Efficacy of Broadcast and Perimeter Applications of S-Methoprene Bait on the Red Imported Fire Ant in Grazed Pastures

MATTHEW D. AUBUCHON,[1] G. R. MULLEN, and M. D. EUBANKS

Department of Entomology and Plant Pathology, 301 Funchess Hall, Auburn University, Auburn, AL 36849

J. Econ. Entomol. 99(3): 621–625 (2006)

ABSTRACT The red imported fire ant, *Solenopsis invicta* (Buren), is a major pest in the United States because of its painful sting. Toxic bait has been an important management tool against fire ants, but site registrations prohibit applications of most baits on grazed pastures. Extinguish, containing the insect growth regulator methoprene, was selected for this study because it has a broad site registration that includes grazed pastures. The primary objective of this research was to evaluate the efficacy for control of red imported fire ants by using broadcast applications of methoprene bait at a label rate of 1,121 g/ha versus applications around the perimeter of a target area at the reduced rate of 280 g/ha. Grazed pastures in Lee County, Alabama, and Chambers County, Alabama, were selected for this study, with broadcast treatments, perimeter treatments, and controls replicated three times at each site. All mounds were counted and rated using the USDA population index before applications and then at 8 and 16 wk posttreatment. Perimeter applications did not significantly reduce *S. invicta* mound abundance, but bait treatments significantly reduced mound abundance at 16 wk posttreatment at site 1 where applications were conducted in early evening. However, broadcast applications were not effective at site 2 where treatments were conducted in early morning with warmer temperatures. Emergence of winged alates was observed at 12 wk posttreatment, followed by a high density of incipient mounds that may have masked the full treatment effect of methoprene applications at site 2. Methoprene bait was effective in reducing abundance of *S. invicta* only when full label rates were applied.

KEY WORDS *Solenopsis invicta*, fire ants, bait, insect growth regualtor, methoprene

The red imported fire ant, *Solenopsis invicta* Buren, was introduced at Mobile, Alabama, in the 1930s and subsequently dispersed throughout the southeastern United States (Brown 1961, Lofgren et al. 1975). Because of its painful sting and high population densities, it is a pest in agricultural, urban, and pasture areas. Attempts to quarantine or eradicate *S. invicta* have been ineffective and have only slowed its expansion (Brown 1961, Allen et al. 1993). Chemical applications can temporarily reduce fire ant populations in confined regions, but they do not prevent recolonization. Although biological control measures are being explored, chemical control remains the only reliable method of managing *S. invicta*, especially in agricultural situations.

Methoprene has been formulated into bait for control of *S. invicta*, although research has primarily focused on laboratory experiments (Vinson et al. 1974, Robeau and Vinson 1976). Methoprene caused retrogression of ovaries of queens, deformities, reduced success in eclosion, caste shifting of developing larvae from workers to alates, and death in some larvae (Cupp and O'Neal 1973, Troisi and Riddiford 1974, Robeau and Vinson 1976, Banks and Schwarz 1980, Glancey and Banks 1988). Active methoprene remained stable for months in the crops of large workers and was distributed throughout the colony via trophallaxis (Morrill 1978, Banks and Schwarz 1980). It also caused gradual decline in laboratory colonies, but its effects were dosage-dependent, with total colony mortality ranging from 4 to 16 mo (Hung 1974).

Foraging studies have revealed evidence of food sharing among adjacent colonies of *S. invicta.* Summerlin et al. (1975) used colored soybean oil to study food sharing along intercolonial boundaries of monogynous *S. invicta.* Drees et al. (1992) showed similar evidence of resource sharing among polygynous colonies by selectively treating mounds with an insect growth regulator (IGR). The presence of IGR in mounds existing in untreated areas suggested that lower application rates of IGRs may be feasible (Drees et al. 1992). If food sharing allows intercolonial transfer of toxic baits, then treatment strategies using transects or perimeter treatments may provide large-scale suppression of *S. invicta* and reduce application costs.

Methoprene bait (Extinguish, Wellmark, Dallas, TX) was selected for this study because it is registered for use in both grazed and nongrazed pastures. Pasture

[1] Current address: Department of Entomology and Nematology, University of Florida, Building 970 Natural Area Dr., Gainesville, FL 32611.

environments often support high densities of *S. invicta* mounds that damage cutter blades used for harvesting hay (Agricultural Extension Service 1998). In addition to damage, cattle ranchers must spend time and money treating fire ants to curb the losses associated with infestation (Agricultural Extension Service 1998).

The elimination of insecticides is impractical, but the reduction of chemical applications is a reasonable goal in fire ant management. Fewer insecticide applications mean that farmers and landowners invest less time, labor, and money managing fire ants. The primary objective of this research was to evaluate the efficacy for control of red imported fire ants using broadcast applications of methoprene bait at label rate of 1,121 g/ha versus applications around the perimeter of a target area at the reduced rate of 280 g/ha.

Materials and Methods

Sites. Two grazed pastures were selected for this study. Site 1 is an ≈8.8-ha pasture located in Chambers County, Alabama, adjacent to Hwy. 147 and is situated 16 km north of Auburn. It is generally flat, with Lloyd clay loam soils and centipedegrass, *Eremochloa ophiuroides* (Munro) Hack, as primary forage vegetation (Carter et al. 1959). Cattle were present daily throughout the field season. Site 2 is an ≈8-ha pasture located in Lee County, Alabama, off County Road 43, 2.4 km south of site 1. This pasture has steeper slopes with Gwinnett sandy loam soils (McNutt 1981). Vegetation consisted of horse nettle, *Solanum carolinense* L.; bahiagrass, *Paspalum notatum* Flugge; Bermuda grass, *Cynodon dactylon* (L.) Pers.; and clover (*Trifolium* spp.). Cattle were present at site 2 on alternate weeks and were rotated among adjacent pastures. Colonies of *S. invicta* at both sites were determined to be monogyne based upon mound density and distribution throughout the plots (Greenberg et al. 1985, Porter et al. 1991, Porter 1992).

Treatments. The treatments used in this study consisted of broadcast and perimeter applications with untreated controls. Broadcast applications consisted of 20 swaths per plot, delivering 454 g per treatment plot. Perimeter applications consisted of one swath applied around the plot border, delivering 113.5 g per treatment plot. All application rates conformed to the label requirements for Extinguish. Plots measured 64 by 64 m (≈0.41 ha), with a 30-m buffer between plots to minimize colony movement among treatment and control plots. Applications of Extinguish were made with a Toro prototype bait spreader which provided a treatment swath of 3 m. Nine plots were established at each site and grouped into three blocks. A broadcast application, perimeter application, and a control were randomly assigned within each block.

Site 1 was treated on 19 June 1999 between 4 and 6 p.m. under partially cloudy conditions, with temperatures ranging from 25 to 27°C. Site 2 was treated on 22 June 1999 between 9 and 10:30 a.m. under sunny conditions, with an initial air temperature at 32°C.

Population Index. Individual mounds were rated using the USDA–Animal and Plant Health Inspection Service (APHIS) population index (PI) (Lofgren and Williams 1982): $PI = \Sigma^{25} K\ (N_K)$, where $K = 1$.

The index assigns a value (K) to each mound based on size and brood production where $1 \leq K \leq 25$. The value K is multiplied by the number of mounds (N_K) within each plot, yielding PI values.

Ant mortality, expressed as mound counts, PI ratings, and percentages, was calculated by subtracting the preliminary measurements from the two posttreatment counts. Because fire ants move brood through the mound to optimize developmental temperatures, mounds were counted and rated only when ambient air temperature between 22 and 30°C to ensure data accuracy.

Data Analysis. This study was set up as a random complete block design where each block contained both treatments and a control. Data were pooled into a three-way analysis of variance (ANOVA) consisting of site, time, and treatments as main factors with mound abundance and population indices as dependent variables (SAS Institute 1992, Cody and Smith 1997). Interaction terms were included in the initial three-way analysis and postanalyses were conducted as needed for significant results. Means separation was conducted using a Student–Newman–Keuls test.

Table 1. Results of the means-separation tests for three-way analysis of variance with site, time, and treatment as main factors and mound abundance and population index as response variables

Main factors	N	Response variables: Mound abundance	Pop index
Site			
1	27	36.63 ± 3.01a	417.41 ± 46.54a
2	27	22.88 ± 1.75b	687.19 ± 56.28b
Time			
Pretreatment	18	31.50 ± 1.94a	672.11 ± 48.42a
8 wk	18	25.26 ± 1.27a	395.89 ± 39.49b
16 wk	18	32.50 ± 5.50a	588.89 ± 95.82a
Treatment			
Broadcast	18	26.55 ± 3.91a	467.89 ± 79.31b
Perimeter	18	28.55 ± 2.67a	498.11 ± 60.30b
Control	18	34.16 ± 3.62a	690.89 ± 61.63a

Means within a column with the same letter are not significantly different ($P = 0.05$ [SAS Institute 1992]).

Results

Results of the overall three-way model showed site 2 had a significantly greater abundance of mounds ($F = 20.97$; df = 1, 36; $P < 0.0001$) and a significantly higher PI ($F = 28.85$; df = 1, 36; $P < 0.0001$) than site 1 (Table 1). Although no other main factors in the overall model were significant for mound abundance, population indices for *S. invicta* were significantly lower in perimeter and broadcast treatments ($F = 7.74$; df = 2, 36; $P = 0.0016$) than in untreated controls (Table 1). Overall PI of *S. invicta* significantly decreased by 8 wk posttreatment ($F = 10.61$; df = 2, 36; $P = 0.0002$), but at 16 wk the PI significantly increased to pretreatment levels (Table 1).

The interaction of site × time was significant for both mound abundance ($F = 8.78$; df = 2, 36; $P =$

Table 2. Results of the means-separation tests for one-way analyses of variance at each site comparing mound abundance and population index through time

Site	Time	*N*	Response variables	
			Mound abundance	Pop index
1	Pretreatment	9	28.33 ± 2.48a	605.00 ± 59.65a
	8 wk	9	23.56 ± 1.62ab	336.22 ± 58.61b
	16 wk	9	16.77 ± 3.58b	311.00 ± 86.57b
2	Pretreatment	9	34.67 ± 2.70ab	739.20 ± 72.69a
	8 wk	9	27.00 ± 1.88b	456.60 ± 48.01b
	16 wk	9	48.22 ± 7.34a	866.80 ± 86.57a

Means within a column with the same letter are not significantly different ($P = 0.05$ [SAS Institute 1992]).

0.0008) and PI ($F = 8.11$; df = 2, 36; $P = 0.0012$) (Table 1). Postanalyses for these interactions consisted of separate one-way analyses of variance for each site with time analyzed against mound abundance and PI. Results showed mean mound abundance at site 1 was significantly lower by 16 wk posttreatment than pretreatment levels ($F = 4.67$; df = 2, 24; $P = 0.0194$) (Table 2). Similarly, the PI for *S. invicta* significantly decreased at site 1 by 8 wk and 16 wk posttreatment ($F = 5.50$; df = 2, 24; $P = 0.0180$) (Table 2). At site 2, postanalysis showed a significant decrease in mound abundance ($F = 5.35$; df = 2, 24; $P = 0.012$) and PI ($F = 6.71$; df = 2, 24; $P = 0.0048$) at 8 wk posttreatment followed by a significant increase of both response variables by 16 wk posttreatment (Table 2).

The interaction of time × treatment was also significant ($F = 3.51$; df = 4, 36; $P = 0.0162$) in the overall model for PI measurements. Therefore, additional one-way ANOVAs were conducted for each level of time with treatment analyzed against PI. Results showed a significant decrease in PI measurements in broadcast and perimeter treatments by 8 wk posttreatment compared with the controls ($F = 8.29$; df = 2, 15; $P = 0.0038$) (Table 3). However, none of the treatments were significantly different from untreated controls at 16 wk posttreatment ($F = 2.63$; df = 2, 15; $P = 0.104$) (Table 3).

Means ± SE and percentages for mound abundance and PI for each site, treatment, and time were generated to describe treatment performance at each site (Table 4). At site 1, broadcast applications of methoprene bait provided gradual reduction of *S. invicta* mounds over 3 to 4 mo and reduced mean mound abundance by 85% at 16 wk with mean PIs reduced by 95% (Table 4). Perimeter treatments provided only a 21% reduction of mean mound abundance with 36% reduction in the mean PI at 16 wk posttreatment (Table 4). At site 2, however, mean mound abundance within broadcast applications initially decreased by 29% by 8 wk posttreatment, but at 16 wk, mean mound abundance was 20% greater than pretreatment measurements (Table 4). The mean PI for broadcast treatments at site 2 yielded only a 26% reduction from pretreatment measurements (Table 4). Mean mound abundance within perimeter treatments also decreased by 26% at 8 wk posttreatment, but at 16 wk mean mound abundance was 8% greater than pretreatment measurements. Similarly, mean PIs within perimeter applications decreased by 41% at 8 wk but increased at 16 wk, yielding a net 17% reduction from pretreatment measurements (Table 4).

Discussion

An alate flight was observed at ≈12 wk posttreatment at site 2 that resulted in a high number of incipient mounds throughout treatment and control plots by 16 wk posttreatment (Table 4). Although reinfestation occurred throughout all treatments, the highest density of incipient mounds occurred within a broadcast plot and a control plot (Table 4). Because new mounds contained worker brood, mean population indices among treatments and controls also increased (Table 4). As a result, the increased means and standard errors for both dependent variables at 16 wk posttreatment not only obscured mortality of *S. invicta* within treatments at site 2 but also may have prevented the three-way model from detecting any significant treatment effects at site 1 where broadcast applications reduced mean mound abundance and mean population indices by >85% (Tables 1 and 4).

High temperatures during and after bait applications at site 2 may have influenced foraging activity by *S. invicta.* Studies on heat tolerance have suggested that *S. invicta* workers forage between 15 and 43°C, with an upper lethal temperature range of 40.8–47.3°C, depending upon prior temperature acclimation (Francke et al. 1985, Porter and Tschinkel 1987). However, Francke et al. (1985) also indicated that 100% RH increased fire ant mortality at lower temperatures compared with mortality measured at 0% RH. Mortality associated with combined effects of high temperature and high relative humidity is more applicable to field conditions in Alabama. Observations by Porter and Tschinkel (1987) in open pastures showed that baiting with meat, a concentrated high-protein food source, evoked a different foraging response than smaller, scattered baits of lower quality. Despite *S. invicta*'s wide activity range, high temperatures can severely restrict foraging activity (Porter and Tschinkel 1987).

Table 3. Results of the means-separation tests for one-way analyses of variance comparing population index among treatments at each level of time

Time	Treatment	*N*	Mean pop index
Pretreatment	Broadcast	6	723.30 ± 58.01a
	Perimeter	6	645.50 ± 120.93a
	Control	6	647.50 ± 71.73a
8 wk	Broadcast	6	274.30 ± 42.15b
	Perimeter	6	357.67 ± 99.21b
	Control	6	555.67 ± 38.11a
16 wk	Broadcast	6	406.00 ± 194.21a
	Perimeter	6	491.20 ± 65.80a
	Control	6	869.50 ± 147.44a

Means within a column with the same letter are not significantly different ($P = 0.05$ [SAS Institute 1992]).

Table 4. Means ± SE for *S. invicta* mound abundance and population indices per site and treatment with percentage difference through time

Mound abundance		*N*	Pretreatment	8 wk	% difference	16 wk	% difference
Site	Treatment						
1	Broadcast	3	32.00 ± 6.93	22.00 ± 1.73	−31	4.67 ± 4.04	−85
	Perimeter	3	23.33 ± 10.50	21.33 ± 5.86	−8	18.00 ± 6.00	−21
	Control	3	29.67 ± 2.08	27.33 ± 5.03	−7	27.67 ± 3.05	−7
2	Broadcast	3	34.67 ± 4.62	24.33 ± 3.51	−29	41.67 ± 31.65	+20
	Perimeter	3	38.67 ± 10.06	28.00 ± 2.64	−26	42.00 ± 9.53	+8
	Control	3	30.67 ± 9.61	28.67 ± 9.61	−6	61.00 ± 21.93	+98
Pop index							
1	Broadcast	3	708.00 ± 121.13	222.00 ± 105.50	−68	33.00 ± 28.62	−95
	Perimeter	3	474.30 ± 241.58	237.67 ± 94.93	−50	302.67 ± 124.99	−36
	Control	3	632.70 ± 111.29	549.00 ± 38.31	−13	597.33 ± 119.82	−5
2	Broadcast	3	738.67 ± 187.36	326.67 ± 85.50	−55	545.30 ± 447.94	−26
	Perimeter	3	816.67 ± 270.42	477.67 ± 112.86	−41	679.70 ± 159.52	−17
	Control	3	662.33 ± 253.25	562.33 ± 142.06	−15	1141.70 ± 299.16	+72

The efficacy of methoprene bait at site 2 also may have been compromised by high temperatures combined with sunny conditions (Schaefer and Dupras 1973, Gill et al. 1974, Mulla and Darwazeh 1975, Norland and Mulla 1975, Quistad et al. 1975). Experiments with methoprene residue under heat and UV light indicated that photolysis was the most significant mechanism of environmental degradation (Quistad et al. 1975). Similar studies with Amdro (hydramethylnon) fire ant bait have shown that UV light quickly degrades the active ingredient, suggesting that evening applications may be more effective than daytime applications (Vander Meer et al. 1982).

Previous studies with fenoxycarb baits have shown significant reductions of fire ant population indices as early as 4 wk posttreatment, with up to 95% mound mortality by 12 to 13 wk posttreatment (Adams et al. 1983, 1988; Callcott and Collins 1992). However, faster effects of Logic bait may have been attributed in part to its formulation at 1% fenoxycarb, compared with 0.5% methoprene in Extinguish (Hung 1974, Cokendolpher and Phillips 1989). Subsequent reinfestations into treatment areas by *S. invicta* also were reported between 3 and 4 mo posttreatment (Adams et al. 1988, Callcott and Collins 1992). Callcott et al. (1992) reported that incipient mounds as well as mature mounds relocating from surrounding areas were the source of reinfestation.

Food sharing as a mechanism for transferring active IGR between fire ant colonies has been documented among colonies; however, it is important to note that previous studies were conducted with polygynous colonies of *S. invicta* (Summerlin et al. 1975, Drees et al. 1992). Polygynous colonies establish higher densities per area and are less territorial than the monogynous form (Vargo and Porter 1989, Porter 1991, Macom and Porter 1996). Neighboring colonies of monogynous *S. invicta* may limit simultaneous foraging along territory boundaries that are rich in resources, or bait (Hays et al. 1982, Ryti and Case 1986, Tschinkel 1992, Korzukhin and Porter 1994). Similar studies on territoriality among harvester ants (*Pogonomyrmex* spp.) revealed that nearest colonies could simultaneously forage along a territory boundary, but resource discovery in that area was significantly slower than other territorial regions (Ryti and Case 1986). Such time lags could increase exposure of methoprene to degradative effects of heat and sunlight (Quistad et al. 1975).

Perimeter applications in this study provided marginal but not significant reduction of *S. invicta* mound abundance and suggest that no active ingredient was transferred toward the central region of the plots. If any bait sharing did occur, the distance between treatment swaths was too great; 113 g of bait per plot was too small of a dosage to significantly affect *S. invicta* activity. Future trials with smaller plots would be necessary to determine the scale at which this approach may be effective. Additionally, broadcast treatments conducted in mid-morning were ineffective. It is recommended that bait applications be made at temperatures when *S. invicta* colonies are most active.

Acknowledgments

We thank George Folkerts for service and invaluable help. Michelle Perdue provided valuable assistance in the field and laboratory. Lawrence Graham, Kathy Flanders, and David Gaylor provided technical and field assistance with global positioning system and geographical information system (GIS) equipment. John Beck, Phil Cheney, and Mark MacKenzie provided assistance with GIS software. Faith Oi and Patricia Cobb provided generous travel assistance for professional meetings. Mark West provided statistical advice, and Doug VanGundy of Zoecon provided Extinguish bait product used in this research. Lee Ensminger of Lee County, Alabama, and Joe Robertson of Chambers County, Alabama, graciously allowed us to conduct the described field studies on their properties.

References Cited

Adams, C. T., W. A. Banks, C. S. Lofgren, B. J. Smittle, and D. P. Harlan. 1983. Impact of the red imported fire ant, *Solenopsis invicta* (Hymenoptera: Formicidae), on the growth and yield of soybeans. J. Econ. Entomol. 76: 1129–1132.

Adams, C. T., W. A. Banks, and C. S. Lofgren. 1988. Red imported fire ant (Hymenoptera: Formicidae): correlation of ant density with damage to two cultivars of potatoes (*Solanum tuberosum* L.). J. Econ. Entomol. 81: 905–909.

Agricultural Extension Service. 1998. Managing red imported fire ants in agriculture, pp. 18. *In* T.A.E. Service [ed.]. The Texas A&M University System, College Station, TX.

Allen, C. R., S. A. Phillips, Jr., and M. R. Trostle. 1993. Range expansion by the ecologically disruptive red imported fire ant into the Texas Rio Grande Valley. Southwest. Entomol. 18: 315–316.

Banks, W. A., and M. Schwarz. 1980. The effects of insect growth regulators on laboratory and field colonies of red imported fire ants, pp. 95–105. *In* The fire ant problem. Tall Timbers Res. Stn., Tallahassee, FL.

Brown, W. L., Jr. 1961. Mass insect control programs: four case histories. Psyche 58: 74–111.

Callcott, A.M.A., and H. L. Collins. 1992. Temporal changes in a red imported fire ant (Hymenoptera: Formicidae) colony classification system following an insecticidal treatment. J. Entomol. Sci. 27: 345–353.

Carter, O. R., E. A. Perry, W. V. Harlin, F. Stephens, W. B. Davey, A. W. Pollard, and I. L. Martin. 1959. Soil survey of Chambers county, Alabama. U.S. Government Printing Office, Washington, DC.

Cody, R. P., and J. K. Smith. 1997. Applied statistics and the SAS programming language. Simon & Schuster, Upper Saddle River, NJ.

Cokendolpher, J. C., and S. A. Phillips, Jr. 1989. Rate of spread of the red imported fire ant, *Solenopsis invicta* (Hymenoptera: Formicidae), in Texas. Southwest. Nat. 34: 443–449.

Cupp, E. W., and J. O'Neal. 1973. The morphogenic effects of two juvenile hormone analogues on larvae of imported fire ants. Environ. Entomol. 2: 191–194.

Drees, B. M., C. L. Barr, and S. B. Vinson. 1992. Effects of spot treatments of Logic (fenoxycarb) on polygynous red imported fire ants: an indication of resource sharing? Southwest. Entomol. 17: 313–317.

Francke, O. F., L. R. Potts, and J. C. Cokendolpher. 1985. Heat tolerances of four species of fire ants (Hymenoptera: Formicidae: *Solenopsis*). Southwest. Nat. 30: 59–68.

Gill, S. S., B. D. Hammock, and J. E. Casida. 1974. Mammalian metabolism and environmental degradation of the juvenoid 1-(4′-ethylphenoxy)-3,7-dimethyl-6,7-epoxy-*trans*-2-octene and related compounds. J. Agric. Food Chem. 22: 386–395.

Glancey, B. M., and W. A. Banks. 1988. Effect of the insect growth regulator fenoxycarb on the ovaries of queens of the red imported fire ant (Hymenoptera: Formicidae). Ann. Entomol. Soc. Am. 81: 642–648.

Greenberg, L., D.J.C. Fletcher, and S. B. Vinson. 1985. Differences in worker size and mound distribution in monogynous and polygynous colonies of the fire ant *Solenopsis invicta* Buren. J. Kans. Entomol. Soc. 58: 9–18.

Hays, S. B., P. M. Horton, J. A. Bass, and D. Stanley. 1982. Colony movement of imported fire ants. J. Ga. Entomol. Soc. 17: 266–274.

Hung, A.C.F. 1974. Ants recovered from refuse pile of the pyramid ant *Conomyrma insana* (Buckley) (Hymenoptera: Formcidae). Ann. Entomol. Soc. Am. 67: 522–523.

Korzukhin, M. D., and S. D. Porter. 1994. Spatial model of territorial competition and population dynamics in the fire ant *Solenopsis invicta* (Hymenoptera: Formicidae). Environ. Entomol. 23: 912–922.

Lofgren, C. S., and D. F. Williams. 1982. Avermectin B1a: highly potent inhibitor of reproduction by queens of the red imported fire ant (Hymenoptera: Formicidae). J. Econ. Entomol. 75: 798–803.

Lofgren, C. S., W. A. Banks, and B. M. Glancey. 1975. Biology and control of imported fire ants. Annu. Rev. Entomol. 20: 1–30.

Macom, T. E., and S. D. Porter. 1996. Comparison of polygyne and monogyne red imported fire ant (Hymenoptera: Formicidae) population densities. Ann. Entomol. Soc. Am. 89: 535–543.

McNutt, R. B. 1981. Soil survey of Lee county, Alabama. U.S. Government Printing Office, Washington, DC.

Morrill, W. L. 1978. Red imported fire ant predation of the alfalfa weevil and pea aphid. J. Econ. Entomol. 71: 867–868.

Mulla, M. S., and H. A. Darwazeh. 1975. Activity and longevity of insect growth regulators against mosquitoes. J. Econ. Entomol. 68: 791–794.

Norland, R. L., and M. S. Mulla. 1975. Impact of altosid on selected members of an aquatic ecosystem. Environ. Entomol. 4: 145–152.

Porter, S. D. 1991. Origins of new queens in polygyne red imported fire ant colonies (Hymenoptera: Formicidae). J. Entomol. Sci. 26: 474–478.

Porter, S. D. 1992. Frequency and distribution of polygyne fire ants (Hymenoptera: Formicidae) in Florida. Fla. Entomol. 75: 248–257.

Porter, S. D., and W. R. Tschinkel. 1987. Foraging in *Solenopsis invicta* (Hymenoptera: Formicidae): effects of weather and season. Environ. Entomol. 16: 802–808.

Porter, S. D., A. Bhatkar, R. Mulder, S. B. Vinson, and D. J. Clair. 1991. Distribution and density of polygyne fire ants (Hymenoptera: Formicidae) in Texas. J. Econ. Entomol. 84: 866–874.

Quistad, G. B., L. E. Staiger, and D. A. Schooley. 1975. Environmental degradation of the insect growth regulator methoprene. Pestic. Biochem. Physiol. 5: 233–241.

Robeau, R., and S. B. Vinson. 1976. Effects of juvenile hormone analogues on caste differentiation in the imported fire ant, *Solenopsis invicta.* J. Ga. Entomol. Soc. 11: 198–203.

Ryti, R. T., and T. J. Case. 1986. Overdisperson of ant colonies: a test of hypotheses. Oecologia (Berl.) 69: 446–453.

SAS Institute. 1992. SAS stat user's guide, version 6. SAS Institute, Cary, NC.

Schaefer, C. H., and E. F. Dupras Jr. 1973. Insect developmental inhibitors. 4. Persistence of ZR-515 in water. J. Econ. Entomol. 66: 923–925.

Summerlin, J. W., W. A. Banks, and K. H. Schroeder. 1975. Food exchange between mounds of the red imported fire ant. Ann. Entomol. Soc. Am. 68: 863–866.

Troisi, S. J., and L. M. Riddiford. 1974. Juvenile hormone effects on metamorphosis and reproduction of the fire ant, *Solenopsis invicta.* Environ. Entomol. 3: 112–116.

Tschinkel, W. R. 1992. Brood raiding in the fire ant, *Solenopsis invicta* (Hymenoptera: Formicidae): laboratory and field observations. Ann. Entomol. Soc. Am. 85: 638–646.

Vander Meer, R. K., D. F. Williams, and C. S. Lofgren. 1982. Degradation of the toxicant AC 217,300 in Amdro imported fire ant bait under field conditions. J. Agric. Food Chem. 30: 1045–1048.

Vargo, E. L., and S. D. Porter. 1989. Colony reproduction by budding in the polygyne form of *Solenopsis invicta* (Hymenoptera: Formicidae). Ann. Entomol. Soc. Amer. 82: 307–313.

Vinson, S. B., R. Rboeau, and L. Dzuik. 1974. Bioassay and activity of several insect growth regulators on the imported fire ant. J. Econ. Entomol. 67: 325–328.

Received 8 September 2005; accepted 7 February 2006.