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Effectiveness of Fenoxycarb for Control of Red Imported Fire Ants (Hymenoptera: Formicidae)[1]

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J. Econ. Entomol. 81(1): 83–87 (1988)

ABSTRACT The insect growth regulator fenoxycarb reduced colony size indices of laboratory colonies of red imported fire ants, *Solenopsis invicta* Buren, by 93–98% within 8 wk after treatment. Reductions were caused by lethality to developing immatures, inhibition of egg production by the queen, and a shift in caste differentiation from worker to sexual forms. No significant difference was noted in the response of colonies to 5 or 10 mg (AI) per colony; the majority of colonies treated at either dosage died as a result of the treatment. In field tests, baits containing fenoxycarb eliminated ca. 60% of the colonies on treated plots and reduced total ant population indices by 67–99% within 12–13 wk after treatment at rates of 6.2–22.6 g (AI)/ha.

KEY WORDS Insecta, fenoxycarb, red imported fire ant, chemical control

RECENT STUDIES to discover and develop new chemical control agents for the red and black imported fire ants, *Solenopsis invicta* Buren and *Solenopsis richteri* Forel, have included chemicals that exhibit low-level toxicity to worker ants but nonetheless cause mortality of colonies through disruption of reproduction or larval and pupal development (Williams et al. 1980, Banks et al. 1981a, Harlan et al. 1981, Lofgren & Williams 1982). For example, we have demonstrated through several laboratory and field studies (Banks et al. 1978, 1983, Banks & Schwarz 1980, Banks & Harlan 1982) that some insect growth regulators (IGRs) inhibit larval development and shift caste determination and can be used to control infestations of red imported fire ants (RIFA).

Fenoxycarb (Maag Agrochemicals RO 13-5223) is one of a group of chemicals with a carbamate moeity that exhibits IGR (juvenile hormone) activity against a variety of insects. Unlike the *N*-ethyl and *N*-methyl carbamates, these compounds do not inhibit cholinesterase. Fenoxycarb is active against cockroaches, mosquitoes, scale insects, psyllids, stored products insects, and certain lepidopterous pests (Dorn et al. 1981, Masner et al. 1981). In preliminary studies (Banks et al. 1983) with RIFA, we found that it caused dramatic alterations in egg-laying and brood development and eventual death of most treated colonies. This study was conducted to assess the effectiveness of fenoxycarb in controlling RIFA.

[1] This article reports the results of research only. Mention of an insecticide or proprietary product does not constitute an endorsement or a recommendation for its use by USDA.

Materials and Methods

Laboratory Tests. Technical grade fenoxycarb was dissolved at 1.0 and 2.0% by weight in once-refined soybean oil (ORSBO); slight heating of the oil to 50–60°C was required for complete dissolution. Calco N-1700 oil-red dye was added to the solutions (0.25% by weight) to serve as a visible tracer.

The oil solutions were offered in 50- or 100-μl pipettes (0.5 ml per colony) to laboratory-reared colonies of RIFA (Banks et al. 1981b) that consisted of a queen, 10–40 ml of brood (eggs, larvae, and pupae), and 30–60 thousand worker ants. Each concentration of the IGR and the control (uncontaminated ORSBO) was tested against a minimum of three colonies. The colonies were given the normal laboratory diet 24 h after treatment and held in the laboratory at 27 ± 2°C for observation. Each colony was examined biweekly through 16 wk and monthly thereafter through 1 yr; most colonies had either died or recovered from obvious effects of the treatment after 1 yr. Each colony was rated at each observation based on the estimated number of worker ants and quantity of worker brood (Table 1).

The numerical value assigned to each rating was used to derive a colony size index by multiplication of the value for worker numbers by the value for brood quantity (e.g., a colony with 20,000 to 35,000 workers and 10 to 20 ml of brood was rated 4D and had a colony index of 4 × 15 = 60). Effectiveness of the treatments was determined by statistical comparison of the colony indices before and after treatment using general linear models. Means

Table 1. Value rating scale for determining the effects of fenoxycarb on laboratory colonies

Worker ants			Worker brood		
Estimated no.	Rating	Value	Estimated ml	Rating	Value
<100	1	1	0	A	1
100–5,000	2	2	1–5	B	5
5,000–20,000	3	3	5–10	C	10
20,000–35,000	4	4	10–20	D	15
35,000–50,000	5	5	20–30	E	20
>50,000	6	6	>30	F	25

Table 2. Method for developing nest index for field colonies treated with Logic bait

No. of worker ants	Worker brood absent		Worker brood present	
	Field rating	Nest index	Field rating	Nest index
<100	1	1	6	5
100–1,000	2	2	7	10
1,000–10,000	3	3	8	15
10,000–50,000	4	4	9	20
>50,000	5	5	10	25

were compared with Duncan's multiple range test ($P = 0.05$; SAS Institute 1982).

Field Tests. The efficacy of fenoxycarb in controlling natural infestations of RIFA was evaluated in four field tests in Georgia and Mississippi. Six bait formulations were prepared in the laboratory. The baits were applied to the test plots with a tractor-mounted granular applicator. Flagmen were used at each end of all plots to ensure proper swath spacing and adequate coverage of the test areas.

All field tests were conducted in nongrazed permanent pastures. Three plots of ca. 0.85 ha each were treated in Hancock County, Miss., in June 1980 (Test 1). Three 0.1-ha subplots were established in each plot for evaluations of ant activity before and after treatment. A single evaluation after treatment was made at 13 wk. Two plots of ca. 2.0 ha each were treated in Harrison County, Miss., in June 1981 (Test 2). Five 0.1-ha subplots were established in each plot for evaluations before and after treatment. One evaluation after treatment was made at 13 wk. Two plots of ca. 2.0 ha each were treated in Brooks County, Ga., in August 1981 (Test 3). Four 0.25-ha subplots were used in each larger plot for evaluations before and after treatment in this test. Evaluation after treatment was made at 12 wk. The fourth test was conducted in Stone County, Miss., in July 1982. Eighteen 0.4-ha plots, with a circular 0.1-ha evaluation subplot in the center of each, were treated. Evaluation after treatment was made at 13 wk. Plots of a size comparable with the test plots were established and left untreated in each test series as controls.

The efficacy of all the treatments was evaluated by the population index method (Harlan et al. 1981) as modified by Lofgren & Williams (1982) and the total ant method of Lofgren & Williams (1985). Both methods involved carefully searching the entire area within each subplot before treatment and at each evaluation after treatment, then opening every nest with a shovel and carefully examining the contents. In the population index method, each active nest was then assigned a rating of 1 to 10 based on the estimated number of worker ants and whether it had worker brood (6–10) or no worker brood (1–5). Since worker brood indicates the colony is probably queenright, these colonies were given a 5-fold higher nest index as shown in Table 2.

The interaction of the number of nests on a subplot and the nest index was used to derive a population index for each subplot that can be expressed mathematically as follows:

$$\text{Population index (PI)} = \sum_{k=1}^{25} K\,(N_k)$$

where N_k is the number of ant colonies on a given subplot with a nest index of K, where ($25 \geq K \geq 1$).

The population indices for plots or treatments in these tests were obtained by summation of the indices for all subplots within the unit. Data from all the field tests were analyzed by analysis of variance (ANOVA). Means were compared with the Waller-Duncan K-ratio t test (K = 100) (SAS Institute 1982).

For the total ant population method, only the five categories for numbers of ants were used. Thus, for category 1, we assumed a total of 100 ants for each nest; for categories 2 to 4, we used a mean of the limits (i.e., 550, 5,500, and 30,000) to assign a numerical size for each nest. Finally, for category 5, we assigned a total of 100,000 ants to each colony. Further details are presented by Lofgren & Williams (1985). The total ants per unit area was simply the number of mounds per category times the assigned average number of ants per mound.

Results and Discussion

Laboratory Tests. The oil solutions of fenoxycarb were very acceptable to the laboratory colonies of RIFA. The 2.0% solution was removed more slowly than the 1.0% solution, indicating possible repellency of the more concentrated solution. Every colony, however, removed all of the oil within 24 h at both concentrations. Substantial amounts of the oil had been passed to the larvae as evidenced by the red dye that was visible through the larval integument at 24 h.

Effects of the fenoxycarb were exhibited by all colonies relatively quickly, with the most obvious effect being a shift from worker brood to sexual brood production. The drastic reduction or total elimination of worker brood resulted in a sharp decline in the colony index by 4 wk after treatment (Table 3). The quantity of worker brood began to decline within 1 wk after treatment and continued

Table 3. Effects of fenoxycarb on laboratory colonies of red imported fire ants

Dosage mg (AI)/colony	No. tests	Avg before treatment colony index[a]	% reduction in colony index after indicated weeks[b]									
			4	8	12	16	20	28	36	44	48	52
5	8	86	85.3a	95.9a	93.9a	97.3a	95.8a	90.5a	87.5a[d]			
10	5	88	92.8a	93.6a	89.8a	95.0a	92.2a	93.0a	94.6a	95.8a	93.8a	91.6a
Control (soybean oil)	8	93.1	−8.0b[c]	−9.4b	−14.1b	0.0b	9.4b	19.6b	24.2b	58.9a	0.0b	70.7a

[a] See text for derivation of colony index.
[b] Means followed by the same letter in a given column are not significantly different ($P = 0.05$; Duncan's multiple range test [SAS Institute 1982]).
[c] Minus sign indicates increase in colony index.
[d] All tests at 5 mg terminated at 36 wk; all treated colonies dead except one that had returned to normal.

to do so until no worker brood was present in any colony (4–8 wk after treatment). No significant differences were noted in the percent reductions in colony indices produced by the dosages of 5 and 10 mg (AI) per colony. At the 5-mg level, however, seven of the eight test colonies had died by 36 wk, whereas the other began recovery between 16 and 20 wk after treatment and had completely recovered by 32 wk. Only three of the five colonies treated at 10 mg had died by 1 yr, and some recovery had occurred in the other two. As we have noted in other studies (Banks 1986), dosage above some minimally effective level does not appear to be a critical factor in the ultimate response of a colony to IGR.

Although the exact mode of action of fenoxycarb on the fire ants is unknown, the disappearance of worker brood could be attributed to three factors: mortality of existing brood through direct toxicity or through disruption of developmental processes (large amounts of dead larvae and pupae were observed in the colony refuse piles during the first two weeks posttreatment); reduction or cessation of egg production by the colony queen; and shift in caste differentiation of new brood from workers to sexual forms (a phenomenon noted in RIFA colonies treated with other IGR (Robeau & Vinson 1976, Banks 1986).

Mortality of laboratory colonies usually required six or more months and could be attributed primarily to lack of worker replacement coupled with natural mortality as the colony aged. We saw little evidence of direct toxicity to the workers or queen (mortality of workers was only 5% after 14 d following 24-h exposure to 1.0% fenoxycarb in the standard bait toxicant test). Accelerated mortality of workers and some queens was noted 8–12 wk after treatment; however, the mortality was probably due more to advancing age of the ants in conjunction with a breakdown in colony organization, maintenance, and food flow, rather than to direct effects of the fenoxycarb.

Field Tests. Baits containing fenoxycarb were very effective in reducing the population indices of the RIFA colonies and the total ant populations in all treated plots except Test 3 (Table 4). Sharp reductions in the number of workers in most nests were noted and worker brood was totally eliminated. No significant differences occurred in the levels of reduction obtained with the different formulations or rates of application in Tests 1 and 2.

In Test 3, the 1.0% formulation produced a higher, though not significantly different, level of population index reduction. The total ant population method revealed no significant difference between reductions produced by the 2.0% bait and the control, and only a 54.8% difference between the 1.0% bait and the control. Reduced effectiveness of the baits in this test was apparently caused by heavy rainfall that left the surface of some plots very wet. The carrier for the baits (pregel defatted corn grits) will disintegrate in water. The assumption that the surface water reduced effectiveness is further supported by the fact that the best control was obtained on the plots (1.0% bait) that were driest. Finally, reductions in this test occurred at the same time that very high increases occurred in the mean indices of the controls.

In Test 4, all doses and rates of application gave high level reductions in the population indices. The only significant difference in levels of reduction occurred with the 1.5% formulation on expanded corncob grits, where the reductions obtained were 6–8% lower than those obtained with the pregel defatted corn grit and the 0.75% expanded corncob grit formulations.

All of the field tests demonstrated that fenoxycarb was effective against natural populations of RIFA. Mortality of colonies occurred more rapidly than had been noted in the laboratory. Overall, an average of ca. 60% of the treated colonies was dead by 13 wk after treatment, and 33.2% more of those that survived at 13 wk had been reduced to <1,000 workers. Only 13.2% of the surviving colonies in the treated plots contained any worker brood, whereas 94.1% of the colonies on the untreated controls contained worker brood.

These tests demonstrate that fenoxycarb is strongly active against RIFA in both the laboratory and field; however, our results in Test 3 emphasize

Table 4. Effects of baits containing fenoxycarb on field populations of red imported fire ants

Formulation[a]	Fenoxycarb g (AI)/ha	Before treatment		$\bar{x}$ reduction (%) after 13 wk[b]		After treatment
		No. active nests	Population index	PI	TAP	% nests with worker brood after 13 wk
			Test 1			
PDCG 1.0%	6.20	59	1,138	91.9a	96.2a	30.9
	9.18	61	1,211	86.9a	97.6a	66.7
PDCG 2.0%	21.17	49	1,070	96.7a	99.4a	16.7
Control	—	65	1,433	25.9b	24.3b	91.7
			Test 2			
PDCG 1.0%	11.74	41	825	97.9a	99.9a	10.0
PDCG 2.0%	20.24	37	865	96.2a	97.2a	0.0
Control	—	58	1,121	11.6b	35.7b	96.1
			Test 3[c]			
PDCG 1.0%	10.85	69	1,513	87.7a	54.8a	0.0
PDCG 2.0%	18.47	54	1,300	68.8a	14.5ab	9.1
Control	—	54	1,155	−58.6b	−184.2b	97.6
			Test 4			
PDCG 0.75%	12.75	45	973	98.2a	94.8a	0.0
	22.65	43	965	98.8a	99.3a	0.0
PDCG 1.50%	13.65	45	890	99.1a	98.2a	0.0
	25.05	48	1,021	98.4a	99.3a	0.0
ECG 0.75%	13.35	43	971	97.5a	98.1a	0.0
ECG 1.50%	11.85	46	960	91.4b	88.0a	9.5
Control	—	44	914	54.6c	37.4b	76.2

[a] PDCG formulations contained 70% pregel defatted corn grits, 30% soybean oil, and toxicant, with concentration of toxicant as indicated; ECG formulations contained 75% expanded corncob grits, 25% soybean oil, and toxicant, with toxicant concentration as indicated; pre- and posttreatment counts made on three to five replicated subplots.

[b] PI, population index; TAP, total ant population. Means followed by the same letter within a column are not significantly different for a given test ($P = 0.05$; Waller-Duncan K-ratio t test [SAS Institute 1982]).

[c] Posttreatment evaluation made at 12 wk in Test 3.

the need to avoid applications to wet soil and vegetation. Efficacy of the chemical in baits as demonstrated in these and other tests (Banks et al. 1983, Banks 1986) has resulted in registration by the U.S. Environmental Protection Agency of a bait (Logic) for RIFA control. Our studies indicate that this bait should provide excellent suppression of RIFA infestations.

Acknowledgment

We thank Maag Agrochemicals for supplying the fenoxycarb and for assistance and encouragement during the studies. We thank J. K. Plumley, D. M. Hicks, P. M. Bishop, L. R. Miles, and J. A. Mitchell for technical assistance and S. W. Avery and Mike Brown for statistical assistance. We also thank the farmers who allowed us to conduct tests on their property.

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Received for publication 2 March 1987; accepted 31 August 1987.