AN EVALUATION OF THE RESIDUAL LIFESPAN OF DDT IN MALARIA CONTROL

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ABSTRACT. The insecticide lifespan of DDT was assessed in huts sprayed for malaria control. The age of the spray deposits ranged from 3 up to 22 months. Blood-fed female *Anopheles arabiensis* were either released into the huts or exposed on sprayed surfaces by a bioassay technique. Mosquitoes released were recovered in exit traps fitted on windows or dead on the floor. Only 50% or less of mosquitoes released in sprayed huts were recovered. Mortality figures for recovered mosquitoes ranged from 94% at 3 months, declining to 19% for huts sprayed 18 months previously. Of the recovered mosquitoes, 60% or more attempted to escape from sprayed huts within two hours postrelease up to 15 months postspray. Bioassays gave average mortalities of 95 and 76% on thatch and mud walls, respectively. Analysis of mud samples from test huts showed that target dose of 2 g AI/ m^2 of DDT was not being achieved. The results support the need for an annual spraying cycle.

INTRODUCTION

The discovery in the early 1940s, that DDT was a very effective insecticide for the control of insects of public health importance, prompted the World Health Organization (WHO) to embark on a global Malaria Eradication Programme in 1955 (Bruce-Chwatt 1980). Malaria eradication was achieved in some parts of the world although some countries registered limited success and others none at all (Bruce-Chwatt 1980, Chapin and Wasserstrom 1983).

The problem of vector resistance and in some cases malaria control program mismanagement had not been envisaged as constraints to eradication. Resistance to DDT by malaria vectors is now very widespread (World Health Organization 1980, Brown 1986) and only a few countries can afford the more expensive alternatives such as the organophosphates, synthetic pyrethroids and carbamates. The WHO still advocates the use of DDT for malaria vector control in areas where vector resistance has not yet emerged (Pant and Fontaine 1983).

Malaria control in Zimbabwe commenced in the late forties and was of limited scope, only responding to epidemics. The program has since been expanded and decentralized and covers most of the known malarious areas of the country (Taylor and Mutambu 1986, Crees and Mhlanga 1985). DDT has been used in Zimbabwe since 1972, replacing hexachlorocyclohexane, to which vectors had developed resistance.

The current malaria control program has an annual budget in excess of Z$2.5 million (approximately US$1.5 million). The insecticide is targeted onto the inside surfaces of dwelling huts, the roof thatch and eaves following set recommendations, to achieve a target of 2 g AI/ m^2.

It is known that the residual life span and efficacy of most insecticides is affected by the chemical nature of the sprayed surface. Mud surfaces containing iron oxides rapidly inactivate DDT spray deposits (Bordas et al. 1953). There is also a direct attrition of insecticide from sprayed human dwellings due to constant occupancy and rubbing off from the walls. As such, it may be folly to rely on data collected utilizing experimental huts to estimate the effective life span of insecticides as used in life situations. Taylor et al. (1981), using experimental huts, estimated DDT residual activity in killing vector mosquitoes to be 24 months. Further studies were carried out to investigate the duration of vector control by DDT in indigenous, occupied huts, to determine a suitable malaria control spraying cycle. Studies commenced in August 1981 and were completed in mid-1984.

MATERIALS AND METHODS

Study areas. Using the annual returns for the National Malaria Control Program, areas were selected, ranging from 3 up to 22 months postspray. The criteria of easy access and proximity were also taken into consideration in choosing study locations. A mobile entomology unit would visit the selected area and select at random a number of test huts. Visual checks for DDT spray deposits were made. The owner(s) consent to spare these huts for the duration of the study was sought. The unit would also identify one unsprayed hut (control) within the community. Such a hut would normally have been constructed after the spraying teams had covered the particular areas or may have been missed out due to owner's absence. Selected huts were cleared of all belongings.

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Traps and doors. Exit traps of the "lobster pot" design were secured over windows of the houses under test. The original doors of the huts were removed and replaced with retractable door frames (Fig. 1). These door passages were then sealed with a black calico sheet attached with pins along the frame's perimeter. The replacement door frames were designed to have a holder for a door exit trap (Fig. 1).

All eaves and crevices on the walls were effectively plugged with cotton waste to avoid mosquito escape. Thus mosquitoes released into the hut would escape only through the window or door exit traps, where they would be retained. The floor of each of the test huts was cleaned and carefully lined with clean, white calico sheets to facilitate the easy detection of any dead or moribund mosquitoes.

Mosquito releases and recordings. Two methods were used. The first method involved the release of known numbers of blood fed, 3–5 day old female *Anopheles arabiensis* Patton. These were derived from a colony strain (KANB) that originated from Kanyemba, Zimbabwe (15° 40′S, 30° 20′E). This strain is known to be susceptible to DDT at the diagnostic dosage of 4% (unpublished data) using the standard method (World Health Organization 1976).

The blood-fed female mosquitoes held in a small cage were released at 1700 hr into the test and control huts. All exit traps were checked at 1900 hr on the evening of release. On subsequent days, checks were made at 0700 and 1900 hr and all live and dead mosquites recorded. Each morning following releases, the calico-covered floor of each hut was searched for any dead mosquitoes, paying particular attention to the junction of the calico sheets and the walls where disoriented mosquitoes often accumulate.

Mosquitoes recovered from the traps, were recorded. Live mosquitoes were held for 24 hours under reasonably humid and warm field conditions with access to 5% sucrose solution. Final mortalities were then recorded.

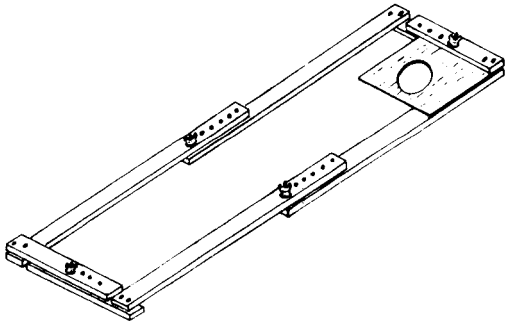

Fig. 1. Retractable doorframe with exit trap.

The second method employed a bioassay technique. Five mosquitoes of similar condition as above were introduced into a petri dish (8.5 cm internal diameter and 1 cm deep) affixed to the internal wall or roof. Three petri dishes were attached to the walls and another three to the roof thatch about 30 cm above the eaves of each of the test huts. The exposure period was in most cases 3 hours duration.

In one instance exposure was made for 1, 2, and 3 hour durations to assess the effect of exposure time on overall mosquito mortality. Hut temperatures during the bioassays and 24 hour holding period were recorded.

Measurement of residual DDT deposits on walls of huts. Mud samples were scraped from a 10 cm^2 area up to a depth of 2 mm from three randomly selected sites of each of the huts tested. The mud scrapings were placed in polythene bags and properly labeled. These were analyzed for total DDT content.

RESULTS

Release of blood-fed female Anopheles arabiensis *into huts.*

Mosquito recoveries (dead/alive). In Fig. 2 it is shown that in all sprayed huts, 50% or less of total mosquitoes released were recovered. The highest recovery was recorded for the 3 months period. The recoveries declined with each subsequent postspray period. The controls exhibited more or less the same trend as sprayed huts but recoveries were in some cases higher than for the sprayed huts.

Mosquito mortalities amongst recoveries. Mor-

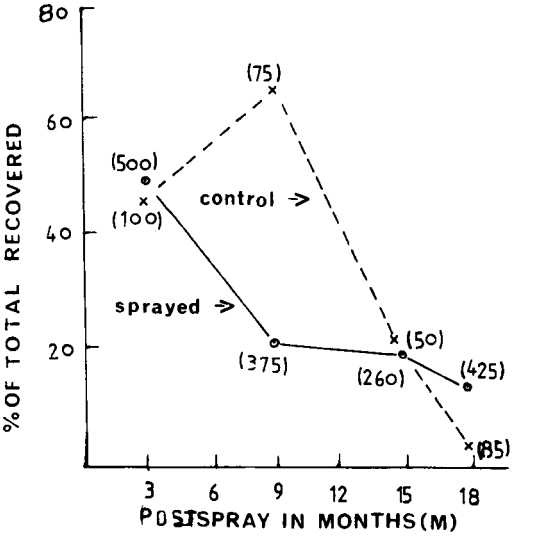

Fig. 2. Mosquito recoveries as percent of totals (×) released.

tality was calculated as a proportion of total number of mosquitoes recovered. It can be shown from Fig. 3 that with progressive age of the spray deposits, fewer mosquitoes were killed. Up to 15 months postspray, over 60% of the recovered mosquitoes died from the DDT exposure. Mortalities after 18 months postspray are comparatively low. The control mortalities are much lower in most cases, with the exception of a high figure (72%) recorded during the 3 months assessment.

Mortalities on hut floor in first 12 hours. Hut floor mortalities during the first 12 hours, for each postspray period are shown in Fig. 4. Mortality declines with increasing postspraying duration. In all instances, the corresponding control values are very low. However, the control mortality recorded for the 3 months period is considered to be very high and cannot be attributed to natural factors.

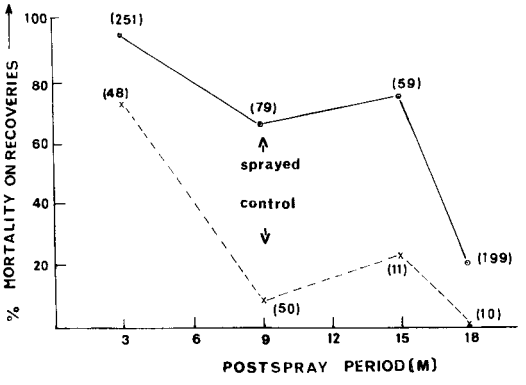

Fig. 3. Mosquito mortalities observed as percent of totals recovered (inclusive of hut floor mortalities and 24 hr holding).

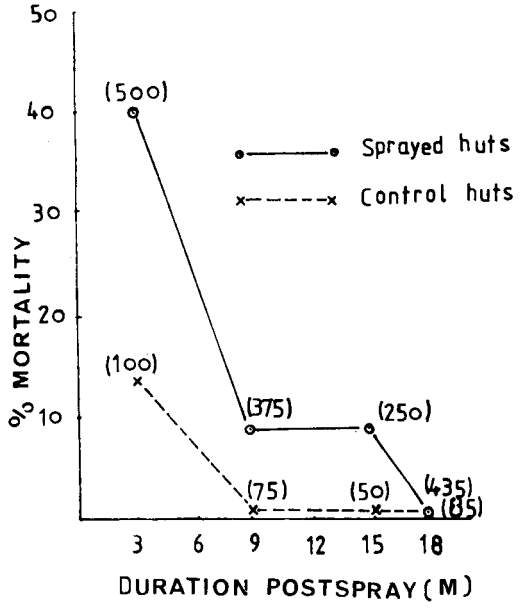

Fig. 4. Hut floor mortalities during first 12 hours postrelease as percent of totals released (×).

Mosquito survival during first 24 hours postrelease. Of the live mosquitoes recovered in this period, those surviving 24 hours holding period increase with increasing duration of postspraying period (Fig. 5). The only exception is the survival rate for 15 months, which is lower than for 9 months. In all instances, survival amongst the controls is always much higher in comparison to sprayed huts. Again the control mortality for 3 months is an exception.

Duration of indoor resting by Anopheles arabiensis. Cumulative captures which were recorded from the window and exit traps for both dead and live mosquitoes are shown in Fig. 6. From the results, it is seen that 60% or more of all the mosquitoes recovered in traps leave the sprayed huts during the first 2 hours of release (i.e., 1900 hr). This holds true for postspraying periods up to 15 months. The 18 months period, recorded only 20% exits over the same period, similar to the control results.

After 12 hours postrelease, i.e., 0700 hr the following morning, 88% or more of the cumulative mosquito recoveries from sprayed huts, have been accounted for, up to 15 months. Comparable exit figures occur in all control huts after 24 hours postrelease. This is also true for 18 months postspray. There were no mosquitoes recovered from the 18 month control hut.

DDT residues in mud scrapings. The determination of the amount of total DDT in mud scrapings is shown in Fig. 7. It can be seen that

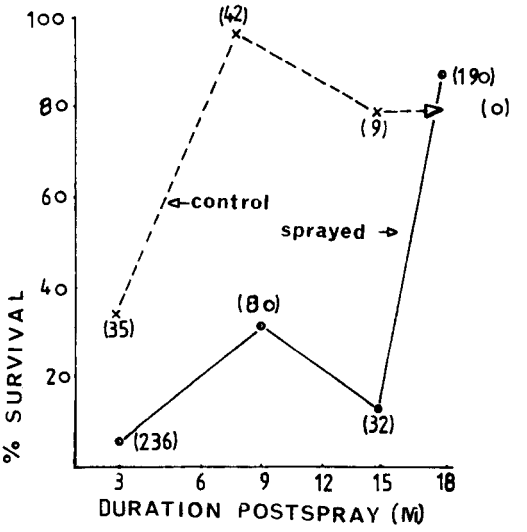

Fig. 5. Mosquito survival (inclusive of 24 hr holding) amongst first 24 hr postrelease escapees.

the results, when plotted alongside mosquito mortality, do not conform to an expected gradual decline in residual insecticidal activity with time. From zero days (samples taken soon after spraying) up to 9 months postspray, the DDT residual levels obtained increased. After 9 months, the DDT residues observed decline. The standard error of the mean for five huts shows the variability in the amounts of DDT assayed. A maximum value of 1.2 g AI/m^2 was calculated for 9 months postspray. From Fig. 7 there is a good correlation whereby observed mosquito mortality decline with subsequent postspray periods. Results for 0 and 3 months probably reflect an underestimate of the amount of DDT present which should have been approximately 2 g AI/m^2. From 9 months onwards there is good agreement between the observed mosquito mortality and DDT levels on the walls.

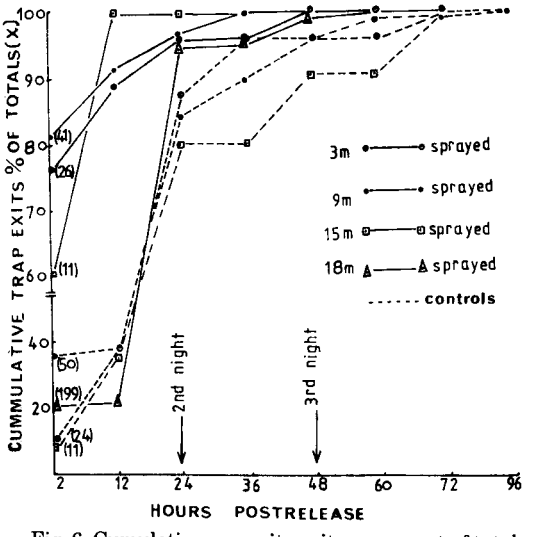

Fig. 6. Cumulative mosquito exits as percent of total trap catches.

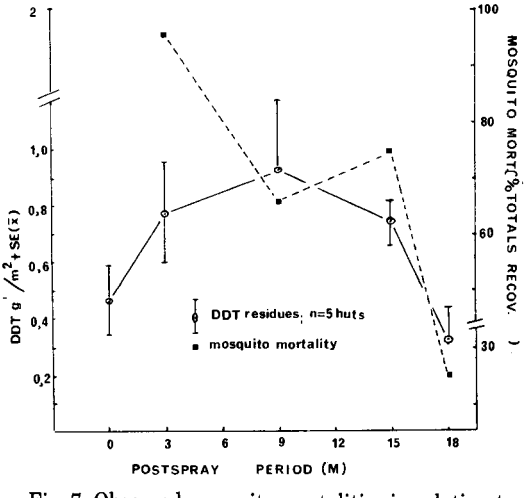

Fig. 7. Observed mosquito mortalities in relation to DDT residues observed in mud scrappings.

RESULTS OF BIOASSAYS

Bioassays on treated hut mud surfaces. The results of these are indicated on Fig. 8. Three month-old deposits showed the highest mosquito mortality rate of 92% which declined subsequently, up to nine months. After the 9 month postspray period, the pattern in overall mortalities follows no clear pattern. A significant departure was observed for 18 months spray deposits with an 80% mortality rate compared with 60% for the 15 month period. It may also be noted from Fig. 8 that, three month old deposits had a very high knockdown effect, with 90% of mosquitoes dead by the third hour of exposure.

Exposure on treated roof thatch surfaces. The trend observed for thatch bioassays was in no way different from that for mud surfaces (Fig. 9) but the variations for the different periods

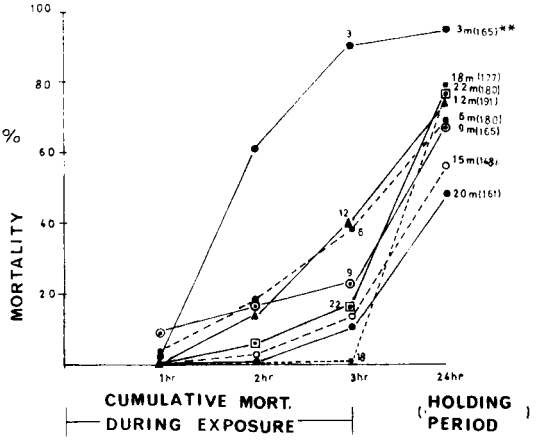

Fig. 8. Bioassay results on mud surfaces (** denotes months (m) postspray and mosquito numbers exposed).

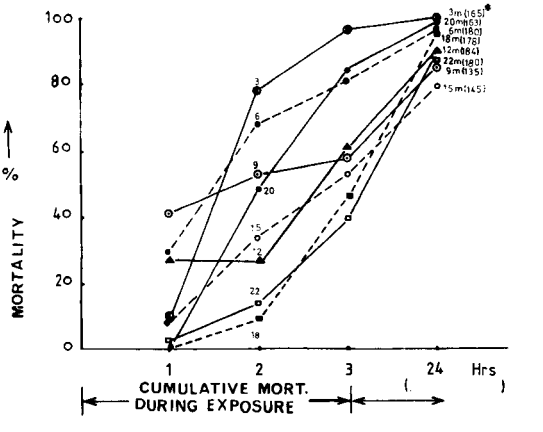

Fig. 9. Bioassay results on thatch (* as in Fig. 8).

Table 1. Bioassay summaries of observed roof and wall mortalities.

Postspray period (months)		3	6	9	11	12	15	18	20	22
Mean 24 hr mortality %	R	100	97	86	100	90	80	95	100	88
Total recovered	W	95	69	66	98	73	55	79	50	75
Ambient temperature of huts degrees C	C	25	23	28	23.5	26.5	24	25	24.5	26
	T	26	23.5	30	21.5	27	24	25	23	26
	H	23	23	25	19	13	13	13	14	17.5

R = roof, W = wall, C = control, T = test, H = 24 hr holding.

Table 2. Relation between period of exposure and 24 hour mosquito mortality (11 months). Fifteen *Anopheles arabiensis* exposed in each group.

Thatch (roof)			Mud (walls)		
Exposure (hr)	Initial mortality (%)	24 hr mortality (%)	Exposure (hr)	Initial mortality (%)	24 hr mortality (%)
1	15	95	1	0	85
2	8	100	2	0	85
3	50	100	3	5	100

are more pronounced here. Table 1 compares the average mortality for mud ($\bar{X}_W$) and thatch ($\bar{X}_R$) bioassays, with the thatch mortalities consistently exceeding the former in all instances. Control mortalities in both assays were nil (total 252).

The thatch bioassays were more difficult to perform than those on the walls. In some cases, mosquitoes irritated and disoriented by the insecticide were penetrating the thatch and becoming lost. Eighty mosquitoes from a pool of 180 were lost this way while testing the 22 month postspray period. Of the 100 that were recovered, 88% died after a 24 hour holding period.

Duration of exposure (bioassays) in relation to final mortality. Table 2 shows the mortalities that were obtained with different exposure times on 11 months old exposure surfaces. From Table 2 it is shown that exposure period has no significant bearing on final mortalities at this postspray period.

DISCUSSION AND CONCLUSIONS

With the widespread apathy towards DDT both as a result of environmental side effects and the emergence of vector resistance, very few studies on the efficacy of this insecticide were done during the 1970s.

The results obtained for the hut release (Fig. 2) indicate high mosquito losses. This was true for both test and control huts. The explanation for this could be scavenging by ants and spiders. Service (1973) was able to prove through precipitin tests the presence of mosquito tissue in some of these predators' gut contents. Taylor et al. (1981) also showed that with progressive age of the insecticide, the frequency of scavengers increased. This is also true here, as evidenced by the good accountability for mosquitoes for the 3 month period compared to subsequent periods. Either the mosquitoes killed by insecticide are picked up on the floor by scavengers or trapped by spider webs in the case of the control huts.

In assessing the effect of the insecticide on mosquitoes released, it was therefore decided to base mortalities only on those accounted for at the end of the releases. Figure 3 amply demonstrates that mortalities decrease with increasing age of spray deposits. The high mortality observed in the control (3 months) indicates possible contamination prior to release since this trend is also observed in Fig. 2. This conclusion is further supported by the low survival rate of escapees from the same control hut (Fig. 5). On the other hand, there is a predictable increase in survivors with time in sprayed huts which is consistent with ageing insecticide deposits. From the results in Fig. 6, it is seen that the bulk of mosquitoes that escape from sprayed huts do so within the first 2 hours of release. However, survival amongst first 24 hour escapees is very low (Fig. 5). This would mean that in nature, a large proportion of vector mosquitoes entering sprayed human habitations, and spending even a minimum of 2 hours are likely to pick up a lethal dose of insecticide. This holds true for up to 15 months postspray when 70% mortality is recorded.

The only worker to have conducted a similar study to the present was Kuhlow in 1962. His major observations were that 24% of *An. gambiae* s.l. survived 24 hour contact with DDT in huts sprayed 3 months previously compared to

our result of 4%. For 4–6 months periods he reported a survival rate of 97% which is even higher than 30% recorded for 9 months in the present study (see Fig. 5). Since we used a sibling species it may be that the data are not comparable to that of previous workers, which makes reference to the species complex. Also, Kuhlow was working with a wild mosquito population and had no exact figures of mosquitoes entering or leaving the huts.

The early exit of mosquitoes in treated huts as compared to the controls could be due to DDT irritability (Cullen and de Zulueta 1962). Comparable numbers of escapees for the controls are recorded on the second night. These mosquitoes would by now be hungry and exit to seek another blood meal. However, Muirhead-Thomson (1951) and Gillies (1954), demonstrated that *An. gambiae* s.l. remained indoors after successful engorgement until fully gravid. Depending on ambient temperature, it would take up to 48 hours for oocytes to mature (McCrae 1983). It is therefore more than likely that irritancy was the factor causing early exits from sprayed huts. The phenomenon of irritability does not therefore negate indoor spraying, since it has already been shown that the bulk of those mosquitoes, that spend a short time indoors, die anyway. Also given the behavioral differences within the taxon, it may be unwise to rely on data referring to the complex.

The results of the analysis of total DDT in the samples are far below the expected dose of 2 g AI/m^2 even in freshly sprayed huts, and seem to suggest that either the technique or the equipment does not achieve this target. Taylor et al. (1981) have shown that there is a wide variation in insecticide deposit following spraying. It would be necessary to ensure that the proper procedure in mixing of insecticides and spraying are adhered to through strict supervision. The householders should also be educated on the need to abstain from replastering sprayed huts.

The value of bioassays in testing insecticide residual activity is doubtful. High mortalities are observed (Figs. 8 and 9) in mosquitoes that have been afforded no choice of resting sites. Since the resting behavior of mosquitoes inside sprayed huts has not been looked into, studies *in situ* are required before any importance could be attached to bioassay results. Furthermore, it has been shown in this study, that the bulk of mosquitoes (>60%) released into sprayed huts exit within the first 2 hours of such release (Fig. 6) as opposed to 3 hours during which they are confined in bioassays.

On the basis of mosquito mortalities alone, the findings of this study (Table 1) are at odds with Langford's observations (cited by Kuhlow 1962) that DDT deposits degrade faster on roofs than on mud. Taylor et al. (1981) have also demonstrated the trend as at present albeit with a different insecticide. It may be possible that there is an effect due to the thatch material. In hot tropical climates the thatch is very cool by day (Schofield and White 1974). This affords a cool resting place for vector mosquitoes, especially as in Zimbabwe, when the vegetation is greatly denuded (August–October) to afford any outdoor resting shelter. This brings the mosquitoes into contact with highly potent insecticide deposits. Thatch is also less biologically active than many mud surfaces and does not suffer from attrition as do the walls.

The results of this study demonstrate that DDT spray deposits are effective in killing malaria vectors for up to 15 months postspray. Bioassay results indicate an even longer duration of control. Both methods of assessing residual activity have drawbacks. Hut releases are the closest to conditions obtaining in the wild, but the problem of mosquito losses complicates interpretation of results. On the other hand bioassays can be misleading as these do not take into account vector behavior when in contact with DDT sprayed surfaces. The duration of vector control appears less in occupied huts compared to experimental huts as reported by Taylor et al. (1981).

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