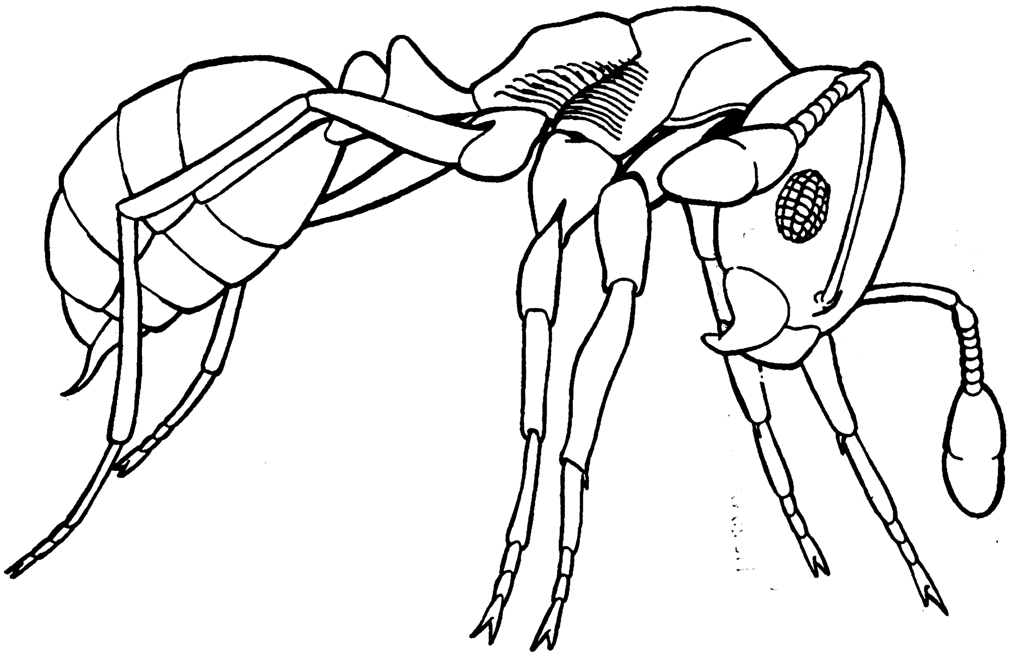
United States
Department of
Agriculture

Animal and
Plant Health
Inspection
Service

Technical
Bulletin No. 1807

Control of Imported Fire Ants

A Review of Current Knowledge



Abstract

Efforts to control imported fire ants (*Solenopsis richteri* Forel, and *S. invicta* Buren) in the Southeastern United States date back to 1937, when calcium cyanide was used against *S. richteri*. In the 1960's, mirex was applied to millions of acres throughout the infested area. The registration of newer baits in the 1980's resulted in more environmentally acceptable, though more expensive, methods of control. In general, broadcast applications of baits are preferred over all other methods of chemical control, such as insecticidal drenches, fumigants, and granular treatments, due to relative cost, effectiveness, and environmental concerns. The search for effective biological control agents has not been successful. Therefore, it appears that chemical control techniques must be relied on for suppressing imported fire ants in the foreseeable future.

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Issued August 1992

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By Homer Collins[1]

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[1] Homer Collins is with the Plant Protection and Quarantine staff of the U.S. Department of Agriculture's Animal and Plant Health Inspection Service. He is located at the Imported Fire Ant Station, Gulfport, MS.

Historical Perspective

Early Control Programs With Contact-Action Insecticides

Less than 10 years after Loding (1929) reported the presence of imported fire ants (IFA) in the United States, the first organized control program began. That program was initiated in February 1937 in Baldwin County, AL, and four Federal, State, and county agencies cooperated. The Alabama Department of Agriculture and Industries provided a field supervisor; the Extension Service of the Alabama Polytechnic Institute provided technical information and assisted in mapping out areas to be treated; the Commissioner's Court of Baldwin County provided the Cyanogas® dust; and the Works Progress Administration provided the labor. One to 3 oz of "A" grade dust (48-percent calcium cyanide) was applied per nest by digging into the mound with a shovel, sprinkling the dust, and covering it with soil. Approximately 2,000 acres of vegetable cropland were treated in this manner (Eden and Arant 1949).

In the spring of 1947, the Mississippi State Plant Board began a limited control and research program, and in 1948 Mississippi appropriated $15,000 to fight the fire ant (Wilson and Eads 1949). Purportedly, good results were obtained with 5-percent chlordane dust.

Research to gain information on the biology, control, distribution, and economic importance of IFA was begun in 1949 in Alabama. This cooperative project was conducted by Alabama, Mississippi, Florida, and the U.S. Department of Agriculture (USDA). In 1952, IFA were found in North Carolina. Treatment was promptly begun, and establishment of the pest was prevented. The Louisiana Legislature appropriated funds in 1952 to purchase chlordane to be furnished at cost to farmers. The Louisiana Extension Service and USDA conducted demonstrations throughout the infested areas of the State to show farmers how to use the insecticide against IFA. In June 1957, the Arkansas Plant Board conducted a fire ant eradication program on 12,000 acres in Union County, including the city of El Dorado. In this project, aircraft applied granular heptachlor at the rate of 2 lb/acre with excellent results (Anonymous 1958).

By 1953, IFA had invaded 102 counties in 10 States (Culpepper 1953), and by 1957, mounting public concern prompted the U.S. Congress to provide funds and authorize USDA to initiate a cooperative Federal–State control/eradication program. For the 12 months beginning in July 1957, $2.4 million was appropriated by Congress to be matched by funds from State agencies, local sources, and/or individual farmers. The first treatments were applied in November 1957. The rate of application was 2 lb of granular dieldrin or heptachlor per acre. In 1959, the rate of application was changed to 1.25 lb of dieldrin or heptachlor per acre. Due to growing concerns about wildlife and residue problems, the rate was soon changed to 0.25 lb/acre, applied twice at 3- to 6-month intervals. In late 1958, Senator Sparkman and Congressman Boykin of Alabama asked that the fire ant campaign be suspended until benefits and dangers could be properly evaluated. Furthermore, the Food and Drug Administration of the U.S. Department of Health, Education, and Welfare lowered the tolerance for heptachlor residues on harvested crops to zero. This change occurred after the disclosure that residues of heptachlor epoxide had been found in meat and milk. In all, some 2.5 million acres were treated with one or more of the formulations discussed above (Brown 1961). For additional details on the history of the imported fire ant in the United States, see Lofgren (1986a).

Development of Toxic Baits

Even before the aerial control programs with chlorinated hydrocarbons began, researchers were aware of the potential hazards of these insecticides and had started to develop a new system of ant control based on the use of poisoned baits. Baits are far more environmentally acceptable than contact-action insecticides because baits use relatively small amounts of pesticide. All baits are comprised of a low-concentration active ingredient (usually less than 1.0 percent), a feeding attractant, and an inert carrier. Green (1952) tested a bait consisting of thallium sulphate with cornmeal and oil and reported that the material was very effective on captive colonies but was ignored when scattered around fire ant mounds in the field. Hays and Arant (1960) developed a peanut butter-based bait that incorporated very low concentrations of an extremely slow-acting toxicant called Kepone®.

The development of fire-ant bait toxicants was an especially slow and tedious process due to the very stringent efficacy requirements. Stringer et al. (1964) noted that an effective bait toxicant must (1) exhibit delayed kill over at least a 10-fold dosage range and preferably above a 100-fold dosage range, (2) be readily transferred from one ant to another via trophylaxis and kill the recipient, and (3) not be repellent to foraging ants. Very few insecticides possess all three characteristics, and only those qualify for use in fire ant baits.

Mirex®—In 1957, USDA launched an extensive search for an effective toxic bait. Lofgren et al. (1962) reported on mirex, a highly effective toxicant that provided 99- to 100-percent control in every test after 4 weeks. More extensive trials (Lofgren et al. 1964) confirmed high levels of control at low rates of application. That year, mirex became the insecticide of choice for use in the cooperative Federal–State control program (Lofgren et al. 1975).

Millions of acres were treated with mirex using airplanes of various types, including converted World War II bombers. In 1962, mirex was applied at a bulk rate of 10 lb/acre; the rate was reduced in 1963 to 2.5 lb/acre and in 1965, to 1.25 lb/acre.

Mirex bait was comprised of three components. The active ingredient was the chemical mirex, and soybean oil was used as the feeding attractant and also as a solvent for the active ingredient. The third component, ground corncob grits, served as an inert carrier for the toxicant and the feeding attractant. At its application rate of 1.25 lb/acre, the formulation contained only 0.06 oz of pesticide. However, USDA investigators and others subsequently showed that mirex persists in the environment and bioaccumulates in the tissues of nontarget organisms (Butler 1969, Markin et al. 1974a and b).

In 1971, the U.S. Environmental Protection Agency (EPA) placed restrictions on mirex, limiting its use to 1 application in any 12-month period. Also, EPA stipulated that estuaries, coastal counties, and other similar areas not be treated with mirex. EPA cancelled all mirex registratons, effective December 31, 1977. Existing stocks of the pesticide had to be used by June 30, 1978, with application by ground equipment only (Johnson 1976). For an indepth review of the Federal–State mirex control program, see Alley (1973). Table 1 relates the chronology of the use of mirex in controlling IFA.

Table 1—Chronology of the Cooperative Federal–State IFA Control Program's use of mirex

1962	Mirex bait adopted as standard treatment
1967	10.7 million acres treated
1968	14.2 million acres treated
1969	11.1 million acres treated
3/18/71	Mirex registration—1st notice of cancellation
1972	18.7 million acres treated
1973	10.6 million acres treated
1974	10.6 million acres treated
3/31/77	Aerial application disapproved
6/30/78	Final cancellation of all registrations

Ferriamicide—In response to mounting concerns over potential environmental consequences from the use of mirex bait, the Mississippi Authority for Control of Fire Ants, a division of the Mississippi Department of Agriculture and Commerce, funded a research effort by the Mississippi State Chemistry Laboratory to develop a biodegradable formulation of mirex. The research effort was led by Earl Alley, and the resulting formulation was known as ferriamicide. Table 2 details components of the ferriamicide formulation.

Table 2—Ferriamicide bait composition and function

Substance	Use
Corncob grit	Carrier
Soybean oil	Attractant
Mirex (0.05%)	Toxicant
Kemamine T1902D	Degradation enhancer
Ferrous chloride	Degradation enhancer
Citric acid	Antioxidant
Propylene glycol	Solvent and kepone inhibitor

Source: Alley (1982).

According to Alley (1982), the amine and ferrous chloride components of the ferriamicide formulation reduced the half-life of mirex from 12 years to about 55 days. An experimental-use permit to evaluate ferriamicide was granted by EPA on September 9, 1977, with an expiration date of October 1, 1978. Collins (1979) reported 84-percent control with ferriamicide 12 weeks following aerial application to test plots in central and southern Mississippi. In 1981, the Mississippi Authority for Control of Fire Ants submitted a request for conditional registration of ferriamicide. This request was subsequently denied by EPA, and the bait was never sold commercially.

Amdro®—Cancellation of mirex initiated an intensive effort by USDA and the pesticide industry to develop other chemical toxicants, as well as insect growth regulators and reproduction inhibitors for use in baits against fire ants (Lofgren 1986b). After testing more than 5,000 compounds, Williams et al. (1980) reported that American Cyanamid AC-217,300 was very effective against laboratory colonies of IFA. Subsequent field trials (Banks et al. 1981, Harlan et al. 1981) confirmed efficacy of the product, to which American Cyanamid ultimately gave the trade name Amdro. It was registered for use by EPA in August 1980. Amdro (active ingredient hydramethylnon) is registered for treatment of individual fire ant colonies or for broadcast application by either ground or aerial dispersal systems. Application may be made to pasture and range grass, lawns, turf, and other nonagricultural land, including plant nurseries.

Prodrone®—Laboratory tests with AI3-36206 (Stauffer MV-678) were initiated by USDA's Agricultural Research Service (ARS) in September 1974. Results of field tests with this insect growth regulator were reported by Banks et al. (1978). Because the mode of action of insect growth regulators is totally different from that of direct toxicants, such as mirex and hydramethylnon, differences in colony effects can be readily observed. Stauffer MV-678 disrupts caste differentiation and also inhibits egg production and worker replacement. This product received EPA registration February 22, 1983, for application to pasture and range grass, lawns, turf, and nonagricultural land. Stauffer Chemical Co. marketed this product as Prodrone for several years. It was applied twice a year at a rate of 0.88 lb of bait per acre. Prodrone is no longer marketed for fire ant control, primarily because homeowners and other applicators proved reluctant to purchase a product that has to be applied twice a year.

Affirm®—The active ingredient in Affirm fire ant bait (avermectin B_1a) was originally derived from the soil micro-organism *Streptomyces avermitilis* (Burg et al. 1979, Miller et al. 1979). Affirm was developed by Merck, Sharp, and Dohme Laboratories. Activity against IFA was first reported by Lofgren and Williams (1982), and registration for use on nonagricultural land was granted April 18, 1986. The primary mode of action of this unique product is prevention of oogenesis by the colony queen (Glancey et al. 1982). Application rate is 50 mg active ingredient per acre in 1 lb of bait. Affirm is no longer marketed for control of IFA by its developer. However, this bait is currently marketed as Black Flag® Fire Ant Ender by Boyle–Midway Household Products, Inc., and by Whitmire Research Laboratories, Inc., as PT® 370 Ascend Fire Ant Bait. Both Ascend and Fire Ant Ender are registered for use on turf, lawns, and other noncrop areas, such as parks and golf courses.

Logic®—The active ingredient in Logic bait (fenoxycarb) is a chemical with a carbamate moeity that acts as an insect growth regulator against a variety of insects. In preliminary studies, Banks et al. (1983) found that fenoxycarb causes dramatic alterations in egg-laying and brood development and eventual death of most treated colonies. Other trials (Banks 1986, Banks et al. 1988) confirmed efficacy, and Maag Agrochemical Company registered a fenoxycarb bait as Logic in October 1985. Fenoxycarb bait is currently marketed by Ciba-Geigy Corporation under the original trade name Logic and also as Award . Logic is approved for use on nonbearing citrus, whereas Award is labelled for application to turf and other nonagricultural land, including parks, playgrounds, lawns, golf courses, nurseries, and sports fields.

Fluoroaliphatic Sulfones—Vander Meer et al. (1985, 1986) reported the discovery of a new class of delayed-action insecticides, fluoroaliphatic sulfones, that showed promise against fire ants and other pests. Griffin Corp. was licensed by the U.S. Department of Commerce to develop these compounds commercially as fire ant toxicants. After assessing all data and availability of compounds, Griffin decided to commercialize compound 29757. This product was first designated GX-071 and later given the common name sulfluramid.

Banks et al. (1992) field-tested several sulfluramid bait formulations and found that rates of 1.0 to 5.5 g active ingredient in 0.75 to 1.5 lb formulated bait per acre resulted in 80- to 99-percent control. FMC Corp. (Philadelphia, PA) was granted exclusive rights from Griffin Corp. in 1992 to market sulfluramid for fire ant control by professional pest control operators on lawns and turf (John F. Wright, pers. commun.). Development of sulfluramid baits for the homeowner market will remain under the auspices of Griffin Corp. (Joe Mares, pers. commun.).

The development of bait toxicants has been a major undertaking, requiring years of testing and the investment of millions of dollars. At last tally, more than 7,000 compounds have been tested as fire-ant bait toxicants (Vander Meer et al. 1986, Banks et al. 1992). However, only five of these toxicants have ever been commercialized, and two of those are no longer available.

Methods of IFA Control

The public has been subjected to a veritable flood of misinformation on fire ant control. As a result, people are often poorly informed and frequently misuse pesticides in an effort to deal with problems caused by IFA. Only by understanding and applying sound biological principles can people successfully manage their fire ant-related problems. Because IFA are widespread in the South and live in many different habitats, each effort toward population suppression or management should be adapted to specific needs. Attempts to achieve fire ant control can be divided into four major categories: broadcast bait applications, spot treatments with contact toxicants or baits, biological control, and cultural control.

Broadcast Bait Applications

As previously mentioned, fire ant baits containing avermectin (Fire Ant Ender and Ascend), fenoxycarb (Logic and Award), or hydramethylnon (Amdro) were commercially available in 1992. All baits are registered for application to nonagricultural land at a rate of 1.0 to 1.5 lb/acre. Amdro is also registered for application to pasture and range grass, and Logic is approved for use on nonbearing citrus. No bait is registered for application to cropland.

Broadcast application of baits is usually the most cost-effective means of fire-ant population suppression and, in general, is preferred over all other methods of control. When properly applied, baits normally kill 85–95 percent of the colonies in a treated area; but 8–12 weeks are often required to reach this level of control, even under optimal conditions. Either aerial or ground dispersal equipment can be used to broadcast bait in the field. However, the low-volume rates of application of fire ant baits place very rigid requirements on dispersal equipment.

Dispersal Equipment—Baits must be uniformly distributed over the treatment area at labelled rates of application in order to maximize effectiveness. Skips or overtreatment should be avoided. Selection of the proper dispersal equipment should be based on the size of the treatment area.

Small Area Equipment—Small areas, such as lawns or playgrounds, can be treated with small, hand-held applicators such as a Cyclone® Seeder, Model 1C1; Red Devil® Model HHBS-125; or Ortho® Whirly Bird. Care must be taken to use the lowest setting and walk rapidly over the treatment area to avoid overtreatment. These small seeders usually provide a swath 10–15 ft wide and are suitable for treatment of up to 1 acre. Their relatively low cost ($10–$25) makes them especially attractive to homeowners.

Mechanized Ground Application Equipment—At least three different systems have been developed for installation on tractors, all-terrain vehicles, trucks, and other vehicles. This type of system is best suited for treatment of areas ranging in size from 1 to about 25 acres. Two are experimental units, but one is commercially available. Williams et al. (1983) described an auger-applicator that can be mounted on a tractor, Jeep , or truck and is capable of accurately applying a variety of granular formulations at 0.75 to 5 lb/acre. Collins (1987 unpubl.) described a different system that can be easily constructed from commercially available components and is usually attached to a farm tractor. The only commercially available system for use with ground equipment is a Herd GT-77A bait applicator (Herd Seeder Co., Logansport, IN).

Aerial Dispersal Systems—All available aerial delivery systems must be modified to achieve the low-volume rate of application of baits. Collins and Roland (1982 unpubl.) described a baffle plate assembly that was used successfully to modify a 1977 Cessna Ag-Truck for the application of fire ant baits.

General Guidelines for Bait Application—

Weather—Efficacy of fire ant baits is directly affected by weather conditions. Ants do not forage when the soil temperature is below 60 °F. If bait is applied under these conditions, it may not be picked up by foraging workers and distributed among other colony members. Foraging is also greatly diminished under extremely hot, dry conditions. Midday application under these conditions should be avoided when possible. Bait should not be applied when plant foliage is wet from heavy dew or recent rainfall. Obviously, wind directly affects bait displacement during aerial application, and wind of varying velocities and directions is far more detrimental than steady winds. There are no hard and fast rules relative to wind, but in general, it is acceptable to continue aerial treatment until the wind velocity exceeds 10–12 mi/h. Pilots prefer to spray crosswind, starting on the downwind side and working into the wind. This pattern keeps the bait off the airplane and also protects the flag carriers from exposure to the falling bait.

Storage and Handling—Fire ant baits must be kept dry. When possible, hangars, warehouses, or other suitable buildings should be used for storage. All currently used fire ant baits employ soybean oil as a feeding attractant, and soybean oil will eventually become rancid and nonpalatable to foraging worker ants. Storage of any bait at high temperatures for long periods should be avoided. Instructions for disposal of empty containers are printed on the pesticide label. Protective clothing such as rubber gloves may be indicated and must be used if required by the label.

Individual Mound or Spot Treatment of Nests

A number of commonly used insecticides, including acephate, bendiocarb, carbaryl, chlorpyrifos, diazinon, and malathion, are registered and marketed as drenches, dusts, granules, and aerosols for spot treatment of fire ant nests. These contact chemicals kill more rapidly than baits and are often favored by homeowners who desire quick kill of only a few mounds. However, due to cost and logistics, the contact chemicals are impractical for use on large areas, such as farms, parks, or playgrounds.

Mound Drenches—Mound drenches with aqueous emulsions or suspensions of an insecticide are a very common approach to treating individual mounds. Good control is often related to the volume of liquid applied to the nest; therefore, the nest must be thoroughly saturated. Banks (1990) recommended 1 gal of solution for mounds up to 8 inches in diameter and 2 gal for larger mounds. Drenches are most effective when applied about midmorning on sunny days after cool nights in the early spring or late fall. The ants, including queens and immatures, are concentrated near the top of the nest at such times and are more likely to be contacted by the insecticide. Drench treatments applied during hot, dry weather, when the ants have retreated deep within the mound, are often ineffective (Banks 1990).

Dusts and Granules—Several dust and granular formulations are labelled for application to the surface of the mound and surrounding soil. They may be left dry, or watered in with a sprinkler can or hose sprinkler, depending on label instructions. These products are generally far less effective than drenches, although acephate dust and diazinon granules have been reported to cause significant fire ant mortality (Hillman 1977, Drees 1986 unpubl., Diffie et al. 1988 unpubl., Lemke and Kissam 1987).

Aerosols and Injectables—Aerosols of chlorpyrifos alone, or in combination with pyrethrins, have been used to treat individual fire ant mounds. A standard pushbutton aerosol cap, fitted with a fiberglass probe, is attached to an aerosol container filled with insecticide. The spray is activated, the probe is inserted into the mound at from one to four sites (depending on its size), and the chemical is released for about 5 seconds at each insertion site. Although the chemical is neatly packaged for easy handling and is dispersed throughout the mound more quickly than drenching would achieve, the method has not been shown to give significantly better control than chlorpyrifos drenches (Horton et al. 1982, Drees 1986 unpubl., Lemke and Kissam 1987, Diffie et al. 1988 unpubl.). The cost per mound is somewhat higher for the aerosol than for the drench (Banks 1990).

A variation of the aerosol injection for individual mound treatment involves the use of thermofumigation apparatus whereby an insecticide is vaporized prior to injection under pressure through a metal probe (Evans 1988). Although the system usually employs resmethrin, other pyrethroids can be used. Thorvilson et al. (1989) obtained very quick kill of fire ants with a mean colony size reduction of 98 percent at 4 weeks after treatment. The unit cost to treat nests of IFA is unknown but is presumed to be far more expensive than drenches or broadcast bait applications due to capital outlay for the apparatus as well as labor.

Fumigants—Methyl chloroform (1, 1, 1-trichloroethane) is registered in some of the fire ant-infested States (see section 24c of the Federal Insecticide, Fungicide and Rodenticide Act) as a pour-on fumigant for treatment of individual mounds. In the majority of efficacy tests, the recommended rate of 2–3 oz of technical liquid per mound provides 40- to 65-percent control (Williams and Lofgren 1983, Drees 1986 unpubl., Lemke and Kissam 1987). However, one study (Scarborough et al. 1982) reported more than 90-percent control.

Fumigation of fire ants with methyl bromide has been used with limited success since the early 1950's (Green 1952, Hillman 1977, Medley and Cuevas 1981 unpubl.). Methyl bromide is currently marketed in 1.5-lb canisters as Brom-O-Gas by Great Lakes Chemical Corporation.

If individual mound treatments are less than 100-percent effective in killing all the ants in a colony, the surviving ants usually abandon the original mound and build 1 or more new mounds nearby. In such cases, additional treatments are necessary to eliminate the colonies. Individual mound treatment, regardless of the technique or pesticide used, is a very labor-intensive method of combating the ants and is impractical for use in large areas. In such situations, the quantity of insecticide applied and the cost per unit area may be much higher and the level of control lower than with broadcast applications of an effective bait (Banks 1990).

Baits—Spot treatments with baits are sometimes applicable to small areas. All baits that are registered for broadcast application can also be used for spot treatment of individual fire ant nests. However, as mentioned above, broadcast applications are usually more effective.

Biological Control

Although scores of species of arthropods have been collected from nests of the red imported fire ant (*Solenopsis invicta* Buren), most associates are transient and have no specific relationship with fire ants (Collins and Markin 1971, Silviera–Guido et al. 1973, Neece and Bartell 1981, Summerlin 1978). However, endoparasites, inquilines, socially parasitic ants, and live-in predators are also known to inhabit fire ant nests. Some diseases, including viral, fungal, and protozoan, have also been identified. Although these natural enemies are known, no single organism has been shown to offer true population suppression of IFA, either in the ants' native South American homeland or in the United States.

Pathogens and other natural enemies of the imported fire ant and the tropical fire ant *(Solenopsis geminata)* have been reviewed by Jouvenaz et al. (1981) and Jouvenaz (1983). For convenience of the reader, each category of natural enemy will be considered separately in this review.

Pathogens—

Viruses—Viruslike particles have been detected in an undescribed *Solenopsis* sp. from Brazil (Avery et al. 1977). Their pathogenicity is yet undetermined, but similar or identical particles in the tropical fire ant appear benign or only mildly pathogenic (Jouvenaz et al. 1981).

Bacteria—A possible bacterial infection was observed in one colony of *S. invicta* in Brazil by Jouvenaz et al. (1980). Unfortunately, at that time it was not possible to isolate and culture this organism under field conditions. Broome (1974) investigated the effect of several bacterial and fungal cultures on IFA. Although a significant effect was achieved in the laboratory, field trials produced only slight success. Miller and Brown (1983) were able to induce low levels of infection in the laboratory with several known insect pathogens, including *Serratia marcescens, Pseudomonas aeruginosa,* and other bacterial cultures.

Fungi—The only micro-organism that appears to be specifically associated with IFA in the United States is an unidentified, unicellular fungus that occurs in the haemolymph of *S. invicta* (Jouvenaz 1986). The cells are club shaped and multiply by budding. A mycelial form develops in vitro and in the haemolymph of lepidopterous larvae (which are susceptible to infection by injection only). The fungus can be transmitted perorally to healthy *S. invicta* colonies. Although the cells may become very numerous in the haemolymph, there are usually no physical or behavioral signs of infection. On occasion, however, high mortality (with death preceded by tremors) has occurred in infected laboratory colonies. Field populations of *S. invicta* are not obviously reduced, even in areas where the infection rates approach 50 percent. Jouvenaz et al. (1977) found this organism in 9.23 percent of 1,007 colonies of *S. invicta* from 6 States.

Beauveria bassiana is a general, nonspecific fungal pathogen that affects many different insect species. Several reports on the pathogenicity of *B. bassiana* against IFA have indicated low-level rates of infection in the laboratory with minimal success under field conditions (Broome et al. 1976, Callcott et al. 1988 unpubl.).

However, for the past several years, Jerry Stimac, at the University of Florida, has worked with a Brazilian isolate of *B. bassiana*. Although there is only limited information on the efficacy of the Brazilian strain of *Beauveria* (Stimac et al. 1988), a patent for the use of this pathogen for control of IFA was granted to Stimac in July 1990. Commercialization remains a possibility. Research on this fungal pathogen is also continuing at Texas Tech University under the direction of Harlan Thorvilson (Sánchez and Thorvilson 1991).

Protozoa—The first specific pathogen isolated from fire ants was detected by W. F. Buren during a taxonomic study of *S. invicta* from Mato Grosso, Brazil (Allen and Buren 1974). While examining alcohol-preserved specimens, Buren observed subspherical, cystlike bodies in the partially cleared gasters of worker ants. These bodies were found to contain spores of a microsporidium that was subsequently named *Thelohania solenopsae* by Knell et al. (1977). *T. solenopsae* infects fat body cells of workers and sexuals and the ovaries of queens. Infected cells hypertrophy, forming the cysts observed by Buren. The disease is not rapidly fatal, but the fat body is destroyed, resulting in premature death of adult ants and debilitation of the colony. Attempts to transmit this microsporidium perorally have failed (Jouvenaz et al. 1981).

Another microsporidium, *Burenella dimorpha*, is a parasite of *S. geminata* in Florida, and is readily transmitted perorally to *S. invicta* and *S. richteri* (Jouvenaz and Hazard 1978). However, the infection does not persist in the laboratory and has not been detected in *S. invicta* in nature.

Mattesia geminata (Apicomplexa: Neogregarinida) infects *S. geminata* in Florida and various other *Solenopsis* spp. in Brazil (Jouvenaz and Anthony 1979). This genus is characterized by cycles of micronuclear and macronuclear merogony, and by gametogeny resulting in the development of two octonucleate spores within a membrane (gametocysts). In *M. geminata,* the gametocyst membrane is transient, and the lemon-shaped spores are confined to the hypodermal tissues. The signs of *M. geminata* infection occur in pupae and are pathognomonic. The developing eyes become blurred and irregular (much like those of pupae infected with the microsporidium *B. dimorpha).* The cuticle then melanizes abnormally, beginning in the legs and posterior margins of the sclerites of the gaster. The pupa progresses from a "sooty" appearance to almost solid black. As in the case of *B. dimorpha*, fire ant pupae infected by *M. geminata* have never been observed to reach maturity.

The mode of transmission of *M. geminata* is unknown; according to Jouvenaz (1986), attempts to transmit infection perorally and by placing diseased pupae in healthy colonies have failed. The intracolonial infection rates are usually less than 5 percent but may exceed 90 percent.

A second (undescribed) neogregarine infects *S. invicta* in Brazil. The spores of this species are morphologically distinct from those of *M. geminata* and develop in the fat body rather than hypodermal tissues. There are neither physical nor behavioral signs of infection, and infected ants survive into adulthood (Jouvenaz 1986).

Nematodes—The potential for entomogenous nematodes in the genus *Neoaplectana (Steinernema)* to control IFA has been investigated by a number of researchers. Poole (1976) determined in laboratory assays that larvae and pupae of the imported fire ant are relatively susceptible to *N. dutkyi* while adult workers are much less suceptible. Quattlebaum (1980) reported that 1 million–2 million infective juvenile *N. carpocapsae* per mound killed 60–97 percent of treated colonies 2 weeks after treatment. Miller et al. (1988) achieved minimal control in a series of field trials in Texas and Florida. Similar results were obtained by Collins et al. (1988 unpubl.) and by Jouvenaz et al. (1990). Collins and Lindregren (1990 unpubl.) evaluated a Mexican isolate of *S. carpocapsae* known to be more virulent against other insects. However, laboratory tests with up to 15 million nematodes per fire ant colony did not result in mortality to adult workers, although infection and subsequent mortality of immatures were observed. Typical "avoidance" behavior was evident in all treated colonies. Such behavior in the field would most likely result in colony relocation and consequent decreased exposure to the nematodes.

A new species of nematode, *Tetradonema solenopsis* (Nematoda: Tetradonematidae), was reported to parasitize *S. invicta* in Brazil by Nickle and Jouvenaz (1987). This nematode was found in 5 of 14 colonies collected on February 5, 1985. The authors noted that in the most heavily parasitized colony, 12.5 percent of the adult workers were infected. Efforts to establish the nematode in laboratory colonies in Gainesville, FL, were not successful. Previous attempts to detect nematodes in surveys for diseases in the United States (Jouvenaz et al. 1977) and in Brazil (Jouvenaz et al. 1980) were not successful.

Parasitic Arthropods—Williams (1980) reviewed the known parasites of fire ants. None of these have been shown to provide population control.

Endoparasitic Arthropods—Three groups of insects are known or strongly suspected to be endoparasites of fire ants. These are a genus of chalcid wasp, two genera of phorid flies, and a species of *Strepsiptera*.

Orasema crassa and *Orasema* spp. (Chalcidoidea: Eucharitidae) parasitize *S. richteri* in Uruguay and *Solenopsis* spp. in Brazil, respectively. The female wasp oviposits in plants that are visited by ants. The newly hatched larvae attach themselves to these foraging ants and are carried to the nest. There they transfer to mature ant larvae or pupae and complete their development, apparently as endoparasites (Williams and Whitcomb 1974).

Numerous species of phorid flies have been collected in association with fire ants in South America, but only *Apodicrania* sp. is a proven endoparasite. Larvae of this fly (one per host) have been dissected from worker ant larvae. Mature *Apodicrania* larvae and pupae that have emerged from their host are tended by fire ant workers as if they were ant brood. Williams and Whitcomb (1974) reported that worker ants in parasitized laboratory colonies were observed to carry *Apodicrania* pupae to the surface, place them in a group, and then carry them below when the nest was disturbed. Adult flies walk about on the soil surface of disturbed mounds without eliciting aggressive reactions from the ants. In contrast to the *Apodicrania* sp. (which masquerades as an ant quite effectively), the females of *Pseudacteon* sp. appear to attack individual ants (Williams et al. 1973). The flies' behavior strongly suggests that they oviposit in or on the ants; however, attempts to rear the parasites or dissect out parasitic larvae have failed.

Jouvenaz (1983), quoting a paper by Teson and De Remes Lenicov (1979), stated that *Stichotrema wigodzinsky* (Strepsiptera: Myrmecolacidae) is listed as an endoparasite of *S. richteri, Camponotus* spp., and *Pseudomyrmex* sp. in Argentina. However, no further information is given on parasitism in the Teson and De Remes Lenicov paper, which treats the taxonomy of several species of *Strepsiptera*.

Social Parasites—The most studied arthropod enemy of fire ants is *Solenopsis* (formerly *Labauchena) daguerri,* a workerless social parasite of *S. richteri* in Uruguay and Argentina. Unfortunately, *S. daguerri* and related parasitic ants are uncommon and do not appear to affect the populations of their hosts significantly. Silviera-Guido et al. (1973) reported that two or three *S. daguerri* queens permanently "yoke" themselves to the host queen by grasping her cephalothoracic membrane with their mandibles and embracing her thorax with their legs. The host workers care for these parasitic queens and their offspring preferentially, reducing attention to their own queen and immatures as the parasite population increases. Burdened with large numbers of unproductive individuals (parasites may constitute more than 70 percent of the total population of a nest), the economy and vigor of the colony are strained, and it eventually deteriorates. Although they are not common anywhere, the greatest densities of *S. daguerri* have been reported from Las Flores, Argentina (Silviera–Guido et al. 1973).

Parasitic ants have not been reported from nests of *S. invicta* and are not common in nests of other *Solenopsis* spp. Because of the low densities of parasitic ants in their native lands, and the lack of evidence that they suppress their hosts, investigators familiar with these ants discount their potential for use in a biological control program in the United States.

Predators—

Myremcophilous Scarabs—Wojcik (1975) observed that *S. invicta* pupae are occasionally consumed by the myrmecophilous beetle *Myrmecophodius excaviticollis* (Scarabaeidae) in the United States. Although this beetle and another Scarabaeid, *Euparia castaenea,* are specifically associated with *Solenopsis* spp., they infest fewer than 5 percent of colonies and are sparse in infested colonies. Because their populations are small, relative to those of their host, and because their diet is varied, the number of ants they destroy is insignificant (Jouvenaz 1983).

General Predators—During the mating and nest-founding period, imported fire ant queens are subject to predation by numerous general predators of insects, such as birds, dragonflies, and spiders (Whitcomb et al. 1973). Several species of *Solenopsis (Diplorhoptrum)* are important natural enemies of colony-founding imported fire ant queens in Texas (MacKay and Vinson 1989). Thompson (1980) found that these predaceous ants are present in large numbers in Florida in all but extremely hydric habitats. These subterranean ant predators readily kill and consume colony-founding fire ant queens. The black widow spider (*Latrodectus mactans*) is also a major predator of fire ants. In one study in cotton fields in Texas (Nyffeler et al. 1988), fire ants comprised 75 percent of black widow prey.

Due to the extremely high reproductive potential of an imported fire ant colony (about 97,000 alate females per acre, according to Morrill 1974a), Jouvenaz et al. (1981) seriously questioned the ability of opportunistic general predators to suppress fire ant populations. The Jouvenaz team also doubted that biological control could be achieved by manipulating populations of these predators.

Predaceous Mites—The straw itch mite, *Pyemotes tritici*, has been reported as a predator of imported fire ants. Bruce and LeCato (1980) reared mites on cigarette beetle pupae and applied 3.4 oz of pupae to individual nests of IFA as the first progeny emerged from the gravid female mites. Three to 10 applications at about 2-wk intervals gave 70-percent control. Other studies with the mite (Collins and Bishop 1985 unpubl., Jouvenaz and Lofgren 1986, Thorvilson et al. 1987) resulted in negligible control. Moreover, the straw itch mite is widely regarded as a pest and causes severe dermatitis in humans. *P. tritici* was, however, commercialized for fire ant control in late 1984 by Biofac, Inc.

Bass and Hays (1976) observed another mite, *Tyrophagus putrescentiae,* feeding on eggs of the imported fire ant under laboratory conditions. It has not been established whether these mites prey on fire ant eggs under normal colony conditions.

Male Sterility—Sterile males of *S. invicta* were found in field populations from College Station, Navasota, and Anderson, TX (Hung et al. 1974). The frequency of sterile males was as high as 100 percent in some colonies. The use of male sterility in genetic control of fire ants has been investigated at Texas A & M University under the direction of S. Bradley Vinson for several years.

Cultural Control

Tillage and Cultivation—Very little information on cultural control of IFA exists. Results of a study at St. Gabriel, LA, from 1977 to 1979 indicated that mound dragging with a steel "I" beam drag (15 ft in length and weighing 2,000 lb) immediately before temperature decreases to below 32 °F reduced mound numbers about 50 percent during the subsequent crop-growing season. Four dragging regimes conducted through fall, spring, and summer did not significantly reduce mound numbers (Blust et al. 1982).

Morrill and Green (1975) found a decrease in the number of fire ant mounds per acre in a soybean field after various experimental tillage practices were conducted prior to planting the crop. However, no differences in numbers of mounds were found after the beans were harvested. Lofgren and Adams (1981) reported mound densities of 30 to 40 per acre in a multistate population survey of IFA in soybean fields. Thus, normal agronomic practices do little to deter fire ant populations in soybean fields.

Marshall and Martin (1980) investigated the effects of anhydrous ammonia on IFA in pastures of "Coastal" bermuda grass hay. Applications injected about 8 inches deep under 125 lb/in^2 of pressure did not effectively suppress the pest. Drenches with urea solutions were also ineffective.

Vegetation Management—Ali et al. (1984) found that fire ant population levels could be *enhanced* in sugarcane through vegetation management. Their results showed that the number of fire-ant prey per unit of dry biomass is higher in areas planted to broadleaf species than in areas planted with grasses or sugarcane alone. If fire ant populations can be enhanced through judicious vegetation management in certain situations, it might be possible to suppress fire ant populations that way, too. However, this hypothesis has not been tested experimentally and appears to have limited practical value.

Mechanical Haymowing Equipment—The large, conical-shaped earthen nests of IFA are quite frequently cited as an impediment to the operation of farm machinery and equipment, especially in haying operations (Green 1952, Arant et al. 1958, Lofgren 1986b, Tedders et al. 1989). Large mounds in heavy clay soils often damage sicklebar hay mowers. Disc-mowers employ counter-rotating spinning discs which, according to anecdotal evidence, tend not to be damaged by fire ant nests as often as sicklebar mowers.

Also, farm laborers usually load small, square hay-type bales from the hay meadow onto trailers by hand. This practice exposes laborers to stings by worker ants that have invaded the bales in search of insects trapped inside by the baling operation. Production and transport of large or modular bales is a totally mechanized operation, so the use of that technology can significantly reduce stings to laborers.

Therefore, selection of particular haymowing equipment can be one method of minimizing the impact of IFA on people and agriculture. It should be noted, however, that disc-mowers and equipment used to produce modular bales may be better suited to large farming operations and will probably be more expensive than sicklebar mowers and conventional hay balers.

Flooding and Controlled Burning—Flooding does not destroy or kill fire ant colonies. In fact, "rafting" in floodwaters is one means of fire ant dispersal into new areas (Green and Hutchins 1960, Morrill 1974b). Likewise, controlled burns have not been shown to suppress populations of IFA. Recent studies by ARS in sugarcane fields near Lake Okeechobee, FL, have shown that burns at harvest may have more effects on other ant species than on IFA. The imported fire ant apparently escapes the fire by retreating deep within the mound (Sauer et al. 1982).

Physical Removal of the Nest—Ladner et al. (1985 unpubl.) reported that excavation and physical removal of fire ant nests from 0.6-acre unreplicated test plots decreased the population index approximately 50 percent but did not kill fire ant colonies.

Summary

Although biological control has not received the funding or intensive research attention devoted to chemical control, all efforts to date indicate that no single organism is capable of inducing population suppression of the imported fire ant. Cultural control, in general, does not appear to offer viable methods of reducing populations of IFA in most situations. Therefore, managers will likely remain totally reliant upon chemical control techniques for the foreseeable future. Due to cost effectiveness, environmental concerns, and other factors, the broadcast application of baits remains the preferred method of imported fire ant control except in special, localized situations where mound drenches might be more appropriate.

Acknowledgments

Bart Drees, Bob Vander Meer, and Randy Westbrooks reviewed earlier drafts and offered many helpful comments for improvement. I also thank Jeannine Levandoski and Janet Wintermute for their invaluable advice and assistance in preparing and editing the manuscript.

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