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Imported Fire Ant (Hymenoptera: Formicidae) Control: Evaluation of Several Chemicals for Individual Mound Treatments[1]

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ABSTRACT Ten pesticides in various formulations were applied as aqueous drenches, fumigants, or baits to mounds of *Solenopsis invicta* Buren at rates recommended by the supplier. The most effective chemicals for drenches were acephate 8 or 15.6 EC, carbaryl 23 suspension, bendiocarb 76 WP, chlordane 72 EC, and diazinon 25 EC at application rates of 2.2 to 3.4, 27.2, 4.6, 4.0, and 7.5 g of AI per mound, respectively. Amdro (tetrahydro-5,5-dimethyl-2(1H)-pyrimidinone, [3-[4-trifluoromethyl)phenyl] 1-[2-[4-(trifluoromethyl)phenyl]ethenyl]-2-propenylidene]hydrazone) 0.88% bait was very effective at rates of 0.1 and 0.2 g per mound.

Numerous chemicals have been evaluated for control of the red imported fire ant (RIFA), *Solenopsis invicta* Buren, by one or more of the following application methods: (1) residual control with broadcast applications of granular formulations of chlorinated hydrocarbons such as chlordane and heptachlor (Blake et al. 1959, Lofgren et al. 1961, 1964a); (2) toxic baits in which a toxicant, a food attractant, and a carrier are combined into a granular bait and applied broadcast over large areas (Lofgren et al. 1964b, 1975, Williams et al. 1980, Williams 1983, Banks et al. 1981); and (3) direct application to individual mounds (Lyle and Fortune 1948, Eden and Arant 1949, Blake and Ruffin 1957, Morrill 1976, 1977, Francke 1983) with a wide variety of chemicals formulated as dusts, granulars, emulsifiable concentrates (EC), wettable powders (WP), and baits. The latter type of control is favored by homeowners and persons responsible for RIFA control in school yards, playgrounds, parks, and cemeteries, because control is rapid (usually less than a week), whereas residual chemicals and toxic baits may take weeks to kill all of the worker ants. Also, individual mound treatments are usually environmentally safe, moderately hazardous to humans and their animals, easy to use, reasonably priced, and effective in one or two applications.

The recent literature on tests with chemicals for the control of individual colonies of imported fire ants is extensive. However, it is very difficult to compare the results because of the numerous variables involved, i.e., type of soil, size of mounds, time of year applications were made, type of formulations used, rate and method of application, colony movement, and procedures used to determine effectiveness of the chemical. These variables make it very difficult to compare the efficacy of the same chemicals evaluated in different tests at various research facilities by different scientists. We have, however, complied a list of all chemicals (Table 1) that have been reported to give > 80% control during one test, even if tested by only one researcher. We did not list most of the chlorinated hydrocarbon insecticides because they are no longer available for RIFA control.

During the past few years nine of the chemicals listed in Table 1 have been registered by EPA for RIFA control as individual mound treatments. Our laboratory also has been asked to evaluate many of these same chemicals. Consequently, we conducted a series of three tests with 10 chemicals to obtain comparative data on their effectiveness when applied at rates recommended by the supplier. The results are presented in this paper with the expectation that the data will be useful to persons required to make recommendations for control of RIFA.

Materials and Methods

Tests were conducted with seven chemicals at Lakeland, Fl., (LF) in October and Novemebr 1978 and Ocala, Fl., (OF) in July and August 1980 and with nine chemicals at Valdosta, Ga., (VG) in September and October 1980. The chemicals and formulations tested at each location are listed in Table 2.

The test site at LF was an improved pasture on reclaimed phosphate-mined land with well-drained, thick to moderately thick acid sands covered with Argentine Bahia grass. The OF test site was located in an improved pasture on a horse farm with predominantly thick to moderately thick acid sandy soil covered with common Bahia grass. The test site at VG was located in a pecan orchard containing a large amount of leaf litter and humus. The soil type was a red clay mixed with acid sand and sandy loam, and the sparse ground cover consisted mainly of bermuda grass.

A randomized complete block design (Steel and Torrie 1960) was used in which 10 or 15 RIFA mounds, depending on the site, were selected for each treatment or as checks. Only queen-right colonies were used. This condition was determined by digging into each mound with a small shovel and observing for the presence of the different ant castes. Queen-right colonies contain large numbers of workers, worker brood (larvae and pupae), and usually some alates (winged forms). Abnormal mounds contain large numbers of major workers, alates, and sex brood, with a conspicuous lack of worker brood.

[1]Mention of a commercial or proprietary product does not constitute an endorsement of this product by the USDA. Received for publication 8 November 1982; accepted 23 August 1983.

The location of each test mound was marked with a stake and a surveyor's flag. Also, a map was drawn of each area, and the location of each mound was plotted on the map by compass bearing. All mounds (active or inactive, treatments and checks) were plotted on the map so that any movement or fragmentation of colonies from its original mound could be detected.

Twenty mounds at the LF site and 15 mounds at the OF and VG sites were randomly selected, and measurements of their diameters and heights were recorded. The volume of soil in the above-ground portion of each mound was calculated assuming that they were in the shape of a hemisphere. Thus, we used the formula for a sphere ($V = \frac{4r^3}{3}$) and divided the result by 2.

Because fundamental differences exist in the reactivity of pesticides on various soils (Barlow and Hadaway 1956, Harris 1964, Getzin 1981), we analyzed the soil at each test site. Soil samples were collected at five locations throughout each test site by inserting a soil sampling tube and removing a plug 15.24 cm long by 2.54 cm in diameter. At the time of soil analysis, the samples for each test site were mixed thoroughly and then subdivided into five subsamples. The pH and parts per million of Ca, Mg, P, and K were determined for each subsample.

All drenches were applied by the method described by Morrill (1976). This method consisted of wetting the top of the mound first, then soaking the perimeter, and finally pouring the remaining solution on to the top of the mound at a height sufficient to allow penetration. Granular formulations such as Amdro (Tetrahydro-5,5-dimethyl-2(1H)-pyrimidinone,[3-[4-trifluoromethyl) phenyl]1-[2-[4-(trifluoromethyl)phenyl]ethenyl]-2-propenylidene]hydrazone) were uniformly distributed within ca. 1 m around the base of each mound. Technical liquids were poured directly on the mounds.

Posttreatment evaluation of all mounds in the LF test was conducted at 1, 2, and 5 weeks; evaluations of the OF and VG test were conducted at 1, 2, 3, and 4 weeks. Control (estimated percent mortality) was determined by digging into each mound and estimating the percent mortality of workers and brood. Thus, mortality within each colony could range from 0 to 100%. This procedure was similar to the method described by Harlan et al. (1981) for estimating colony size in their toxic bait studies. The same individuals made all of the estimates to minimize variations associated with personal judgments. Estimates of colony size or mortality included colony fragments or satellites induced by the chemical treatments. The percent control obtained with each chemical (treatment) was obtained by averaging the percent mortalities observed at all posttreatment observations for all mounds (replications) treated with each chemical. Therefore, each percent mortality reported in Table 2 represents the average of 30 to 60 separate population estimates (10 or 15 colonies × three or four observations) over a period of 4 or 5 weeks. All untreated mounds (water only) were evaluated in the same manner as the treated mounds. Colony activity and movement of any mound (distance and frequency) was plotted on the location map so that variations in colony movement or fragmentation could be detected from one observation period to the next.

Analysis of the data was accomplished by using general linear models (GLM) in SAS (79.5 version) with mortality as the dependent variable; Duncan's multiple range test was used to compare means for each insecticide. The effect of insecticide, dose, time, replication

Table 1. Chemicals reported effective for control (>80%) of individual colonies of RIFA in their mounds[a]

Chemical	Reference(s)
Acephate[b]	Marshall and Martin (1980), Gardner (1980), Bass and Hays (1982)
Amdro[b,c]	Francke (1983)
Bant[c,d]	Francke (1983)
Bendiocarb[b]	Gardner (1980), Gardner (1981), Francke (1983)
Bufencarb	Hillman (1977)
Carbaryl[b]	Morrill (1976), Bass and Hays (1982), Francke (1983)
Chlordane[e]	Hillman (1976, 1977)
Chlorpyrifos[b]	Hillman (1976, 1977), Morrill (1977), Gardner (1980), Marshall and Martin (1980), Bass and Hays (1982), Horton et al. (1982), Francke (1983)
Diazinon[b]	Hillman (1976, 1977), Morrill (1977), Gardner (1980, 1981), Bass and Hays (1982), Francke (1983)
Malathion	Morrill (1976), Hillman (1976)
Methyl bromide[b]	Hillman (1976, 1977)
Mirex[c,e]	Bass and Hays (1982)
Permethrin	Bass and Hays (1982), Bass et al. (1982)
Rotenone[b]	Morrill (1976)
Trichlorfon	Morrill (1976)
1,1,1-Trichloroethane[b]	Scarborough et al. (1982)

[a]Details of formulation, dosage, and evaluation procedures vary greatly; see individual publications for this information.
[b]EPA registration based on information received from EPA dated 15 March 1983.
[c]Bait formulations.
[d]Development of product discontinued by Eli Lilly Co.
[e]EPA registrations withdrawn.

Table 2. Toxicity of 10 insecticides applied as drenches to nests of the RIFA

Insecticide	Formulation	AI (g/nest)	Mean % mortality at[a,b]:			
			Lakeland, Fla. (LF)	Ocala, Fla. (OF)	Valdosta, Ga. (VG)	Ocala-Valdosta[c]
Acephate	75SP	4.5	89a			
	15.6 EC	3.4	80ab			
	8 EC	2.3		93a	89a	91a
	15.6 EC	2.2		90a	91a	91a
Carbaryl[d]	23 Suspension[e]	27.2		83abc	94a	87ab
	Sevimol[f]	13.6	53de			
Bendiocarb[d]	76 WP	4.6		78bc	95a	87ab
Chlordane	72 EC	4.0	83ab		94a	
Diazinon	25 EC	7.5	71bc	87ab	82ab	85ab
Amdro[g]	0.88 Bait	0.2		81bc	84ab	82b
		0.1		78bc		
Phosmet	50 WP	4.0	77ab	82abc	65c	73c
Chlorpyrifos	6.7 EC	7.0			68c	
		3.5–3.8	60cd	74c	70c	71c
Permethrin	25 EC	7.1			68c	
1,1,1-Trichloroethane	Technical	284.0	44e			
		142.0	32e			
(Check)			4f	4d	0d	2d

[a]Mean percent mortality of 10 nests per treatment at Ocala and Valdosta; 15 nests at Lakeland. Posttreatment evaluations at Lakeland were conducted at 1, 2, and 5 weeks, and those at Ocala and Valdosta were at 1, 2, 3, and 4 weeks.

[b]Means followed by the same letter for the location indicated are not significantly different at the $P = 0.05$ level, by Duncan's multiple range test.

[c]This column averages the results of the Ocala and Valdosta tests.

[d]Applied 7.6 liters of water per mound. All other drenches were applied at 3.8 liters per mound.

[e]Formulation was an aqueous, water-base suspension.

[f]Formulation was an aqueous, molasses-base suspension.

[g]Applied as a granular bait around the base of each mound.

and interactions of dose × insecticide and time × insecticide were tested for all locations. Also, the interaction between two of the locations (Ocala, Fla., and Valdosta, Ga.) was tested for differences in mortality that might exist. Finally, the data from soil analysis at each location were analyzed by GLM in SAS (79.6 version) with the soil pH and the ppm of Ca, Mg, P, and K as dependent variables; the Waller-Duncan K Ratio *t* test was used to compare variables for each location.

Results and Discussion

The test results at the three sites are presented in Table 2. The most effective chemicals, when compared at the rates that were recommended by the suppliers, were acephate, chlordane, and carbaryl (mean control of 81 to 94%). Our results with chlordane and carbaryl, although slightly less effective, were still consistent with tests reported by Hillman (1976) and Morrill (1976). No significant differences were noted between the SP and EC formulations of acephate; however, the Sevimol formulation of carbaryl was significantly less effective than the suspension formulation.

Diazinon, Amdro, bendiocarb, and phosmet were very effective also (71 to 95% mortality), but they were significantly less effective than acephate, chlordane, and carbaryl in at least one test. Chlorpyrifos (60 to 74% mortality) was significantly less effective than acephate at all three test sites, but was equal in effectiveness to the other chemicals at one or two test sites. The moderate control with chlorpyrifos differs from the 90%+ control reported by Hillman (1976, 1977) and Morrill (1977).

Permethrin, which was tested only at VG, gave control comparable to chlorpyrifos and phosmet. 1,1,1-Trichloroethane was relatively ineffective. Our results with this compound are in sharp contrast to those reported by Scarborough and Burne (1982). The reason for the poor control we obtained might be due to the different soil types in the two test areas. This chemical is very volatile and may be less effective in the loose, sandy soils found in Lakeland, Fla., than in soils that are more compact and contain more organic material.

The comparative analysis of the results at the OF and VG sites revealed no significant differences ($P > 0.05$); thus, the results of those chemicals tested at the same rates at both locations were pooled and analyzed. This analysis showed no significant difference in control with five of the chemicals: acephate (EC, 2 g of AI), carbaryl (suspension, 27.2 g of AI), bendiocarb (76 WP, 4.6 g AI), chlordane (72 EC, 2 g of AI), and diazinon (25 EC, 7.5 g of AI). Amdro bait (0.88%, 0.2 g of AI) was as effective as the last four chemicals, but phosmet and chlorpyrifos were less effective than all five chemicals.

No significant difference could be associated with different application rates of acephate, Amdro, and chlorpyrifos.

Although our tests were conducted in the summer and fall due to our work schedule, it is important to note that better control is obtained if treatments are made in the spring or fall of the year and not in the hot summer

Table 3. Size of mounds at test sites

Site	Mean and range (cm)		
	Diam	Height	Vol (cm^3)[a]
Lakeland, Fla.	74 (46–104)	28 (15–38)	106,088
Ocala, Fla.	40 (27–52)	8 (3–15)	16,755
Valdosta, Ga.	63 (43–91)	16 (5–28)	68,629

[a]Volume based on above-ground dimensions of mounds.

months (Hillman 1967). Also, applications made during wet periods when the brood in the mound is near the top of the mound give better control (Morrill 1977).

The average diameter, height, and volume of the mounds are reported in Table 3. The largest mounds occurred at LF and the smallest at OF. When the RIFA control data are reviewed with respect to mound size, better control was obviously obtained with the colonies occupying the smaller mounds. This was expected, since large mounds require a larger volume of an insecticide drench to obtain complete coverage and saturation (Hillman 1977). A corollary axiom is that escape of workers from a mound drench may be associated with lack of insecticide coverage and penetration of mounds that are very large. Morrill (1976) reported a reduction in control in mounds which had been knocked down during a mowing operation and were rebuilt into irregular shapes, making complete coverage with drenches difficult.

The movement of some of the colonies from their original mounds occurred in every treatment, including those mounds treated with water only (checks). This occurred at each test site. This is a rather common occurrence when individual mounds of the RIFA are treated and thus disturbed (Hillman 1976, 1977, Gardner 1980, Bass and Hays 1982, Scarborough et al. 1982).

The largest amount of colony movement (93%) occurred when mounds were treated with 1,1,1-trichloroethane, whereas treatments with both chlorpyrifos and bendiocarb resulted in movement of 80% of the colonies. The smallest amount of colony movement occurred with the acephate (11%) and Amdro bait (20%) treatments. The remaining chemicals were similar in effect to the check (water-only treatments), which caused 60% of the colonies to move from their original location. This high rate of colony movement is not unusual, since many times RIFA colonies will relocate their mounds for no apparent reason (Hays et al. 1982). In fact, Green (1952) reported that colonies change location of the mound often, and one colony which he observed constructed three mounds during a 24-h period.

The movement of colonies as a result of insecticidal treatments can cause a great deal of confusion on the part of researchers making evaluations (Francke 1983). This problem is undoubtedly one of the major causes of differences in results reported by various researchers with the same chemical. Any researcher evaluating control techniques against RIFA must plot and record on a map the exact location of all active and inactive mounds before and throughout the test period. Without this information, the test results will be largely biased in favor of 100% control when, in reality, the colony may have simply moved to another location. Another related factor involves the ability to determine whether or not the queen may have been killed. If so, these satellite colonies will die; if not, the queen will be cared for by the workers and the colony will rebuild itself. This condition can be detected by the presence of worker brood.

The pH at all locations was slightly acidic and was not significantly different ($P > 0.05$) between locations (Table 4). Analysis of the data of the four soil elements indicated that the primary difference involved the concentration of Ca and Mg. The OF and VG locations contained significantly more of these two elements than the LF location. This difference correlates with the degree of control at the three locations and suggests that further research is needed on the effect of Ca and Mg on RIFA control with insecticidal drenches.

The results that we obtained with all of the chemicals tested are consistent with those of other researchers, except with three chemicals: chlorpyrifos, permethrin and 1,1,1-trichloroethane. These three chemicals did not give the high control reported by other researchers. The moderate degree of control we obtained with chlorpyrifos is perplexing, since eight separate references (Table 1) report over 80% control of RIFA. However, the results of our three tests were consistent. The reasons for the differences could be due to a number of factors; however, the wide variety of techniques used by the different researchers, as well as the lack of information on environmental, edaphic, and biological conditions, make speculation on the causes difficult and inappropriate at this time. Despite this problem, it is evident that certain chemicals have consistently controlled RIFA colonies and can be recommended for use when applied according to the label approved by EPA.

Table 4. Analysis of soil from test sites

Site	pH	Avg ppm of[a]:			
		Ca	Mg	P	K
Lakeland, Fla.	6.8 (6.4–7.1)a	352 (295–520)a	21 (20–22)a	65 (50–74)a	23 (19–32)a
Ocala, Fla.	6.9 (6.4–7.3)a	1,006 (890–1,200)b	95 (73–100)b	41 (34–46)b	15 (7–31)ab
Valdosta, Ga.	6.6 (6.0–7.0)a	989 (455–1,210)b	67 (11–110)b	83 (43–103)a	9 (5–13)b

[a]Means followed by the same letter for the location indicated are not significantly different at the $P = 0.05$ level, by Waller-Duncan's K Ratio *t* test.

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