EVALUATION OF HYDROPRENE POINT SOURCE IN COMBINATION WITH HYDRAMETHYLNON GEL BAITS AGAINST THE GERMAN COCKROACH (*BLATTELLA GERMANICA*) IN SIMULATED DOMESTIC ENVIRONMENTS

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Abstract—Four simulated domestic environments were each infested with mixed populations (3,300 insects) of German cockroaches (*Blattella germanica*). The simulated domestic environments (containers) were maintained at 25°C and 45% r.h. and cockroaches were fed and watered *ad lib.* After an acclimation period of eight weeks, three of the containers were treated and one was left as an untreated control. One container was treated with four hydroprene point sources each containing 120mg technical grade S-hydroprene and 20% butylated hydroxy toluene. The point sources used were supplied by Sandoz Speciality Pest Control and were applied as indicated by the manufacturers proposed label instructions. One container was treated with hydramethylnon gel bait (Maxforce gel) at the manufacturers recommended rate. The final container was treated with both hydroprene and hydramethylnon at the above rates. All treatments were repeated at three monthly intervals.

During the acclimation period, cockroach populations were monitored at weekly intervals using live catch Roatel® traps. After treatment, populations were monitored at fortnightly intervals until the populations were eradicated. During each monitoring, effects on the population size, structure and reproduction were recorded. Numbers of deformed adults (twisted wings) were recorded at each monitoring since it has been shown in the literature that the percentage of deformed adults is directly related to inhibition of reproduction. Effects on reproduction were monitored at monthly intervals by isolating ten females from the containers in one litre glass jars until one ootheca had been produced and hatched. Numbers of nymphs hatching were then recorded before returning the insects to the appropriate container.

In the environment treated with hydroprene alone, the cockroach population was eradicated after 18 months. Treatment of the environment with hydramethylnon gel on its own eradicated the cockroaches after four months. In the combined hydroprene/ hydramethylnon treatment cockroaches remained for up to seven months before eradication.

The data presented suggest that the combination of hydroprene and hydramethylnon would be effective in the field. Combining these two treatments ensured that any residual infestation remaining after the bait treatment could not multiply. Furthermore, the use of the bait to reduce the initial population size also reduced the time taken to eradication compared to when hydroprene was used alone.

INTRODUCTION

Control of cockroaches in institutional and domestic premises has been exceptionally difficult for many years. Old buildings provide ideal harbourages for cockroaches and therefore create many difficulties for spray treatments with conventional insecticides, especially when they are permanently occupied. Difficulties in gaining access to premises generally means that thorough treatment is extremely difficult and time consuming. If areas of an infested premises remain untreated, pockets of infestation will spread unless action is taken to treat them. Conventional spray, dust or lacquer treatments are also very disruptive to the occupants of a building whether they are employees, patients or home owners. People must be moved away from areas being treated, and electrical appliances, food utensils and food storage areas all need to be protected from treatment and food preparation areas must be thoroughly cleaned afterwards. These problems make conventional treatments very time consuming and in some instances inappropriate.

Toxic baits for cockroach control have been used for many years with varying degrees of success. However, the use of modern baits with delayed toxic action have, in recent years improved levels of cockroach control (Aho and Thomas, 1993; Lucas *et al.*, 1992; Ogg and Gold, 1993). The main difficulty with bait treatments is getting the bait to enough of the cockroach population to achieve an acceptable level of control. Treatment therefore relies on using an appropriate density of baits for each area treated. Baits are however much easier and less disruptive to apply than sprays, and their discrete placement minimises environmental contamination and poses less hazard to operators, consumers and non-target organisms.

Proceedings of the Second International Conference on Urban Pests.
K.B. Wildey (editor). 1996

The novel insecticide hydramethylnon [tetrahydro-5, 5-dimethyl-2(1H)- pyrimidone (3-[4-(trifluoromethyl) phenyl]-1-(2-[4-(trifluoromethyl) phenyl] ethenyl)-2 propenylidene) hydrazone] (Maxforce®) is similar in action to many conventional insecticides in that it kills cockroaches by direct toxic action. However, hydramethylnon works as an energy inhibitor at the mitochondrial level. Importantly, its slow mode of action enables a transfer of toxic effect to other cockroaches (that have no direct contact with the bait), which in turn results in considerable mortality from indirect exposure (Short *et al.*, 1994). In addition, the very low mammalian toxicity (LD_{50} oral rat >5000mg/kg) of hydramethylnon coupled with its effectiveness in controlling cockroaches, makes hydramethylnon a very good alternative to conventional spray treatments. Baits incorporating hydramethylnon have been available in the USA since 1985 and in the UK since 1991, and field performance against cockroaches and ants has been well documented (e.g. Milio *et al.*, 1986; Appel, 1990; Lucas *et al.*, 1992) Reports from the USA (Milio, *et al.*, 1986; MacDonald, *et al.*, 1987 and Appel, 1990) suggest that this compound is very effective against populations of the German cockroach (*Blattella germanica)* when baits are applied correctly and maintained appropriately. Moreover, infestations of German cockroaches which had proved virtually impossible to control by conventional means have been readily controlled with hydramethylnon (Lucas, *et al.*, 1992).

Much work has been done at the Central Science Laboratory (CSL) on the juvenile hormone analogue (JHA) S-hydroprene which has an extremely low mammalian toxicity (acute oral LD_{50} rat approx. 34,000 mg/Kg). To date, this work has investigated the effects of S-hydroprene emulsion concentrates (EC) in laboratory experiments and on semi-natural populations as a surface deposit, a fogger and as point sources (a discrete source from which the hydroprene is slowly released into the environment being treated) against the Oriental cockroach *Blatta orientalis* (Edwards and Short, 1993; Short and Edwards, 1992 and 1993). Recent experiments with hydroprene point sources (Short and Edwards, 1993) have shown that this is also a practical and effective control measure against Oriental cockroaches in artificial domestic environments. However, due to the action of JHA's, there is no direct toxic effect on the cockroaches. Sterile adults are produced after nymphs have been exposed to hydroprene. The population is then eradicated as a result of suppression of reproduction. Adults already present in an infestation are unaffected by hydroprene treatment and will continue to produce viable ootheacae until death. Eradication therefore, takes a considerable period of time (up to two years for *B. orientalis* in artificial domestic environments) and no reduction in the population is observed until the original adults present have been replaced by sterile ones. This long time factor would be unacceptable in many field situations. However, a combination treatment utilising a product that gives good initial reduction in numbers of cockroaches (especially adults) together with hydroprene point sources should offer an effective control measure. The combined use of hydramethylnon baits with hydroprene point source would offer a practical and simple treatment for cockroaches with minimum disruption to persons occupying the premise and minimal toxicological hazard to those applying the treatment and to non- target organisms. Consequently, with funding from the Food Protection Association, the Central Science Laboratory undertook trials to investigate the effectiveness of hydroprene point sources in combination with hydramethylnon baits against German cockroaches in artificial domestic environments.

MATERIALS AND METHODS

Insects

The "laboratory susceptible" strain of the German cockroach *B. germanica* was used for these investigations. This strain has been in culture at CSL for over 20 years and has shown no resistance to any known group of insecticides. Cockroaches at CSL are maintained at 27°C and 45% r.h. on a standard laboratory diet of rolled oats, wheatfeed, fishmeal, ground dog biscuits, yeast and ground peanuts, in the ratio 5:5:2:2:1:1 by weight.

Insecticides

Hydramethylnon gel bait ("Maxforce® gel") (2.04% a.i. w/w) was purchased from Killgerm Chemicals Ltd, Ossett, W. Yorkshire and applied according to the label instructions. Hydroprene point sources containing 120mg technical grade (98% pure) S-hydroprene (ethyl [S]-3,7,11-trimethyl-2[E],4[E]-dodecadienoate) and 20% w/w butylated hydroxy toluene were supplied by Sandoz Speciality Pest Control, Dallas, Texas, U.S.A. Point sources consisted of a plastic mesh sandwich containing a breakable capsule of technical S-hydroprene and 5.5mm filter paper to absorb the released contents. These were applied as indicated by the manufacturer's proposed label instructions.

Artificial domestic environments

The tests were carried out in four specially modified freight containers hired from Genstar Instant Space, Gerrards Cross, Bucks (floor area 11.6 sq. metres). Freight containers were insulated internally with 3" expanded polystyrene and fitted out with domestic vinyl flooring, melamine wall and ceiling panels and an internal door. Heating and humidity controls regulated and maintained the environmental conditions at 25°C and 45% r.h. Cardboard harbourages for the cockroaches were provided using five large cardboard boxes with 15 internal divisions.

Infesting the containers

Each container was inoculated with a mixed population of 3,300 German cockroaches comprising 1,000 small nymphs, 1,000 medium nymphs, 1,000 large nymphs (size category arbitrary, selected by age) and 300 adults (sex ratio 1:1). Cockroach food and water was provided *ad libitum* and the populations were allowed to acclimatise for eight weeks prior to treatment.

Treatment of the containers

Four containers were used for the treatments:

(1) The control container was left untreated.
(2) One container was treated with hydramethylnon gel baits (Maxforce®) only. Hydramethylnon gel bait (Maxforce®) was applied using a grease gun applicator to place discrete amounts at the wall-floor and wall-ceiling junctions and to other appropriate places such as light fittings, according to the label instructions. An application rate of 0.5 mg/m^2 a.i. was achieved in this container.
(3) One container was treated with hydroprene point sources only. The manufacturers recommended rate of application was used. Hence, four sources were attached centrally to the ceiling of each container giving a total treatment rate of 480mg/11.6m^2 or 41.4mg/m^2 floor area.
(4) The final container was treated with both hydramethylnon gel bait at the manufacturers recommended application rate, and with four hydroprene point sources attached to the ceiling as described above.

Monitoring cockroach populations

Cockroach populations were monitored weekly in each container for a period of 8 weeks prior to the first treatment, and subsequently at fortnightly intervals for a period of 12 months or until the populations were eradicated. Monitoring of the cockroach populations was performed using Roatel® traps, these permitted the live trapping of cockroaches which were subsequently returned to the appropriate container after each assessment. Six traps were placed in marked positions on the floor of each container and left in position for 24 h. After this time, each trap was examined. The numbers of adults and nymphs (size categories: large, medium and small) trapped were recorded at each monitoring. The sex of adults trapped was also determined, and numbers of deformed adults recorded at each monitoring. All counts were converted into monthly (four weekly) means and expressed graphically.

Monitoring reproduction

Every 4 weeks throughout the experiment, 10 adult females carrying oothecae were removed from those trapped in each container and isolated individually in 1 litre glass jars at 25°C and 45% r.h.

Females were maintained under these conditions until the oothecae either hatched, desiccated, or the female died. The hatching of oothecae and the number of nymphs produced was recorded for each ootheca. The adult females, plus any nymphs produced, were then returned to the appropriate container.

RESULTS

Changes in cockroach populations

The monthly means for total trap catches from each container at each monitoring are shown in Figure 1 and Table 1. Over the eight week acclimation period, trap catches of cockroaches in all four containers increased. The first trap counts represented 7% of the introduced insects. The counts for the acclimation period were averaged to give a baseline initial population value (mean) prior to treatment for each container. These baseline means were similar (control=311.0, hydramethylnon=431.0, hydroprene=357.9 and combination=415.9). These values represent between 9% –13% of the initial populations of 3,300 German cockroaches.

After the first treatment, trap catches in the containers treated with hydramethylnon or with a combination of hydramethylnon and hydroprene fell rapidly. No insects were trapped in the hydramethylnon treated container after 4 months. However, the occasional cockroach was trapped in the combined treatment up to 7 months. Thereafter, no insects were caught in the traps used to monitor this container. It was assumed therefore that the populations in these containers had been eradicated when no further cockroaches were trapped. A visual search of all harbourages confirmed this.

By contrast, the trap catches from the hydroprene-treated container were initially very similar to those from the control, and both populations continued to increase up to 3 months after treatment. After this time, trap catches in the hydroprene-treated container started to decline. An initial rapid decline in trap catches occurred between 4 and 5 months in this container which was followed by a temporary recovery before a gradual decline to zero. This fluctuation was probably the result of a loss of temperature control that occurred over one weekend and resulted in temperatures exceeding 40°C for several hours. The population in this container was eradicated within 18 months. Trap catches in the control container remained high throughout the trial although a cyclical pattern in numbers of insects trapped was apparent.

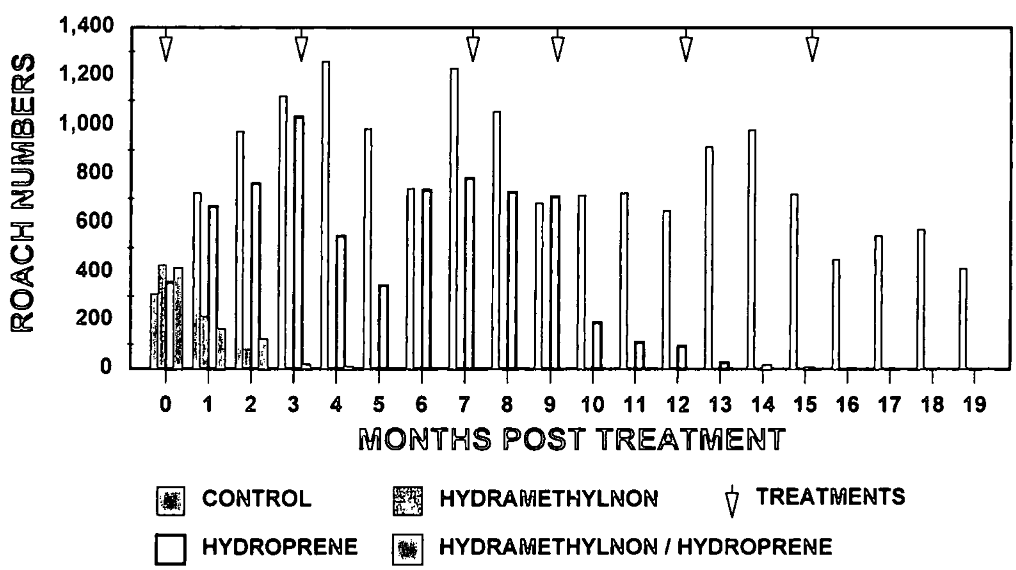

Figure 1. Effect of Hydroprene, Hydramethylnon and Hydramethylnon/Hydroprene Combined on Semi-Natural Populations of *B. germanica*.

Table 1. Changes in populations of *B. germanica* after treatment with hydroprene, hydramethylnon or a combination of both.

Time after treatment (months)		0	1	2	3	4	5	6	7	8	9
Mean trap catch	Control	311.9	725.0	978.5	1118.5	1261.0	988.5	742.5	1231.5	1058.0	683.0
	Hmeth.	431.0	216.5	6.0	1.0	0.0	–	–	–	–	
	Hyd.	357.9	667.0	761.5	1034.5	547.0	345.0	735.0	783.0	726.5	707.0
	Comb.	415.9	160.5	117.0	15.0	7.0	1.0	0.0	0.5	0.0	–
% deformed adults	Control	9.5	7.7	10.3	10.1	11.3	12.4	13.4	15.8	16.8	28.0
	Hmeth.	11.0	29.2	0.0	0.0	0.0	–	–	–	–	–
	Hyd.	5.9	14.3	32.0	50.2	68.9	79.7	87.0	93.7	96.7	99.0
	Comb.	9.9	27.5	0.0	50.0	0.0	50.0	–	–	–	–
Time after treatment (months)		**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Mean trap catch	Control	717.0	725.0	652.5	916.0	984.0	719.0	457.0	552.0	578.0	419.5
	Hmeth.	–	–	–	–	–	–	–	–	–	–
	Hyd.	189.5	107.5	93.0	26.5	13.5	4.5	1.0	1.0	0.0	0.0
	Comb.	–	–	–	–	–	–	–	–	–	–
% deformed adults	Control	36.7	37.6	35.2	22.5	12.8	4.8	13.2	11.7	12.2	15.2
	Hmeth.	–	–	–	–	–	–	–	–	–	–
	Hyd.	98	100	100	100	100	100	100	100	–	–
	Comb.	–	–	–	–	–	–	–	–	–	

Key: Hmeth. – Hydramethylnon, Hyd. – Hydroprene, Comb. – Hydramethylnon / Hydroprene combined

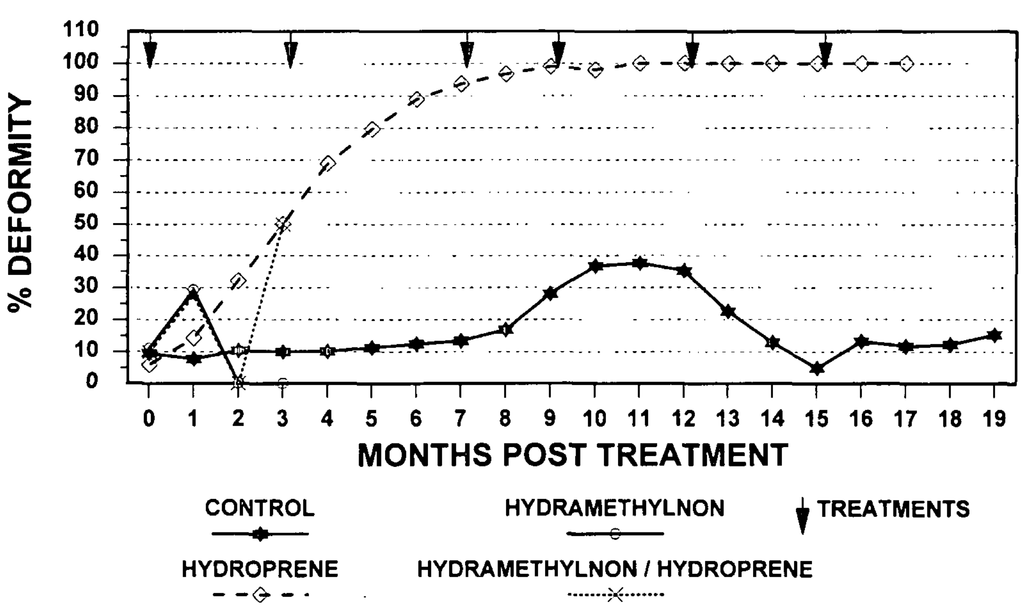

Figure 2. Percentage of deformed adults in traps, *B. germanica.*

Adult deformities of the type previously described by Bennett *et al.*, (1986); King and Bennett, (1989) and Short and Edwards (1992), were seen in the *B.germanica* trapped during these experiments. The percentage of deformed adults recorded in the traps prior to treatment remained below 15% (Figure 2) in all containers. After treatment, some deformed adults (about 30%) were recorded in insects trapped from the hydramethylnon treated container at four weeks. In the combined treatment, about 50% of adults trapped were deformed at three months. After this time no further adults were trapped. In the hydroprene-treated container the number of deformed adults trapped, increased from the start of treatment until, at six months, the number exceeded 85%. By seven months 90% of adults were deformed and the number of deformed adults remained above 95% thereafter. In the hydroprene-treated container the population slowly started to decline three months after treatment (Fig. 1) at which time the number of deformed adults trapped was only 50% (Fig. 2). It has previously been shown with the cockroach, *Blatta orientalis,* that the population would not start to decline until numbers of deformed adults reached at least 85% (Edwards and Short, 1988 and 1993). However, recent work with *B. germanica* (Reid and Bennett, 1994) has shown that provided the percentage of deformed adults in a population is maintained at about 80% then population suppression could be achieved.

Small nymphs accounted for 40–50% of the cockroaches trapped in the control and hydroprene-treated container for the first three months (Table 2). There was however, a decline in proportion of small nymphs after this time in both these containers. In the control however, the proportion of small nymphs trapped subsequently recovered. The initial decline in small nymphs in the control and hydroprene-treated containers corresponded to the time of maximum population size and, in the hydroprene-treated container, the time when the numbers of cockroaches trapped began to respond to hydroprene treatment (Fig. 1, total trap catch). The decline in numbers of small nymphs trapped also followed a very low hatch of oothecae (Table 2, Table 3). Results from the two containers treated with hydramethylnon showed a much greater increase in proportion of small nymphs (60–70%) during the first two months (Table 2). At this time a decline in total population between months 0–2 and 3-4 (Fig. 1) was recorded and the numbers of larger nymphal stages and adults visibly declined in these containers.

The percentage of medium sized nymphs trapped in all the containers remained similar at approximately 20–42% until hydramethylnon treatment reduced the populations to near zero in those containers where Maxforce® baits were applied (Table 2). In all the populations monitored, medium sized nymphs formed the largest proportion of nymphs trapped before the populations became affected by the treatments. This size category is comprised of all nymphs that are between the third and fifth instar, whilst the large size category is comprised of nymphs from the sixth instar until the adult moult. Consequently, the medium sized category of cockroach populations in the containers was expected to be the largest. In the hydroprene-treated container the numbers of medium nymphs remained similar to the control until one year after the start of treatment. At this time the population was reduced and close to eradication. The reduced numbers of medium nymphs at this point reflects the cessation of reproduction that occurred some six months earlier (Table 3).

The changes in the proportion of large nymphs trapped throughout the monitoring period are also shown in Table 2. Large nymphs formed less than 4% of the cockroaches trapped after hydramethylnon-treatment and, after six weeks, no large nymphs were trapped in either of the containers that were treated with hydramethylnon. In the control, numbers of large nymphs trapped remained fairly constant at between six and eleven percent of the total trap catch. However, in the hydroprene treated container the percentage of large nymphs trapped increased up to about 35% by seven months and remained at about 20–30% until 14 months. After this time no further large nymphs were trapped. Increasing proportions of large nymphs trapped after hydroprene treatments have been reported previously (Short and Edwards 1992) and indicates that nymphs may undergo extra moults after hydroprene treatment so prolonging nymphal development.

Reproduction in control and treated populations

In the control container, 60–80% of the oothecae carried by females at the time of monitoring, hatched each month during the first three months of the trial (Table 3). During the following nine months the hatch of oothecae collected from the control container was surprisingly low, although it

Table 2. Changes in the proportion of nymphs of *B. germanica* after treatment with hydroprene, hydramethylnon or a combination of both.

Time after treatment (months)		0	1	2	3	4	5	6	7	8	9
% small nymphs	Control	35.7	49.4	46.7	47.0	33.6	26.9	15.0	9.6	6.5	7.7
	Hmeth.	39.0	73.9	66.8	38.9	50.0	-	-	-	-	-
	Hyd.	40.4	48.2	45.5	37.7	22.5	7.3	6.0	3.4	2.4	0.8
	Comb.	43.2	66.6	78.7	20.7	32.2	0.0	0.0	0.0	-	-
% medium nymphs	Control	15.7	27.5	29.6	32.6	31.6	37.5	34.4	30.7	27.4	20.2
	Hmeth.	14.6	20.4	31.7	27.8	0.0	-	-	-	-	-
	Hyd.	12.2	24.4	28.6	36.2	38.5	48.5	46.8	48.5	32.5	30.7
	Comb.	17.5	24.6	11.8	27.6	10.7	100	0.0	50.0	-	-
% large nymphs	Control	6.0	4.8	4.0	4.9	4.3	3.0	4.7	5.1	10.7	11.0
	Hmeth.	5.3	1.6	0.8	0.0	0.0	-	-	-	-	-
	Hyd.	6.7	4.3	5.3	7.6	11.8	17.2	17.6	20.0	25.6	29.7
	Comb.	5.5	4.3	0.5	0.0	0.0	0.0	0.0	0.0	-	-
Time after treatment (months)		**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
% small nymphs	Control	3.3	5.8	12.9	28.5	39.6	42.8	51.7	34.7	34.9	38.0
	Hmeth.	-	-	-	-	-	-	-	-	-	-
	Hyd.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
	Comb.	-	-	-	-	-	-	-	-	-	-
% medium nymphs	Control	9.3	7.8	8.3	14.8	24.0	26.7	31.0	37.0	24.5	28.4
	Hmeth.	-	-	-	-	-	-	-	-	-	-
	Hyd.	8.3	7.8	1.9	3.5	0.0	0.0	0.0	0.0	-	-
	Comb.	-	-	-	-	-	-	-	-	-	-
% large nymphs	Control	8.1	3.9	3.9	4.8	6.8	7.5	6.6	6.1	10.3	6.7
	Hmeth.	-	-	-	-	-	-	-	-	-	-
	Hyd.	28.5	34.1	19.4	27..0	19.1	0.0	0.0	0.0	-	-
	Comb.	34.1	19.4	27.0	19.1	0.0	0.0	0.0	0.0	-	-

Key: Hmeth. - Hydramethylnon, Hyd. - Hydroprene, Comb. - Hydramethylnon / Hydroprene combined.

recovered later. Examination of temperature and humidity charts for this period indicated that the average monthly temperature in the control was slightly low during months 3-5 (20–22°C) and thereafter remained at about 25.5°C. No failure of r.h. control had occurred during or preceding this time in this container.

In the two containers treated with hydramethylnon, no females were carrying oothecae after one month. In the container treated with hydroprene alone, ten females carrying oothecae were collected each month until six months after the start of treatment. Subsequently, (months 7–9) only five of the females trapped were carrying oothecae, and after seven months none of the females trapped were carrying oothecae (Table 3).

Where females carrying oothecae were collected from hydramethylnon-treated containers, a proportion of them hatched. There was no significant difference (Students t-test $p>0.05$) in the number of emerging nymphs per ootheca between the control and hydramethylnon-treated container during the acclimation period and up to one month after treatment (Table 4). After the hydroprene treatment, there was a significant difference (Students t-test $p >0.005$) between the baseline emergence of 19.1 nymphs per ootheca and the post treatment emergence of 5.4 nymphs per ootheca. In a previous study, hydroprene had had no effect on the number of nymphs of *B. orientalis* emerging from oothecae but later prevented the formation of ootheca after a few months (Edwards and Short, 1993).

Table 3. Effect of hydroprene and / or hydramethylnon treatments on production and hatch o oothecae of *B.germanica.*

Months post treatment	Control (Hatch/Collected)	Hydramethylnon (Hatch/Collected)	Hydroprene (Hatch/Collected)	Hydramethylnon + Hydroprene (Hatch/Collected)
pre-treatment mean	5/10	6/10	6.5/10	6/10
1	8/10	6/10	5/10	0/0
2	7/10	0/10	3/10	0/0
3*	6/10	0/0	1/10	0/0
4	1/10	0/0	2/10	0/0
5	1/10	0/0	0/10	0/0
6	3/10	0/0	1/10	0/0
7*	4/10	0/0	0/10	0/0
8	3/10	0/0	1/10	0/0
9*	2/10	0/0	0/5	0/0
10	1/10	0/0	0/5	0/0
11	2/10	0/0	0/5	0/0
12*	3/10	0/0	0/0	0/0
13	6/10	0/0	0/0	0/0
14	7/10	0/0	0/0	0/0
15*	6/10	0/0	0/0	0/0
16	8/10	0/0	0/0	0/0
17	5/10	0/0	0/0	0/0
18	6/10	0/0	0/0	0/0

* Time of treatments

Table 4. Effect of hydroprene and / or hydramethylnon on mean number of nymphs hatched per ootheca +/- S.E. in *B.germanica.*

Time (months)	Control	Hydramethylnon	Hydroprene	Hydramethylnon + Hydroprene
pre-treatment mean	14.9 +/- 5.1	19.1 +/- 5.4	19.1 +/- 5.2	18.4 +/- 5.3
1	19.4 +/- 4.5	16.9 +/- 5.1	8.7 +/- 5.2	16.6 +/- 5.9
2	21.4 +/- 4.6	N/A	10.8 +/- 5.5	N/A
3*	13.5 +/- 4.1	N/A	2.3 +/- 2.3	N/A
4	3.2 +/- 3.2	N/A	2.6 +/- 1.7	N/A
5	1.8 +/- 1.8	N/A	0 +/- 0	N/A
6	8.2 +/- 4.3	N/A	2.4 +/- 2.4	N/A
7*	7.6 +-/ 3.9	N/A	0 +/-0	N/A
8	5.5 +/- 3.2	N/A	0 +/- 0	N/A
9*	4.8 +/- 3.2	N/A	0 +/- 0	N/A
10	1.5 +-/ 1.5	N/A	0 +/- 0	N/A
11	4.5 +/- 3.2	N/A	N/A	N/A
12*	7.7 +/- 3.9	N/A	N/A	N/A
13	18.3 +/- 5.3	N/A	N/A	N/A
14	21.5 +/- 5.1	N/A	N/A	N/A
15*	17.5 +/- 5.5	N/A	N/A	N/A
16	22.7 +/- 4.4	N/A	N/A	N/A
17	13.3 +/- 5.1	N/A	N/A	N/A
18	17.4 +/- 5.3	N/A	N/A	N/A

N/A = No data recorded

*Time of treatments.

DISCUSSION

The results obtained in this trial show that all treatments eradicated populations of German cockroaches. As expected, the two hydramethylnon treatments produced the most rapid reductions, due to the direct toxic effect of this chemical on all stages. In the hydramethylnon-treated container cockroaches were eradicated after only four months. It should be remembered however, that the container is a confined environment whereas a field situation allows much greater migration of cockroaches and consequently in practice, eradication maybe more difficult to achieve when using this chemical alone. This is probably due to the difficulty in positioning the bait close enough to all of the harbourages to ensure that all cockroaches are exposed to treatment. A thorough bait treatment is therefore much easier to achieve in a confined artificial domestic environment as used here, than in a field infestation.

Maxforce® baits appeared to selectively remove the larger, more widely foraging individuals from the population before the smallest and less active nymphs. The results indicate that all large nymphs were removed from the hydramethylnon- treated container after two months. In fact, three and a half months after treatment, just prior to eradication, the total trap catch from the hydramethylnon treated container consisted of two cockroaches, both of which were small nymphs. Rivault and Cloarec (1991) showed that in *B.germanica*, food sources are exploited in relation to their distance from harbourages, the nearest first, in a step by step manner. And, Cloarec and Rivault (1991) showed that adults and larger nymphs of *B.germanica* in a field population found and exploited food sources before small nymphs, and indicated that foraging performance increased as the nymphs grew larger. These authors also discuss how size differences between individuals, different locomotory capacities and learning may lead to differing foraging behaviour. In summary, they were able to show that small nymphs explored smaller areas, and covered shorter distances, than larger nymphs and adults even though they were capable of moving much longer distances. Moreover, foraging performance in the cockroaches studied improved as they grew older indicating that individual experience could also influence the speed and efficiency with which food is found. Previous laboratory studies also describe movement of both adult and nymphal cockroaches and stress the importance of the proximity of food sources to shelters (Ebeling *et al.*, 1967; Bret *et al.*, 1983; Ross *et al.*,1984; Bret and Ross, 1985).

In the combined treatment, hydramethylnon did not appear to kill all of the cockroaches as rapidly as was the case in the treatment with hydramethylnon alone since low numbers remained for seven months after treatment. However, the presence of hydroprene in this container ensured that surviving nymphs developed into sterile adults (Short and Edwards, 1992). Hence, suppression of reproduction occurred from two months onwards and the population was eradicated after about seven months. Hydroprene point source took approximately 18 months to achieve eradication when used alone, some nine months longer than the simultaneous application of the two chemicals. The removal of a large part of the infestation and more importantly of the more mature and more widely foraging cockroaches using hydramethylnon, reduced the time lag usually associated with a hormone treatment for cockroach control. Hydroprene has little direct toxic effect on cockroaches, and adults already present in a population will continue to reproduce, unaffected by hydroprene treatment, until they die of old age (Edwards and Short, 1993; Short and Edwards, 1993). It is only when these existing adults are replaced by adults developed from insects that have been exposed to hydroprene as nymphs, and are therefore sterile, that there is any reduction in population. Hence, by removing the larger cockroaches and in particular the adult females from the population with a toxic bait, control and eradication can be achieved in less than half the time required than when the JHA is used alone. It is also important to note that by removing the more mature insects from the population and rapidly reducing the size of the population, the treatment will be much more acceptable to those living and working in the infested environment.

A combination treatment of this type also has an added advantage that the application methods used are much less disruptive to those living and working in the area to be treated. Application of insecticidal baits such as Maxforce®, using a Mastic® gun applicator, is simple and safe, and the materials can be applied rapidly using the optimum number of small bait points to target the cockroach infestation effectively. Similarly, point sources of hydroprene can also be applied rapidly to the ceilings of infested premises, one or two to a room depending on its size. Rapid treatment of a premise is a major advantage over spray treatments and should allow pest control operators to offer a less time consuming and more thorough treatment regime. Both treatments are also likely to remain in place and not be removed by cleaning operations etc., because of their discrete placement. These factors together with the very low toxicity of these chemicals to mammals, make them a much more acceptable means of cockroach control than older conventional treatment methods.

The use of combined treatments utilising conventional insecticides with JHA's to improve cockroach control are not new. However, the use of more simple and acceptable application methods is a large step forward in this field and, from the data produced in this trial and in previous work, it appears that hydroprene may be more effective in controlling several cockroach species than other JHA combined treatments (Brenner *et al.*, 1988; Ogg and Gold, 1988 and Koehler and Patterson, 1991). The major factor influencing the effectiveness of hydroprene appears to be its mobility in the vapour phase. Although little is understood about the nature of the mobility of hydroprene it seems likely that its main mode of dispersal from a point source is by diffusion through the air to the target insect population as discussed by Short and Edwards, (1993). This mobility factor gives hydroprene treatments a distinct advantage over other juvenoids and conventional insecticides used in cockroach control, in that even normally inaccessible areas in an infested premise would eventually be treated without the need to dismantle equipment or to drill holes in void covers or cavity walls and floors. This would represent a major saving in the time taken to achieve a thorough treatment and greatly reduce the disruption of normal life of residents or employees in the premise. In addition, hydroprene can be applied in an infested premise without the need for complex formulations containing solvents and emulsifiers which should improve the already impressive toxicological acceptability of such treatments.

Finally, the use of hydroprene to prevent reproduction in populations of cockroaches being simultaneously treated with hydramethylnon may prevent or slow down the rapid build up of resistance to hydramethylnon by ensuring eradication. Without this type of integrated approach and, in the absence of alternative effective treatments, resistance to hydramethylnon will probably occur if sole reliance on one simple effective treatment is continued in the field. In order to continue the control of cockroaches with hydramethylnon in the future then resistance to this molecule must be prevented.

Hydroprene point sources used in conjunction with hydramethylnon baits offer a unique opportunity to achieve effective control of cockroach infestations, with maximum ease of application and minimal toxicological hazard. The data produced in this trial indicate that hydroprene point sources and hydramethylnon baits can both be effective control measures against German cockroach infestations. Moreover, the combined use of these two insecticides for cockroach control offers savings in the length of time taken to achieve control and ensures eradication of the infestation. Combined treatments may also prevent resistance to hydramethylnon occurring and ensure that it has a long lease of life in UK cockroach control programmes.

ACKNOWLEDGEMENTS

We wish to thank the contributors to the CSL Food Protection Association for funding this project. We also wish to thank Sandoz Speciality Pest Control, Dallas, Texas, U.S.A. for the supply of hydroprene point sources.

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