

places. Unfed female *A. quadrimaculatus* began entering buildings containing animals and feeding before dark; however, most feeding occurred after dark. The influx continued throughout the night, but many left before morning. Unoccupied buildings were ignored at night. Males as well as females rested in buildings during the daytime. However, a high proportion of the gravid females and

most of the males spent the night outdoors. Most, but not all adult *A. quadrimaculatus* changed their daytime resting sites from one day to another.

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EFFECT OF RESIDUAL APPLICATIONS OF BAYGON® AND CARBARYL ON THE ACTIVITIES OF MOSQUITOES IN BUILDINGS¹

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Baygon® (*o*-isopropoxyphenyl methylcarbamate) and carbaryl are two insecticides that have attracted considerable attention as possible replacements for the DDT and dieldrin used in residual spray programs against anopheline mosquitoes in malaria control programs. LaBrecque *et al.* (1960), Gahan *et al.* (1961), and Schoof *et al.* (1962) found these two materials promising in laboratory tests. Later, Smith and Hocking (1963a, 1963b) and Gahan *et al.* (1964) reported that Baygon produced at least several months' control of free flying mosquitoes in buildings that contained natural infestations of either *Anopheles gambiae* Giles or *Anopheles quadrimaculatus* Say. Both groups of investigators found carbaryl much less effective, and Smith and Hocking (1963b) observed that many mosquitoes entering huts treated with carbaryl were irritated by the chemical and escaped before they made lethal contact. Gahan *et al.* (1964) reported that after adults of *A. quadrimaculatus* entered at dawn into buildings

sprayed with either of these insecticides and rested on the treated surfaces, Baygon eliminated them all within 1 or 2 hours after sunrise whereas carbaryl, a much slower acting material, often failed to eliminate them by noon or even by late afternoon.

In field studies made to evaluate new insecticides as residual treatments against natural infestations of *A. quadrimaculatus* we have used the absence of resting adults during the daytime as an indication of the effectiveness of a compound. This method of evaluation has allowed us to eliminate from further consideration many compounds that lose their toxicity too rapidly to be highly effective residual sprays. However, malarial parasites require 7 or more days to complete their developmental cycle in the mosquito before the disease can be transmitted to other hosts (Young, 1960), so fast action and prevention of all biting are not required characteristics for insecticides used as residual sprays in malaria eradication campaigns. (The characteristics are still desirable because they help those conducting such campaigns to obtain cooperation from the beneficiaries.)

¹ Mention of a pesticide in this paper does not constitute a recommendation of this product by the USDA.

We were therefore interested in studying in more detail the effect of residual treatments of Baygon and carbaryl on densities of mosquitoes and on their biting activities. Since anopheline mosquitoes feed after dark, we made a series of night observations between July 23 and August 22, 1968 in buildings located in the vicinity of Stuttgart, Arkansas that had been

following morning. During the investigation, the sun set between 8:19 and 8:10 p.m. and rose between 6:12 and 6:20 a.m. CDT. Complete darkness occurred about 30 minutes after sunset, and the first light of dawn appeared high in the sky about 30-45 minutes before sunrise.

Treatments and observation periods are summarized below.

Insecticide	Type of building	Date treated	Date of observations		Host animal
			Pretreatment	Posttreatment	
Baygon	Chicken house 1	June 27	None	July 29	Chickens
	Storage shed	July 16	None	August 1	Horse
	Stable 1	July 24	July 23	July 25, August 19 and 21	Horse
Carbaryl	Chicken house 2	June 12	None	July 29	Chickens
	Chicken house 3	June 12	None	July 29	Chickens
	Stable 2	July 28	July 23	July 29, August 19 and 21	Horse

treated with Baygon and carbaryl. Rice fields in this area produce large numbers of *A. quadrimaculatus*. Our program involved a study of both the density and biting activity in the treated buildings in the presence of host animals. Since *Psorophora* spp. (primarily *P. confinis* (Lynch Arribáizaga) and *P. discolor* (Coquillett)) were extremely abundant on some occasions, we also observed them. In addition, we made collections of adult *A. quadrimaculatus* escaping from some treated buildings during the daytime to determine whether they had obtained a lethal dose of insecticide and released others collected from untreated buildings into a building treated with Baygon to determine the speed of kill.

DENSITY AND BITING ACTIVITIES

We treated 6 buildings—3 chicken houses, 1 storage shed, and 2 stables—with either Baygon or carbaryl at the rate of 2 g/m² by spraying all interior surfaces. Then visits were made every 2 hours between 5 and 6 p.m. Central Daylight Time (CDT) and 6 and 7:30 a.m. the

A flock of chickens occupied each chicken house after dark, and a single horse was locked in the stables or storage shed after 6 p.m.

STUDIES OF *Anopheles quadrimaculatus*. During each visit, the walls and ceilings were examined with a flashlight, and an attempt was made to determine the approximate number of *A. quadrimaculatus* present. When the infestation was less than 500-600, every adult that could be found was counted. However, when densities were high, the total was obtained by counting 100 mosquitoes and estimating the number of similar samples in the building. The proportion of each sex in the total was also determined, and the females present were classified as unfed, freshly fed, or gravid. If less than 150 *A. quadrimaculatus* were present, this classification was obtained by examining every mosquito but if more than this number were present, about 100 selected at random were examined.

It was obvious that the residual sprays of Baygon and carbaryl failed to prevent all feeding by *A. quadrimaculatus* because adults were present throughout the night

in every building examined but one. That exception, chicken house 1, had an average of 298 *A. quadrimaculatus* resting in it during the daytime before it was sprayed with Baygon. Four and a half weeks later, it contained 2 engorged females at 8:35 p.m., but it was free of mosquitoes at 6:35 p.m. and throughout the remainder of that night.

The storage shed sprayed with Baygon was located on a farm that had chickens, cows, and several goats nearby. Although the shed was unoccupied before treatment, some *A. quadrimaculatus* were found inside during the daytime; however, the number seldom exceeded 100. Sixteen days after application of the Baygon, no mosquitoes were found during the daytime. Also, no mosquitoes were found in the building at 6 and 8 p.m. when a horse was placed in the shed about 3 p.m., but by 10 p.m., 116 female *A. quadrimaculatus* were seen resting on the walls and ceiling, and 10 percent of them had already fed. Between midnight and 5:15 a.m., the number present on the walls, ceiling, and horse (all females) ranged from 13 to 57; 68 to 94 percent of them were freshly engorged. Then at about 5:30 a.m., when the first faint glow of dawn appeared in the sky, the mosquito population began to increase rapidly: at 5:35 and 5:45 a.m., the counts were 206 and 217, respectively, and only 41 and 26 percent, respectively, were fed. These mosquitoes were those that normally enter buildings at dawn to rest throughout the day, not those primarily interested in feeding. By 6 a.m., the number present was again decreasing as the Baygon rapidly killed those that contacted treated surfaces. Counts made at 6 a.m. showed 67 mosquitoes were present, 93 percent of which were females. At 6:15 a.m. only 13 mosquitoes were found and 77 percent of them were females. On both occasions 47-50 percent of the females were freshly engorged. The shed was again free of mosquitoes by 6:35 a.m.

At about 4 a.m. in the same shed, the dead and dying *A. quadrimaculatus* seen on a narrow ledge in one corner of this

building were brushed off onto the floor. At 6:45 a.m., another 53 newly killed *A. quadrimaculatus* were observed on the ledge. Also a metal tub 24 inches in diameter that had been partly filled with clean water and placed in one corner of the building the previous afternoon contained 538 dead mosquitoes at 6:50 a.m.

Chicken houses 2 and 3 were treated with carbaryl. Before treatment the daytime infestations in these buildings averaged 727 and 733 *A. quadrimaculatus*, respectively. When the night observations were made neither building was entirely free of mosquitoes at any time during the day.

Carbaryl appeared to be no more effective in reducing nighttime annoyance than Baygon. In chicken house 2, the infestation increased considerably after dark and reached a nighttime peak of 526 about 10:40 p.m. Throughout the remaining hours of darkness, *A. quadrimaculatus* were numerous, but the density gradually decreased. The counts varied from 332 to 133 between 12:40 a.m. and 4:40 a.m. In chicken house 3, the infestation did not build up after dark, because the building was on a farm that had many animals and other buildings. (A large untreated barn about 100 meters away regularly had 25 or 50 cattle in or around it, and this barn was particularly attractive to *A. quadrimaculatus*: several thousand were usually resting in it during the daytime. Pig pens and a pony barn were also in the vicinity, and some of the chickens spent the night outdoors in trees.) We believe many mosquitoes in this area were feeding outdoors or in other buildings at night and only came into the chicken house at dawn. At dawn both buildings had a huge influx of *A. quadrimaculatus* seeking daytime resting places and the numbers present exceeded 1,000 by 6:40 a.m. to 7:10 a.m.

Stables 1 and 2 were used to make a direct comparison of the activities of *A. quadrimaculatus* in the same building before and after treatment with the 2 insecticides. Table 1 gives the results of this test; the figures shown for the pretreat-

TABLE 1.—Density of *Anopheles quadrimaculatus* in buildings after spraying with Baygon or carbaryl. Pretreatment data in parentheses.

Time of day (CDT)	Total number of mosquitoes	Percent females	Percent of females that were:		
			Gravid	Freshly engorged	Unfed
Stable 1 treated with Baygon July 24, 1968					
5:30 p.m. (6:00 p.m.)	0 (101)	0 (98)	0 (100)	0 (0)	0 (0)
7:30 p.m. (8:00 p.m.)	0 (57)	0 (100)	0 (91)	0 (0)	0 (9)
8:19 p.m.—sunset					
9:30 p.m. (10:00 p.m.)	39 (21)	100 (100)	0 (0)	46 (38)	54 (62)
11:30 p.m. (12:00 M)	18 (79)	100 (100)	2 (1)	64 (38)	34 (61)
1:30 a.m. (2:00 a.m.)	136 (157)	100 (100)	1 (2)	86 (66)	13 (32)
3:30 a.m. (4:00 a.m.)	116 (225)	100 (100)	0 (0)	88 (88)	12 (12)
5:30 a.m. (6:00 a.m.)	38 (546)	100 (99.6)	2 (3)	97 (76)	1 (21)
7:00 a.m. (7:00 a.m.)	0 (682)	0 (99.3)	0 (13)	0 (78)	0 (9)
Stable 2 treated with carbaryl July 28, 1968					
6:00 p.m. (6:00 p.m.)	11 (>2,000)	100 (86)	79 (95)	7 (1)	14 (4)
8:00 p.m. (8:00 p.m.)	12 (>1,000)	81 (100)	66 (89)	7 (4)	27 (7)
8:19 p.m.—sunset					
10:00 p.m. (10:00 p.m.)	> 576 (12)	100 (100)	2 (25)	70 (17)	28 (58)
12:00 M (12:00 M)	> 753 (98)	100 (99)	4 (6)	82 (55)	14 (38)
2:00 a.m. (2:00 a.m.)	589 (177)	100 (100)	4 (10)	93 (62)	3 (28)
4:00 a.m. (4:00 a.m.)	585 (126)	100 (100)	3 (8)	95 (70)	2 (22)
6:00 a.m. (6:00 a.m.)	>1,000 (>2,000)	96 (98)	10 (52)	82 (48)	8 (0)

ment observations represent counts made the night before spraying. The posttreatment data are averages of counts made on 3 nights during the first month after sprays were applied. The density of *A. quadrimaculatus* after dark in stable 1 was reduced only slightly by Baygon, and annoyance continued throughout most of the night on all 3 occasions. Daytime was the only period during which 100 percent control was apparent. The nighttime counts in stable 2 (treated with carbaryl) increased considerably after the spray was applied, but the reason for this increase is unknown. It could have resulted from a change in the density of the population in the area between the pretreatment and posttreatment observations or there may have been an interaction between the *Psorophora* spp. and the anopheline species. *Psorophora* spp. were much more numerous before treatment than after treatment.

Male *A. quadrimaculatus* were seen in buildings sprayed with Baygon only early in the morning when they were seeking daytime shelter. The same situation usually prevailed in buildings treated with

carbaryl, but 19 were found in stable 2 at 8 p.m. on one occasion.

Gravid females were frequently found in both treated and untreated buildings. Usually, however, they were a larger proportion of the total population before than after treatment.

STUDIES ON *Psorophora* spp. In the stables examined before and after treatment, *Psorophora* spp. were so numerous at the times of the pretreatment and first posttreatment observations (an estimated 70,000 in stable 2 at 12:30 a.m. on July 28) that the effect the insecticide had on the density could only be evaluated by counting the number resting on 1-ft² areas of the inside and outside walls. Both insecticides substantially reduced the nighttime density in the two stables and actually caused a greater reduction of these species than of *A. quadrimaculatus*. As shown in table 2, Baygon was more effective than carbaryl during the first posttreatment observation period: it reduced the counts per ft² from 33–74 before treatment to 0–2 after treatment on the inside walls and from 12 to 34 before treatment to 0 to 13 after treatment on the outside

TABLE 2.—Density of *Psorophora* spp. on the inside and outside walls of buildings sprayed with Baygon or carbaryl. Counts taken immediately before and one day after treatment.

Time	Number of mosquitoes/ft ² of wall			
	Before treatments		After treatments	
	Inside	Outside	Inside	Outside
Stable 1 sprayed with Baygon				
6:00 p.m.	0	0	0	0
8:00 p.m.	1	0	0	0
10:00 p.m.	74	26	2	3
12:00 midnight	64	19	0	13
2:00 a.m.	59	34	1	2
4:00 a.m.	33	12	0	0
6:00 a.m.	0	0	0	0
7:00 a.m.	0	0
Stable 2 sprayed with Carbaryl				
6:30 p.m.	0	0	0	0
8:30 p.m.	0	0	0	0
10:30 p.m.	113	34	57	28
12:30 a.m.	146	14	13	6
2:30 a.m.	98	19	2	4
4:30 a.m.	61	17	2	2
6:15 a.m.	25	0	0	0

walls. However, at 10 p.m. more than 500 mosquitoes were present on the horse and many others were flying (most of them *Psorophora* spp.). By 4 a.m., the density was sufficiently reduced so that only 16 were on the horse and none were on the inside wall. At 6 a.m., 24 were on the horse and none were on the walls. Carbaryl was considerably less effective than Baygon during the early hours of darkness but only slightly less effective during the latter part of the night. Both treatments gave the horse considerable relief, especially throughout the latter part of the night.

By August 19 to 21 the total number present in all parts of the buildings ranged from 4 to 73 in stable 1 and 22 to 310 in stable 2. Since the general population of *Psorophora* spp. in the area had shown a tremendous decrease by that time, the insecticides could not be given credit for the low densities observed.

MORTALITY OF COLLECTED ADULTS

Free-flying adult *A. quadrimaculatus* that are affected by chemicals applied as residual sprays frequently escape from

treated buildings unless the windows or doors are covered. Since the mosquitoes that escape are seldom seen again, the percentage that die cannot be determined. Many investigators capture the mosquitoes that attempt to leave by covering the doors and windows and forcing the insects to find small openings in screen cages. However, we believe this type of capture forces the insects to make more contact with the treated surfaces than they normally would if the doors and windows were as open as at the time the entrance was made.

To clarify the effect residues of carbaryl and Baygon had on the mosquitoes that escaped from treated buildings, we covered the doorways and window openings in 6 buildings treated with carbaryl and one treated with Baygon between June 12–26, 1968 with nylon netting sometime between dawn and noon. Then as adults of *A. quadrimaculatus* came to the nettings, they were caught in glass vials and transferred to 1-pint cardboard cartons with muslin lids. It was assumed that any mosquitoes landing on the netting were attempting to leave the buildings. These insects were held in an air-condi-

tioned room, and the mortality was recorded 24 and 48 hours after the collections were made. Because Baygon was fast acting, collections were made between 6 and 6:30 a.m. in the building treated with this insecticide. In buildings treated with carbaryl, which acts more slowly, the collections were made between 11 a.m. and 1:30 p.m.

Between July 25 and August 16, a total of 342 mosquitoes that had been exposed to carbaryl were caught as they attempted to leave the building. The mortality averaged 65 percent in 24 hours and 71 percent in 48 hours; in no case did all the mosquitoes from any building treated with carbaryl die in 48 hours.

On July 24, only 9 adult *A. quadrimaculatus* were seen at 6 a.m. in the building treated with Baygon, and all were captured on the cloth before 6:30 a.m.; 67 percent died in 24 hours but the others which showed signs of being affected when they were first caught recovered and were still alive after 48 hours. Another 8 were collected at the same time of day on July 25; all died within 24 hours. We also saw 11 adults on the floor of this building that had been knocked down by the chemical but were still alive.

Because many *A. quadrimaculatus* that enter buildings early in the morning continue to fly or to move frequently during the first 30 to 60 minutes, some of those caught in the chicken house sprayed with Baygon had probably made little, if any, contact with the treated surfaces. We therefore released 50 adult *A. quadrimaculatus* caught in an untreated stable in the treated chicken house at 9:45 a.m. on July 24 so collections could be made during the part of the day when the species was usually quiet (and also nearer the time of day the collections were made in buildings treated with carbaryl).

The first mosquito that tried to escape was caught on the netting within 5 minutes after it was released. Within 15 minutes, another 5 were caught. By this time, the building was empty of live mosquitoes. Eight were found dead on the floor, but the remaining 36 could not be

located. All those caught while trying to escape were dead within 1 hour. The same test was repeated 2 more times on August 1, but on this occasion, wrapping paper was placed on the floor so more of the knocked-down insects could be found. Only 1 mosquito attempted to escape, and it died within 1 hour after being caught. Of the 106 mosquitoes used in these 2 releases, a total of 74 were collected on the floor immediately after the insecticide knocked them down. In both tests, the first mosquitoes fell 7 to 8 minutes after the releases were made. Since no live mosquitoes were in the building 20 minutes after the tests were started, the 32 that were not located must have been lost in the debris on the portion of the floor that could not be covered with paper. All the recaptured mosquitoes died within 24 hours.

DISCUSSION

It is obvious that neither Baygon nor carbaryl can be depended on to give a high degree of protection from mosquito bites as long as high densities of *A. quadrimaculatus* or *Psorophora* spp. are in the vicinity. Moreover, since Baygon is one of the fastest acting chemicals available that has long residual action, there is doubt that any chemicals now being considered as substitutes for DDT and diel-drin will give adequate relief from annoyance until enough mosquitoes have been killed to reduce the infestation in the area to a low level.

Carbaryl not only killed more slowly than Baygon but also irritated the mosquitoes and increased flying activity. However, it was not repellent because the insects readily rested on surfaces treated with it though both species flew much more frequently in buildings sprayed with carbaryl than they did in structures sprayed with Baygon or that were unsprayed. Indeed, in buildings treated with carbaryl, the mosquitoes flew so frequently at night that there was constant noise and during the daytime, they seldom sat more than 2 or 3 minutes in one place, even when the temperature was above 85° F. Also, while

they were on a treated surface, the mosquitoes continuously moved their hind legs, fluttered their wings, or brushed their wings with their hind legs. Eventually they became so irritated that they flew outdoors into the bright sunlight.

Both insecticides killed mosquitoes. However, we believe carbaryl is enough of an irritant that many free-flying *A. quadrimaculatus* leave surfaces treated with it frequently enough to escape being killed. No evidence was obtained to show that any large proportion of the mosquitoes entering buildings treated with Baygon were irritated sufficiently to leave before they were exposed to a lethal dose.

SUMMARY

Residual applications of Baygon (*o*-isopropoxyphenyl methylcarbamate) and carbaryl in buildings naturally infested with *Anopheles quadrimaculatus* Say and *Psorophora* spp. failed to eliminate all annoyance to and feeding on chickens and horses during the nighttime. In two buildings where direct comparisons were made before and after treatment, the nighttime density of *A. quadrimaculatus* decreased only slightly after spraying with Baygon and increased considerably after spraying with carbaryl. Male *A. quadrimaculatus* were usually found only early in the morning when the mosquitoes were seeking daytime shelter. Gravid females were present but represented a higher proportion of the total before than after treatment.

Both insecticides substantially reduced the nighttime density of *Psorophora* spp.,

and Baygon was the more effective of the two. Therefore, horses confined in treated buildings obtained considerable relief from the bites of these mosquitoes, especially throughout the later part of the night.

Carbaryl permitted more *A. quadrimaculatus* to escape from buildings during the daytime without being killed than Baygon. Also, carbaryl was slower acting and more of an irritant than Baygon. As a result, many mosquitoes left surfaces treated with carbaryl often enough to escape being killed.

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