for one day in July and a few days in August). The maximum values in that same period did not fall below 70% (except for a few days in August). September and October were the dryest months, with minimum relative humidity values inside the hut ranging from 32% to 60% and maximum values from 64% to 88%. From November onwards the humidity slowly increased again. Fig. 4 gives a picture of the maximum and minimum humidity variations inside the huts. No calculations have been carried out to find the accurate average humidity, but it is obvious from the graphs that the average was well over 70% for the months April, May, June and July, and over 60% for August, i.e., 3½ months after the end of the rainy season. Even during the driest months, September and October, the average did not fall much below 60%, after which there was a gradual increase.

The rather surprising feature of these observations is that the average relative humidity inside the huts is kept at a reasonably high level throughout the dry season, and it seems that the extreme diurnal variations outside the hut, caused by the regular changes in temperature during the day, are levelled off to a considerable extent inside. This is understandable because temperature variations inside are less extreme, but factors such as release of moisture from the mud walls and from the people sleeping during the night may also contribute.

It is interesting to consider the possible implications of this as regards the performance of dieldrin on sorptive mud surface under various conditions of exposure. With the present knowledge of the influence of humidity on mobility and availability of sorbed dieldrin it is understandable that during the wet season, with the average humidity inside the huts at a level of well over 70%, sorbed dieldrin is quite effective and therefore no differences between dieldrin and dieldrin/resin can be observed, irrespective of exposure time. With the advance of the dry season, and the consequent fall of the average humidity to a level of slightly under 60%, it can be assumed that the availability of the sorbed dieldrin becomes less, and longer exposure times would be necessary to produce the maximum effectiveness of the dieldrin present in the top layer of the mud wall. In other words, differences in performance between dieldrin and dieldrin/resin may well then show up in wall exposure tests with a limited exposure time, owing to the reduced availability of the sorbed dieldrin. However, when assessing the mortalities of mosquitos naturally entering the huts and resting on the wall for considerably longer periods, the differences in performance disappear, because the availability of the sorbed dieldrin is still sufficient to produce its lethal action under conditions of prolonged exposure.

Theoretically, one may expect serious deterioration of the residual effectiveness in the field when the average humidity inside the huts falls below the critical point where the effectiveness of sorbed dieldrin becomes negligibly low. From experience in laboratory experiments this could be expected at an average humidity level below 50%, and it would be interesting to discover whether these expectations could be confirmed in the field. However, no experiments on this aspect could be carried out in the present investigation as the required conditions did not prevail.

DISCUSSION

The over-all results of the laboratory and field experiments described in this paper now permit a general discussion on the significance of the previous discrepancies between laboratory and field results regarding the relative merits of dieldrin and dieldrin/resin products on sorptive mud, and on the validity of laboratory techniques and controlled field tests as indications for field performance. Furthermore, it seems opportune to give some further consideration to the importance of the sorption phenomenon in general and its implications under field conditions.

The recent experiments at Arusha have undoubtedly led to a better understanding of the various causes responsible for previous discrepancies between the laboratory results with different methods (the Woodstock panel exposure method and the Savannah exposure chamber method), and between results obtained in the laboratory and in the field. The present indications are that all results can be explained provided that a number of factors are taken into account. These factors are the following:

1. Mobility of the insects during exposure as influenced by:

(*a*) insect species, and

(*b*) exposure conditions.

2. Inherent toxicity of the dieldrin/resin particles.

3. Average relative humidity inside the experimental huts.

In general, improved performance as compared with dieldrin alone can be expected with all dieldrin/resin products providing that the pick-up of particles is facilitated by mobility of the insects during exposure. These conditions did actually exist in the majority of the panel exposure tests at Woodstock, carried out with *Musca domestica* and *Aëdes aegypti.*

The relative performance of the dieldrin/resin becomes more critical in tests with insects in the resting state. This applies, for example, to experiments with *Aëdes aegypti* using the Savannah exposure chamber method, and to experiments with *Anopheles gambiae*, which species prefers the resting state irrespective of exposure conditions. Toxicity then mostly depends on the uptake of dieldrin from material in the sorbed state or on a direct uptake of dieldrin from the dieldrin/resin particles. Obviously, dieldrin/gilsonite does not meet the necessary requirements, and although it may perform satisfactorily under favourable exposure conditions when using particular insect species, it bears the risk of failure when exposure conditions become more stringent (e.g., the Savannah method) or a different species, like *Anopheles gambiae*, is used. Favourable results with insects in the resting state can be expected only when using products with a considerably higher inherent toxicity than dieldrin/gilsonite, and this requirement is met by dieldrin-Aroclor. This product has undoubtedly given the most satisfactory results, and it has been proved that the improvement in persistence of dieldrin/resin combinations can be demonstrated in the laboratory, irrespective of species or exposure conditions, as well as in wall exposure tests in the field.

However, two facts have been observed which strongly emphasize the importance of humidity as regards the relative performance of dieldrin/resin and dieldrin alone on sorptive mud under field conditions.

Firstly, the favourable effect of dieldrin/Aroclor in the wall exposure tests is noticeable only during the dry season. During the period of long rains no differences in performance can be observed, and with the onset of the short rains there is again a tendency to smaller differences because the dieldrin without resin shows improved toxicity.

Secondly, no differences in performance between dieldrin/Aroclor and dieldrin alone can be found when considering the mortalities of mosquitos naturally entering and resting in the huts, and this applies to the dry season as well.

In this connexion the observations on relative humidity values inside the huts are of importance. It was observed that the average relative humidity inside the huts is sufficiently high throughout the dry season to allow for a sufficient degree of activity of dieldrin in the sorbed state, particularly in view of the long contact time of mosquitos naturally entering and resting in the huts. This makes it understandable that the differences in performance between dieldrin/Aroclor and dieldrin alone, as evident in wall exposure tests with a limited exposure time, do not show up.

The validity of laboratory techniques and controlled field tests as indicators of field performance is an important consideration. There is no doubt that previous discrepancies between laboratory and field resultshave given rise to certain doubts in this respect.

From the experience obtained from the recent laboratory and field tests in East Africa it can be stated that the main factors responsible for these discrepancies have now been found. There is no doubt that the superiority in persistence of the dieldrin/resin as observed under selected and strictly controlled laboratory conditions tends to become less marked in partially controlled field tests, and disappears under uncontrolled field conditions involving unrestricted contact periods coupled with comparatively high average relative humidity. This strongly emphasizes the extreme care needed in the extrapolation of laboratory results into the field, and also the fact that small-scale field tests in an early stage of investigations of this type are indispensable in order to check laboratory findings.

The importance of the choice of the technique as well as the test insect species used in exposure tests has been clearly demonstrated, and factors such as mobility of the insects during exposure, which is to a large extent governed by the exposure conditions and the insect species, can influence the results of a laboratory experiment considerably, and in certain instances lead to results deviating from those obtained in the field.

Equally careful consideration should be given regarding the value of wall exposure tests as indicators of field performance. As was shown in the experiments reported above, the results of the wall tests in the dry season correspond to those obtained in the laboratory, but do not agree with the over-all field performance expressed in terms of mortality of mosquitos naturally entering the huts. Wall tests should therefore be considered as having restricted validity, and it should be borne in mind that differences between products as shown in wall tests with limited exposure time need not necessarily show up under natural conditions, where mosquitos rest on treated walls for very much longer periods.

Some final remarks are desirable in connexion with the sorption problem in general and its implications in the field. The striking feature of the recent Arusha experiments is the long period during which dieldrin remains effective in the field, as compared with panel exposure tests on sorptive mud in the laboratory. This agrees with the general experience obtained under practical conditions of actual spraying programmes. Examples of such programmes, which were carried out as part of a more thorough investigation, are the Taveta-Pare project under the auspices of the East African Institute of Malaria and the Mexican dieldrin project mentioned at the beginning of this paper. The over-all results indicate that dieldrin has a satisfactory persistence on sorptive mud surface under field conditions existing in these areas. As the phenomenon of sorption can be demonstrated in wall exposure tests in the dry season, the logical conclusion is that, although sorption actually occurs, it does not seem to be a major problem interfering with mosquito control in these areas. As outlined above, a sufficiently long contact period and adequate average humidity are the factors most likely to be responsible for the satisfactory performance of dieldrin on sorptive mud.

It must be mentioned that this does not imply that sorption could not possibly be a problem of importance under less favourable conditions. For instance, it seems conceivable to assume that in areas where the presence of sorptive mud is coupled with long periods of low humidity inside the huts, insecticide sorption could well become a major factor affecting the persistence of dieldrin. However, so far there is no experimental evidence that this combination of factors exists in any particular area, but this does certainly not rule out the potential hazard of insecticide sorption, and no doubt this matter is worthy of further investigation.

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RÉSUMÉ

Les expériences faites sur le terrain en vue de diminuer les effets de la sorption, en ajoutant à l'insecticide un adjuvant protecteur, la gilsonite en particulier, n'ont pas confirmé les résultats obtenus en laboratoire. Les différences étaient si importantes qu'une étude de leurs causes a été entreprise à la station d'Arusha (Tanganyika).

L'auteur a utilisé d'autres adjuvants que la gilsonite, et a choisi *A. gambiae* comme moustique d'épreuve. Il a modifié graduellement les conditions du laboratoire pour les rapprocher de celles de la nature (substrat, technique de pulvérisation, conservation des surfaces traitées, temps d'exposition des moustiques, humidité, nature de l'adjuvant). Seules de ces variables, la nature de l'adjuvant et le degré d'humidité relative ont paru influer sur les résultats expérimentaux. Le mélange Aroclor-dieldrine se montra nettement supérieur à la dieldrine seule, mais dans les conditions correspondant à celles de la saison sèche seulement. Lorsque l'humidité est forte, les résultats tendent à être uniformes. C'est aussi ce que l'on a observé dans les huttes de boue séchée: durant toute la saison sèche, l'humidité reste à un niveau assez élevé pour que la dieldrine sorbée reste active, à condition que les moustiques se reposent assez longtemps sur les parois. Aussi les différences entre la dieldrine sans — ou avec — adjuvant, tendent-elles à disparaître lorsqu'on les évalue en fonction de la mortalité des moustiques.

Il semble donc que le phénomène de sorption, tout réel qu'il soit dans la nature comme au laboratoire, ne soit pas assez important pour affecter les résultats des campagnes de lutte antipaludique. Il faut cependant réserver le cas des régions où de longues périodes de sécheresse abaisseraient sensiblement le degré d'humidité des parois des huttes. Cette possibilité reste à prouver.

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