A FIELD EVALUATION OF PERMETHRIN (OMS 1821) AND NRDC 161 (OMS 1998) FOR RESIDUAL CONTROL OF MOSQUITOES

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ABSTRACT. Permethrin (125 mg m^{-2}) and fenitrothion (2000 mg m^{-2}) as wettable powders and NRDC 161 (15 mg^{-2}) as an emulsifiable concentrate or suspension concentrate were applied as deposits on interior surfaces of houses in a village in Kenya to control endophilic mosquitoes. Mosquito populations and behavior were assessed using pyrethrum spray counts, exit traps, human bait catches and light traps.

Permethrin and NRDC 161 formulations reduced the number of anopheline mosquitoes resting in houses. The reduction was at least as effective as in fenitrothion-treated houses over the 24 wk post-treatment assessment period. The results bear out previous work that indicates that reduction in pyrethroid treated houses is at least partly a repellent effect.

Residual sprays of permethrin and NRDC 161 also reduced biting in houses by *Mansonia* spp.

INTRODUCTION

The development of light stable pyrethroid insecticides has provided alternatives to persistent organochlorine compounds, once used widely to control mosquito vectors of human disease but now being phased out because of possible environmental pollution and insecticide resistance. Available pyrethroids possess the general properties of the group of high insecticidal activity, low mammalian toxicity and rapid decomposition in biotic environments (Elliott et al. 1978). Thus those which are light stable and remain active on biologically inert surfaces are candidates for use as surface treatments inside buildings for the control of malaria mosquitoes. Barlow et al. (1977) assessed several such compounds in laboratory tests and concluded that those examined including permethrin (OMS 1821) and NRDC 161* (OMS 1998), might be valuable in malaria control programs if suitable formulations were devised.

Both permethrin and NRDC 161 have been examined under field conditions in the WHO program for the evaluation and testing of new insecticides (Wright 1971). Permethrin was studied in a Stage IV evaluation by application of a 25% wettable powder (WP) formulation to experimental huts at 500 mg m^{-2} active ingredient (AI).

Although the deposit had good residual effectiveness on wood and thatch, superior to fenitrothion (OMS 43) WP applied at 2000 mg m^{-2} AI, it was irritating to mosquitoes causing them to leave houses before picking up a lethal dose (Coosemans and Sales 1977). In the same study NRDC 161 WP applied at 25 mg m^{-2} AI also persisted satisfactorily on mud, thatch, and wood surfaces but again was irritating to mosquitoes, although a larger proportion of those leaving eventually died. Attempts to decrease the repellent effect by increasing the NRDC 161 deposit to 50 and 100 mg m^{-2} AI (Coosemans and Sales 1978) or 125 mg m^{-2} AI (Rishikesh et al. 1978b) had only limited success.

Rishikesh et al. (1978a) evaluated permethrin WP (500 mg m^{-2} AI) and NRDC 161 WP (50 mg m^{-2} AI) in whole village treatments involving 2 spray rounds (WHO Stage V). Both insecticides showed a satisfactory reduction on *Anopheles gambiae* s.l. and *An. funestus* Giles hut resting densities during the 12 week assessment period after each spray round, but there was again evidence of irritability, particularly by permethrin, causing exodus of mosquitoes. However in an extended Stage V trial involving 23 villages, 2 applications of NRDC 161 WP (50 mg m^{-2}AI) at a 3-month interval provided effective residual control (Rishikesh et al. 1979). Despite confirmed exodus of mosquitoes from treated houses the overall effect was sufficient to reduce satisfactorily *An. gambiae* and *An. funestus* indoor resting, exit trap, and biting densities and to eliminate infective mosquitoes.

Overall these studies indicated a distinct potential for NRDC 161 in vector mosquito control, but the future use of permethrin was less clear. The apparent irritancy to mosquitoes by permethrin prevented its continued evaluation by WHO, but measurement of behavioral effects of insecticides in practice is often difficult and may be open to interpretation. Consequently repeated observation at different locations and under different circumstances may be useful, as well as consideration of alternative or modified techniques. Furthermore, the deposit levels of permethrin and NRDC 161 used so far, although less than those of established organophosphorus or organochlorine insecticides, are high compared with deposits used to provide residual control of other insect species (Carter and Chadwick 1978, Lhoste and Piedallu 1977) or when the high intrinsic insecticidal activity of pyrethroids is considered (Anonymous 1979, Elliott et al. 1978). Finally, different formulations may alter sub-lethal effects of an insecticide. This report gives details of a comparative trial with deposits of permethrin, NRDC 161 and fenitrothion applied to internal surfaces of houses to control endophilic mosquitoes.

MATERIALS AND METHODS

TRIAL SITE AND INSECTICIDE APPLICATION. The trial was carried out between June and December, 1979, in Village I on

* The proposed common name of NRDC 161 is Deltamethrin. It has formerly been designated Decamethrin.

the West Kano Irrigation Scheme, located approximately 20 km east of Kisumu, in Nyanza province, Kenya. Houses were built to a standard design consisting of a wooden frame with mud filled walls and metal roofs. Each house, approximately 6.5 × 5.5 × 2 m, was divided internally into 4 sections used as a cooking area, living room, main bedroom and second bedroom or store. In some the walls did not touch the roof creating a space of approximately 20 to 30 cm, but in others they were built up further leaving no space or only a narrow gap. Windows and doors, which were wooden and generally tight fitting, were closed at night.

Details of the insecticides and application rates are given in Table 1.

The village contained 81 houses systematically arranged in rows and files. Experimental houses were selected in a stratified random manner (Snedecor and Cochran 1973) from those in which at least 3 people slept. Each insecticide treatment was applied to 6 houses and a further 7 were used as untreated controls. After mixing with water, insecticides were applied with manual compression sprayers (GLORIA models 2001 and 172 fitted with standard nozzles). Externally only eaves were treated, but insecticide was applied to all internal surfaces. Furniture, picture frames, mirrors and other possessions were removed so that building surfaces could be thoroughly treated. A mean of 10 liters of diluted insecticide was applied over a surface area of approximately 200 m^{-2} in each house.

POPULATION ASSESSMENT—PYRETHRUM SPRAY COUNT. The daytime resting mosquito density was assessed using a modification of the standard pyrethrum spray count (Service 1976). Counts were made between 08.00 and 10.00 hr in selected houses. Seven pieces of calico sheeting each 1 m^2 were laid on the floor so that approximately 20% of the floor area was covered. Sheets were placed with 1 edge against the wall; 3 were always in the main bedroom and the remainder in the living room and second bedroom/store.

All windows and doors were closed and 1 operator sprayed an aerosol containing synergized pyrethrins (0.4% pyrethrins/1.0% piperonyl butoxide) inwards through the eaves, whilst a 2nd operator sprayed inside. After 10 min, all mosquitoes found on the sheets or between the sheet edge and the wall were collected and later identified. Female *An. gambiae* and *An. funestus* were separated into different physiological states by observation of external abdominal appearance (WHO 1975), the classification used being unfed, fed, and gravid. It was not possible to classify females from all assessments because trained personnel were not always available.

A minimum of 6 days elapsed before the next assessment in the same house. Counts were made weekly during the first month after insecticide application then

Table 1. Insecticides and application rates.

Insecticide	Supplier	Quantity of formulated insecticide added to 5 liters water	Target deposit levels (mg m^{-2} AI)
Permethrin (Coopex) wettable powder WP 250g kg^{-1} AI	Wellcome Foundation Ltd.	50 g	125
NRDC 161 emulsifiable concentrate (EC) 25 gl^{-1} AI	Roussel-Uclaf S. A.	60 ml	15
NRDC 161 suspension concentrate (SC) 200 gl^{-1} AI	Wellcome Foundation Ltd.	7.5 ml	15
Fenitrothion wettable powder WP 400 g kg^{-1} AI	Sumitomo Chemical Company	500 g	2,000

each fortnight until week 10 when weekly counts were resumed. Monthly counts were made between weeks 12 and 24.

LIGHT TRAPS. Light traps were used to obtain information on the range of mosquito species entering houses at night. Modified CDC light traps were hung at a height of approximately 2 m in the living room of untreated houses or before insecticide treatments had been carried out. Catches were made between 18.30 hr and 07.00 hr.

EXIT TRAPS. Verandah type exit traps (WHO 1975) were erected alongside treated and control houses to assess the number of mosquitoes leaving. Each consisted of a wooden frame 2 m wide and approximately 2.5 m high, sunk into the ground about 1 m from a vertical wall. The frame, which was higher than the roof edge, was covered with mosquito netting, and the netting was attached to the roof and walls of the house and secured at ground level so that mosquitoes could not escape. Traps were sited on the open-eaved wall of an occupied bedroom and, where possible, covered a window on the eastern side. The open eaves of the bedroom on either side of the trap were roughly closed with further sheeting to maximize the catch, but eaves of the opposing walls were left open. Traps were moved from one house to another every 24 or 48 hrs. They were set up at 18.00 hr, and then at 08.00 hr the following morning trapped mosquitoes were collected with suction tubes for later identification.

BAIT CATCHES. Human bait catches were made to evaluate the effect of different insecticide treatments on mosquito biting behavior. Catches were made over 4 nights in weeks 11 and 12 between 22.00 hr and 01.00 hr in 4 selected, open eaved houses. One house was untreated and the others treated with permethrin WP, NRDC 161 suspension concentrate (SC), or fenitrothion WP. Eight operators worked in pairs. To eliminate possible bias caused by differences in individual attractiveness to mosquitoes each pair spent 1 night in each house.

To make catches, operators sat opposite each other in the living room with legs bared. As mosquitoes settled to bite they were caught in suction tubes and kept for identification.

RESULTS

PYRETHRUM SPRAY COUNTS. Results of post-treatment pyrethrum spray counts are given in Tables 2 and 3. As only few *An. funestus* were found in treated houses, figures for *An. gambiae* and *An. funestus* females were summed to calculate the mean resting counts shown in Table 2. The number of replicates for each treatment varied since it was not always possible to visit every house, either because entry was restricted or there were insufficient operators or time. However, no less than 3 replicates were used to obtain the mean count for a treatment in any one week. The mean resting counts in untreated houses varied almost ten-fold (3.8 to 33.5) over the post-treatment period, higher counts being recorded later in the trial. The degree of control, expressed as the percentage reduction from the mean resting count in untreated houses, was calculated for each insecticide at each post-treatment assessment.

All insecticide treatments reduced the number of resting mosquitoes. Both NRDC 161 formulations were 100% effective initially. The emulsifiable concentrate (EC) reduced the mean resting count from levels found in untreated houses by 85% or more until the last assessment 6 months after treatment, and control with the SC never fell below 85%. Permethrin WP also provided control of 85% or better until week 20 although the initial effect was slightly less than for NRDC 161 treatments. During the first 8 weeks after treatment fenitrothion WP was as effective as the pyrethroids, but only incomplete control (55 to 73% reduction) was obtained in weeks 10 to 12 although reduction in the number of resting mosquitoes improved in subsequent counts.

An analysis of all *An. gambiae* and *An.*

funestus caught in pyrethrum spray counts is given in Table 3. Where females were classified by their physiological state, the number in each group is also expressed as a percentage of those classified. However, in calculating the overall total in each treatment group and the relative proportion of each sex, all females including those not classified physiologically have been taken into account.

More *An. gambiae* (973) than *An. funestus* (263) were found in untreated houses. There was little difference between the 2 species in the proportion of females in each physiological class, but a greater proportion of *An. gambiae* males were

Table 2. Mean resting counts of *An. gambiae* and *An. funestus* in houses assessed by pyrethrum sprays.

			Insecticide			
		Untreated	Permethrin WP 125 mg m^{-2}	NRDC 161 EC 15 mg m^{-2}	NRDC 161 SC 15 mg m^{-2}	Fenitrothion WP 2000 mg m^{-2}
Weeks After Treatment 1	Number of houses	7	5	4	5	4
	Mean number of females* per count	5.6	0.4(93)	0(100)	0(100)	0(100)
2	Number of houses	6	6	6	6	6
	Mean number of females per count	6.0	0.8(87)	0(100)	0(100)	0.3(95)
3	Number of houses	6	5	4	5	5
	Mean number of females per count	3.8	0.2(95)	0.25(93)	0(100)	0.4(89)
4	Number of houses	4	4	4	4	4
	Mean number of females per count	12.3	0.3(98)	0.5(96)	0.5(96)	0.5(96)
6	Number of houses	6	5	3	4	4
	Mean number of females per count	10.0	1.2(88)	0.2(98)	0.5(95)	0.8(92)
8	Number of houses	6	5	5	5	5
	Mean number of females per count	6.8	0(100)	0.4(94)	0.2(97)	1.0(85)
10	Number of houses	6	5	5	5	6
	Mean number of females per count	15.0	1.8(88)	1.2(92)	1.4(91)	6.7(55)
11	Number of houses	6	5	5	5	5
	Mean number of females per count	30.8	2.6(92)	0.8(97)	2.0(94)	8.4(73)
12	Number of houses	4	4	4	4	4
	Mean number of females per count	33.5	4.8(86)	1.8(95)	4.5(87)	9.5(72)
16	Number of houses	4	3	3	4	3
	Mean number of females per count	26.0	0.6(98)	2.0(92)	0(100)	4.3(83)
20	Number of houses	4	3	5	4	4
	Mean number of females per count	23.0	5.3(77)	1.8(92)	0.5(98)	2.3(90)
24	Number of houses	4	3	5	4	4
	Mean number of females per count	10.0	1.0(90)	2.0(80)	0.8(92)	1.5(85)

* *Anopheles gambiae* and *funestus*.
() % reduction from mean resting count in untreated houses.

Table 3. Analysis of anopheline mosquitoes caught in pyrethrum spray counts.

Treatment	Species	Females				Totals		
		Unfed	Fed	Gravid	Unclassified	Females	Males	All
No treatment	*An. gambiae*	116	319	22	197	654	319	973
		25.4*	69.8*	4.8*	—	67.2†	32.8†	100
	An. funestus	26	51	16	112	205	58	263
		28.0	54.8	17.2	—	77.9	22.1	100
	Both species	142	370	38	309	859	377	1236
		25.8	67.3	6.9	—	69.5	30.5	100
Permethrin WP	Both species	22	25	0	30	77	20	97
125 mg m^{-2}		46.8	53.2	0	—	79.4	20.6	100
NRDC 161 EC	Both species	5	10	1	29	45	48	93
15 mg m^{-2}		31.2	62.5	6.2	—	48.4	51.6	100
NRDC 161 SC	Both species	10	23	0	12	45	14	59
15 mg m^{-2}		30.3	69.7	0	—	76.3	23.7	100
Fenitrothion WP	Both species	32	57	16	62	167	80	247
2000 mg m^{-2}		30.5	54.3	15.2	—	67.6	32.4	100

* percentage of classified females only.
† percentage of total caught including males and all females.

caught than of *An. funestus*. As only small numbers of mosquitoes were found in treated houses, particularly where pyrethroids were used, counts for both anopheline species were summed. Overall, there was no consistent difference between results for untreated or treated houses with respect to the contribution of each class of the population. There were, however, differences between individual treatments; a comparatively high proportion of unfed females were found in permethrin WP treated houses, only a single gravid female was recovered from all pyrethroid treated houses compared with 16 out of 105 from fenitrothion treated houses and an unusually high proportion of males occurred in those houses where NRDC 161 EC had been used.

LIGHT TRAPS. Results with light traps placed in houses during the week before insecticide treatment and in untreated houses in the 3 immediate post-treatment weeks are shown in Table 4. Anopheline mosquitoes were separated from the

Table 4. Results of light trap catches in untreated houses.

Species	Pre-treatment (14 trap nights)		Post-treatment weeks 1, 2 & 3 (16 trap nights)	
	Number	Percentage of total catch	Number	Percentage of total catch
Anopheles gambiae	84	4.1	84	2.0
An. funestus	59	2.9	29	0.7
An. pharoensis Theobald	4	0.2	7	0.2
An. ziemanni Grünberg	69	3.4	112	2.7
Mansonia uniformis	1486	72.1	3556	84.6
Ma. africana	172	8.3	263	6.3
Other culicines	187	9.1	154	3.7
Total	2061	100	4205	100

catch and identified, as were the other important man-biting species *Mansonia uniformis* Theobald and *Ma. africana* Theobald. Other culicines, which commonly included *Culex quinquefasciatus* Say, *Cx. antennatus* Becker and *Cx. univittatus* Theobald, and small numbers of *Aedes* and *Coquillettidia* spp. were grouped together as they were considered of minor importance to the trial.

A large proportion of both pre and post-treatment catches consisted of *Mansonia* spp. The malaria vectors *An. gambiae* and *An. funestus* dropped from 4.1 to 2.0% and 2.9 to 0.7% of the catch respectively after application of the insecticides, probably because of increased total numbers of culicines in the catch.

EXIT TRAPS. Results with verandah traps used between post-treatment weeks 1 to 4 (including traps on houses of all treatments) and weeks 11 and 12 (excluding houses treated with NRDC 161 EC) are shown in Table 5. Numbers of mosquitoes caught each night varied but were usually small even in nets erected alongside untreated houses. Only 7 *An. funestus* females were caught in all houses over the entire period so results for *An. gambiae* and *An. funestus* were combined. More anopheline females were caught in weeks 11 and 12 than in 1 to 4, again indicating an increased population. Occasional catches were large, 32 female *An. gambiae* being caught in a single net in one instance.

Data for anopheline females caught in nets over the first 4 weeks resembled a Poisson distribution for each treatment regimen. Statistical tests were carried out on various combinations of regimens to determine if any could be grouped (Snedecor and Cochran 1973), but none appeared feasible. In the first few weeks more mosquitoes were caught in nets on permethrin-treated houses than in those on untreated houses, but this was reversed in weeks 11 and 12. Fewer mosquitoes left houses treated with fenitrothion WP than NRDC 161 SC, but no anophelines were caught in traps on NRDC 161 EC treated houses. There was no change in the proportion of female *An. gambiae* in different physiological states caught before or after insecticide application.

The distribution of culicine mosquitoes caught in traps did not fit either a Poisson or negative binomial distribution. Mean results for *Mansonia* spp. showed larger numbers in nets from untreated than from treated houses. The sequence for treated houses again varied between different assessment periods; in weeks 1 to 4 largest numbers were found in fenitrothion WP treated houses, then permethrin WP, NRDC 161 SC and NRDC 161 EC, but in weeks 11 to 12 there was little difference between treatments. In the case of other culicine species, consisting mostly of *Cx. quinquefasciatus* or *Cx. antennatus* slightly more insects were found on the average in nets attached to permethrin WP treated houses than in untreated controls.

HUMAN BAIT CATCHES. Of the anopheline mosquitoes captured using human baits, only *An. gambiae* occurred in substantial numbers (Table 6). Although the mean biting rates of *An. gambiae* in insecticide treated houses were about half that for the untreated control, numbers varied widely over the 4 collection nights, and a non-parametric test on ranked data (Kruskal-Wallis test in Siegel 1956) indicated there was no significant difference between biting rates of anopheline mosquitoes in insecticide treated or control houses.

High indoor biting rates were found from *Mansonia* spp., but insecticide treatments clearly affected results. Biting rates in houses which had been treated with permethrin WP or NRDC 161 SC were substantially and statistically significantly lower than untreated or fenitrothion WP treated houses. There were no significant differences between biting rates in fenitrothion WP and control houses or between permethrin WP and NRDC 161 SC houses.

Table 5. Summary of exit trap results.

Insecticide		No treatment	Permethrin WP 125mg m^{-2}	NRDC 161 EC 15mg m^{-2}	NRDC 161 SC 15mg m^{-2}	Fenitrothion WP 2000mg m^{-2}
Number of replicates	Weeks 1 to 4	15	12	10	16	17
	Weeks 11 & 12	6	6	0	5	5
Mean number of females caught each night	Weeks 1 to 4	0.9	1.2	0	0.4	0.2
	Weeks 11 & 12	6.7	4.0	—	2.2	1.0
Anopheles spp.						
Total number females caught	Unfed	63	31	0	18	7
	fed	10	4	0	4	0
	gravid	9	3	0	0	1
	males	24	12	0	10	3
Mansonia spp.						
Mean number of females caught each night	Weeks 1 to 4	3.5	1.8	0.8	1.3	2.8
	Weeks 11 & 12	6.8	1.2	—	0.6	0.8
Total number caught		94	29	8	23	52
Other culicines						
Mean number of females caught each night	Weeks 1 to 4	2.2	2.5	0.4	1.6	0.5
Weeks	11 & 12	0	0	—	0	0
Total number caught		33	30	4	25	9

—means No counts made.

Table 6. Results of bait catches.

Insecticide Treatment	Mean biting rate (number of mosquitoes alighting per team per night) over a four night period						
	Anophelines				Culicines		
	An. gambiae	*An. funestus*	*An. pharoensis*	*An. ziemanni*	*Ma. uniformis*	*Ma. africana*	*Cx. antennatus*
No treatment	19.3	0	0.5	2.3	117.8	38.5	0.8
Permethrin WP 125 mg m^{-2}	10.5	0	0	0	2.8	1.3	0.3
NRDC 161 SC 15 mg m^{-2}	10.8	0	0	0.5	8.8	2.0	0
Fenitrothion WP 2000 mg m^{-2}	11.3	0.3	0.3	0.8	56.0	20.5	0.3

DISCUSSION

The concept of indoor residual application of insecticides as a measure against malaria is well established. It depends on the behavior of females of some of the major vector species which settle on treated surfaces and pick up a lethal dose of insecticide when they enter human dwellings to obtain blood meals or find shelter. To prevent transmission of malaria, a treatment must cover a sufficient area to reduce significantly the vector population. Not every new candidate insecticide can be evaluated in a full scale program to determine its impact on disease transmission, although this is the final test. Hence it is necessary to examine the performance of a new chemical on a wild mosquito population by assessing its impact on the survival and behavior of mosquitoes entering treated houses. Specially designed experimental huts may be used to determine inward and outward movement of mosquitoes and to estimate the population killed inside the hut or after leaving (Service 1976). Such huts were used by Coosemans and Sales (1977, 1978) in their WHO Stage IV evaluation of permethrin and NRDC 161. An alternative approach used here was aimed at comparing effects of different insecticides on mosquitoes in occupied houses under normal conditions of use.

By treating only a small proportion of houses there was no overall impact on the local *An. gambiae* and *An. funestus* populations, so that treated and untreated houses were subject to a similar challenge. This is borne out by the results of human bait catches which indicated no difference in the number of anophelines entering untreated or treated houses. It may also be concluded from this that none of the treatments altered the entry behavior of anophelines despite possible contact with the insecticide when moving through the eaves, the usual place of mosquito entry in this locality (Hill and Highton, unpublished results). This contrasts with Coosemans and Sales (1977) finding of fewer mosquitoes in treated houses, NRDC 161 WP being most repellent to *An. gambiae* followed by fenitrothion WP than permethrin WP.

All insecticides and formulations clearly affected mosquitoes settling in the houses as they reduced anopheline house resting densities over a 24-week period. Fenitrothion WP applied at 2000 mg m^{-2} AI is known to be highly effective throughout a 12-week post-treatment period (Fontaine 1978). Here, it showed signs of becoming less effective after 12 weeks but did not fail completely, and provided improved control in later weeks. Previously the long residual effect of pyrethroids has only been shown at higher application rates (permethrin 500 mg m^{-2} AI and NRDC 161 25 to 125 mg m^{-2}AI) using WP formulations. This trial demonstrates that lower, more economical deposit rates have a persistent biological effect, and that NRDC 161 in formulations other than a wettable powder has an excellent residual activity. Both NRDC 161 formulations lasted equally well and compared favourably with permethrin and fenitrothion wettable powders.

Compared with previous results the persistence of fenitrothion here was better than expected (Fontaine 1978, Jurjevskis and Stiles 1979). Consequently the residual effect of pyrethroids may not be equally prolonged under different conditions.

For example, building materials vary and may alter the degree of control achieved. Traditional houses with thatched roofs probably support higher anopheline resting densities than those where metal is used, as thick thatch provides suitable day time resting sites whereas metal becomes too hot in the sun. In addition persistence of insecticides differs on various surfaces, non-porous biologically inert substrates such as metal providing more favorable conditions than mud, thatch, wood or leaves. Nevertheless the deposits used in this trial were always exposed to moderately high anopheline populations as measured by house resting densities. The population fluctuated, probably because of changes in breeding caused by irrigation practices in adjacent rice paddies and sugar stands rather than general climate (Chandler et al. 1975, Hill et al. 1978), but higher densities occurred later in the trial providing greater challenge when insecticide deposits were not fresh. Furthermore, insecticides were subjected to normal conditions of soot deposition and abrasion from walls by contact with occupants and their animals.

It is important to consider the precise influence of each insecticide on survival and behavior of anophelines after they have entered treated houses. In this trial it was not feasible to recover mosquitoes killed inside houses or those that were caught in exit traps and died after leaving, nor was it possible to obtain reliable data on survival of trapped mosquitoes. Earlier studies have shown that permethrin WP (500 mg m^{-2}AI) killed only 15% of all *An. gambiae* entering and leaving experimental huts over a 5 month period whereas NRDC 161 (25 mg m^{-2}AI) killed 23% and fenitrothion (2000 mg m^{-2} AI) 81% (Coosemans and Sales 1977). Similar figures for *An. funestus* were 15, 14 and 59%. In the same study a considerably higher proportion of the total number of anophelines recovered from pyrethroid treated houses were caught in exit traps compared to untreated houses, but only small numbers left fenitrothion treated houses. The findings of this trial, like those of Rishikesh et al. (1978a), may be interpreted from Coosemans and Sales' (1977) conclusion that the pyrethroids irritate mosquitoes causing them to leave treated houses without picking up a lethal dose. Although the same number of mosquitoes entered all houses (bait catch results), far fewer remained in treated houses (pyrethrum spray results); but about the same number left untreated and permethrin treated houses; and fewer left NRDC 161 SC than fenitrothion treated houses (exit trap results).

Exceptionally low exit trap counts with

NRDC 161 EC were obtained early in the trial during a period of very low population and are probably anomalous. It is possible, therefore, that increased exodus of mosquitoes is largely responsible for low house resting densities in permethrin treated houses, mortality is the main component for reduction by the fenitrothion treatment, but both contribute to the action of NRDC 161. This is supported by the observation that comparatively large proportions of unfed females were found in permethrin treated houses and of gravid females in fenitrothion treated houses. These differences suggest that more females in permethrin treated houses are recent arrivals so that proportionally fewer remain but, in contrast, more of those females that survive in fenitrothion houses stay there. It is of note that the WHO extended Stage V trials with NRDC 161 applied at 50 mg m^{-2}AI proved successful in reducing anopheline resting, exit trap and biting densities, but at this dose survival of mosquitoes was high (Rishikesh et al. 1979).

The influence of pyrethroid insecticide treatments on culicine populations, particularly *Mansonia* spp. differs from that on anophelines. Considerably fewer *Mansonia* spp. were found in human bait catches, thus either the insecticide prevented mosquitoes biting or inhibited their entry. The latter is more probable as bait catch operators observed fewer mosquitoes in treated houses and reduced entry of *Mansonia* spp. into permethrin treated houses has been observed before (Coosemans and Sales 1977). Results with exit traps show a tendency, although weak, for more culicines generally to leave permethrin treated houses than those where other insecticides were applied.

To conclude, this trial showed that low deposits of permethrin WP (125 mg m^{-2} AI) and EC and SC formulations of NRDC 161 (15 mg m^{-2}AI) on mud walls of houses substantially reduce the house resting densities of anopheline mosquitoes over a 24 week period as effectively as fenitrothion WP (2000 mg m^{-2} AI). The results bear out previous work which indicates that reduction of mosquitoes in pyrethroid treated houses results, at least partly, from a repellent effect which causes mosquitoes to leave treated surfaces.

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