Review article

Biological control of fire ants: an update on new techniques

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Objective: To review the present understanding of biological control methods for imported fire ants (IFAs).

Data Sources: We searched MEDLINE, Biological Abstracts, and the US Department of Agriculture Formis Ant Literature database.

Study Selection: All articles published in the last 10 years on biological control of fire ants were selected.

Results: The decapitating flies *Pseudacteon tricuspis, Pseudacteon curvatus*, and *Pseudacteon litoralis* have been successfully released in the United States. The continued releases of multiple species of decapitating flies will expand the area of impact, applying greater pressure on IFA populations throughout the southern United States. The microsporidium *Thelohania solenopsae* causes the slow demise of a fire ant colony. The advantages of *T solenopsae* as a biological control agent include debilitation of queens, specificity for IFAs, self-sustaining infections, and lower relative tolerance to chemical pesticides. *Solenopsis daguerrei* has also been shown to have detrimental effects on IFA colony growth, the number of sexual reproductives produced, and the number of host queens in multiple queen colonies; however, this parasite is difficult to rear in the laboratory and to introduce into IFA colonies.

Conclusions: It is unlikely that IFAs can be completely eradicated from the United States. However, technology using chemicals and/or natural control agents could eventually maintain populations at low levels if an integrated approach is used for control.

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INTRODUCTION

During the last several years, we have detailed the medical consequences of stings from imported fire ants (IFAs).[1–4] Control measures to halt the rapid expansion of their range have failed. Recently, the US Department of Agriculture, Agricultural Research Service (USDA-ARS) instituted several innovative fire ant control programs, which may be useful in controlling these insects and decreasing the use of insecticides.

FIRE ANTS IN NORTH AMERICA

Imported fire ants, *Solenopsis richteri* and *Solenopsis invicta,* were accidentally introduced into the United States between 1918 and 1930 from South America. They currently infest more than 320 million acres in 14 states (Alabama, Arkansas, California, Florida, Georgia, Louisiana, Mississippi, New Mexico, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia), with limited infestations in Arizona, Maryland, and Delaware.[5–7] Infestations also occur in a number of Caribbean islands, including Puerto Rico, the Bahamas, the British and US Virgin Islands, Antigua, and Trinidad.[8] Continued expansion of the IFA range is expected northward along both US coasts and southward into Mexico and other areas of the Caribbean. Recently, IFAs were detected in Australia (Brisbane), where eradication efforts are under way,[9] and in New Zealand, where they were eliminated (Ministry of Agriculture and Forestry, New Zealand, www.maf.govt.nz/biosecutiry, 2002). The USDA regularly updates quarantines for transport of nursery stock and other agricultural materials in the area of infestation (USDA, Animal and Plant Health Inspection Service, 2003)[10] (Fig 1). An ultimate potential range has been proposed, but the final range of the IFAs is unknown.[11]

In infested areas, fire ants are the dominant arthropod,[12] resulting in a major impact on humans, animals, agriculture, and wildlife.[13–17] During the past 2 decades, expansion of the polygynous form, characterized by multiple queens rather than the traditional single queen per colony, has resulted in even greater population densities per unit area, worsening the impact and the difficulties in managing this pest.

EFFECTS OF FIRE ANT INFESTATION

Although the exact economic costs of fire ant damage and control are unknown, estimates for the southeastern United States have been a half billion to several billion dollars per year.[18–20] This includes the IFA's impact in urban areas, medical costs, pesticide costs, crop and livestock losses, and damage to farm implements. In addition, the cost of produc-

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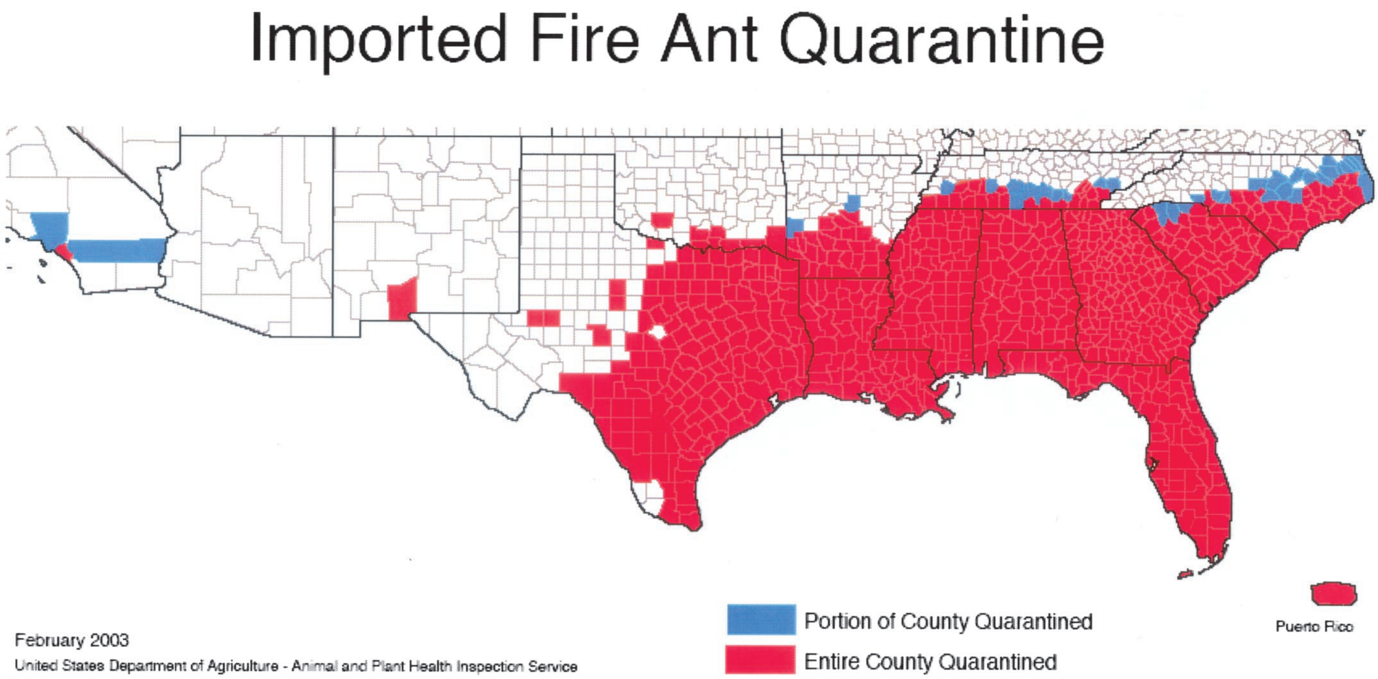


Figure 1. Current imported fire ant (*Solenopsis invicta*) quarantine areas in the United States (www.aphis.usda.gov/ppq/maps/fireant.pdf).

ing agricultural commodities, such as nursery and sod, has increased in infested areas, because quarantine regulations mandate treatment of materials to be shipped to noninfested areas.

Fire ants are highly aggressive when their nests are disturbed and cause painful stings to humans, pets, domestic animals, and wildlife. A variety of medical consequences of IFA stings have been reported. More than 50% of the people in the infested areas are stung each year, with anaphylaxis occurring in 0.6% to 16% of those people.[4] More than 80 deaths from fire ants have been reported.[1–4]

Fire ants occur across a wide variety of ecological habitats distributed broadly across season, geography, and climate. They are most commonly found in open, sunny habitats where soil has been disturbed and are ever present in parks, pastures, yards, and cultivated fields. Like weeds, the aggressive and abundant IFAs reduce biodiversity, particularly ants and other ground nesting species, including birds.[21–24] Under certain conditions, such as extreme weather and/or food shortages, IFAs move indoors, where they can come in contact with and sting humans. This now presents a major problem in health care facilities, where increasing numbers of debilitated individuals are being stung.[3,4]

CONTROL OF FIRE ANT INFESTATION: INTEGRATED PEST MANAGEMENT

Until recently, attempts to control IFAs centered on the use of insecticides.[2,25] To be successful in killing IFA colonies, an insecticide needs to reach the queen or queens of a colony. Queens are sequestered deep within the colony and are fed predigested food by other castes of ants. The chemical insecticides available for use are only effective for short-term control (3–12 months), require periodic reapplication, and can be detrimental to nontarget organisms.[26] Furthermore, chemicals are not economical for large-acreage situations, such as farms, ranches, roadsides, and natural areas.[27] Their utility is also limited because most are not approved for use where food-bearing crops are grown or in environmentally sensitive areas, including wetlands, habitats of endangered species, and animal care facilities. Because untreated areas serve as a reservoir of populations that reinfest adjacent treated areas, reapplication of chemicals is necessary. Regardless, chemicals still are one of the most important tools for rapid fire ant control, especially in those areas considered as significant risks for humans, such as infested yards, school grounds, recreational areas, or health care facilities.

The absence of natural enemies for IFAs in the United States appears to have allowed the IFAs to reach much higher population densities (5- to 7-fold greater) than in South America, where as many as 40 parasites, pathogens, predators, and competitors are believed to be the major controls on density.[28–32] The successful establishment of biological control agents could narrow the ecological gap between IFAs and native ants, allowing native ants to better compete. If this happens, fire ant populations in the United States could be reduced to the low-density levels found in South America and contact with humans and animals would be diminished.[33] Thus, an integrated management strategy of biological control agents and the judicious use of chemicals could not only offer longer control but also reduce the risk of pesticides to humans and the environment.[33,34]

Research on biological control of fire ants is currently being conducted on natural enemies by the USDA-ARS and in some universities in the United States. We will review some of the more promising techniques under study. An in-depth review of biological control agents used against fire ants has been previously published.[33] We searched MEDLINE, Biological Abstracts, and the US Department of Agriculture Formis Ant Literature database. All articles published in the last 10 years on biological control of fire ants were selected.

BIOLOGICAL CONTROL OF FIRE ANTS

Two biological control agents now being used against IFAs are the small decapitating (phorid) flies belonging to the genus *Pseudacteon* (Diptera: Phoridae)[35] and a protozoan pathogen, *Thelohania solenopsae*.[36] Successful laboratory rearing and production techniques have made experimental field releases of decapitating flies possible.[37,38] The discovery of the microsporidium *T solenopsae* (Knell, Allen, and Hazard) in fire ant populations in the United States[36] and development of methods to spread the disease to other colonies[39] have allowed investigation of the use of this protozoan as a biological control agent. An ant species parasitic for IFAs is also under study.

DECAPITATING FLIES

There are approximately 20 species of *Pseudacteon* decapitating flies that attack fire ants in South America.[40,41] Some of these parasitic flies attack large workers, whereas others attack small to medium-sized workers.[42,43] Some species are active during the early morning and evening hours, whereas others are active at different times throughout the day.[44] Most flies are active throughout most of the year,[45–47] are host specific (attacking only fire ants),[40,48] and are no danger to other organisms.[49,50]

The first decapitating fly to be released in the United States was *Pseudacteon tricuspis*. This small fly attacks individual worker ants.[42,51] These flies hover over fire ant workers (Fig 2A) and in an instant swoop down, attacking the worker and depositing an egg in the thorax of the ant. The egg hatches in a few days,[42,51] and the larvae begin chewing their way forward toward the head region. After reaching the head, the larvae completely eat the fire ant glands and muscles and release an enzyme that causes the head to fall off (Fig 2B). The larva pushes the now useless mouthparts out of the way and seals itself in the head capsule until pupation. The total developmental time from egg to adult is between 30 and 90 days, depending on temperature.[40] Once the adult fly emerges (Fig 2C), it has only a few days to look for a mate to repeat the attack cycle.

The IFAs quickly learn to avoid the flies and will rapidly withdraw or hide under any available object to avoid the attacking flies. Therefore, a single fly can stop the foraging of hundreds of workers. A few flies in and around an IFA mound are adequate to stop foraging by an entire colony of fire ants.[52–54] Decreased foraging by IFAs could cause a shift in the use of food resources and in favor of other ant species.[52,53,55]

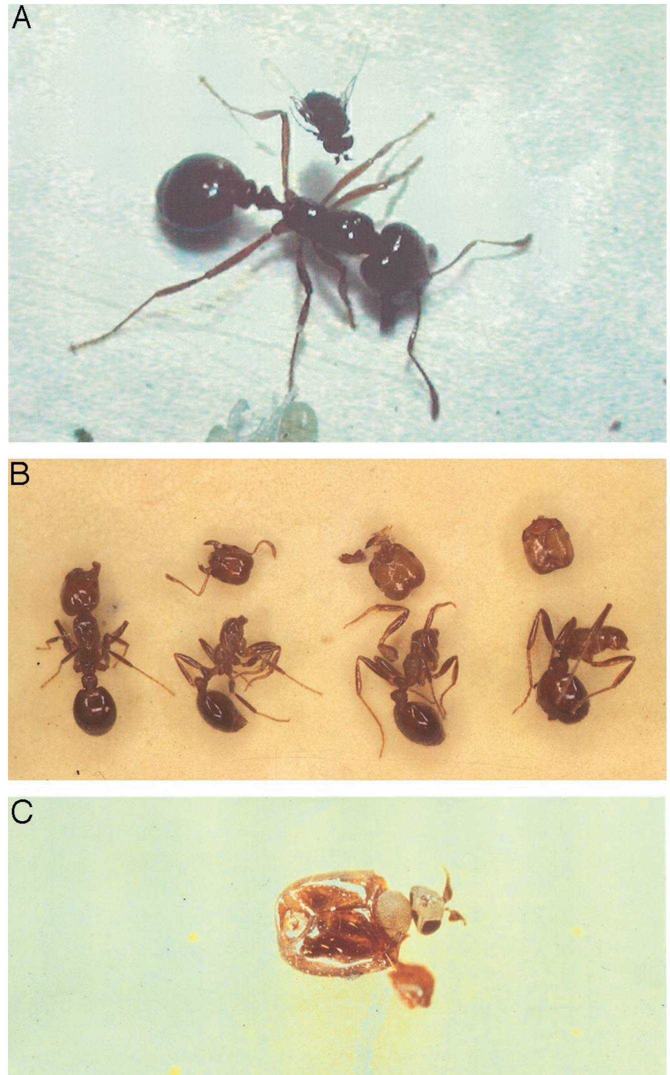
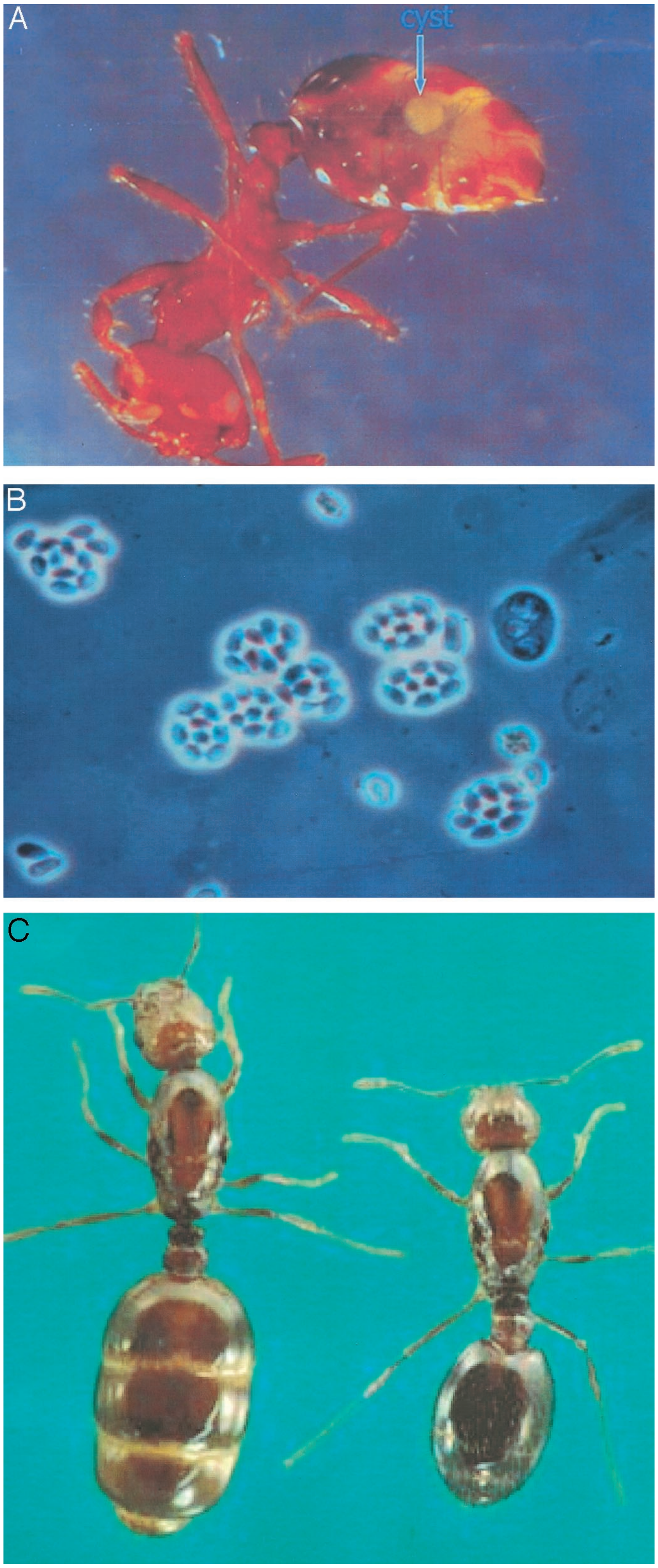


Figure 2. A, A *Pseudacteon tricuspis* decapitating fly attacking an imported fire ant (IFA) worker. B, The heads of these IFA workers are falling off as a result of parasitism by decapitating flies. C, A decapitating fly emerges from the head capsule of the parasitized IFA worker.

P tricuspis was first successfully released in Gainesville, FL, in 1997. Populations are spreading at a rate of 10 to 18 miles per year and occupied an area of more than 3,000 square miles within the first 4 years.[47] Generations of flies originating from this initial release are continuing to attack fire ants. *P tricuspis* has subsequently been released in 11 states (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, and Texas) and has successfully reproduced and ex-



panded its habitat in 7 states (Alabama, Florida, Louisiana, Mississippi, South Carolina, Tennessee, and Texas).

A second species of decapitating flies, *Pseudacteon curvatus*, has been successfully released at several sites in Alabama, Mississippi, and Florida. A third species, *Pseudacteon litoralis,* was recently released at a site north of Gainesville, FL. The continued releases of multiple species of decapitating flies will expand the area of impact, applying greater pressure on IFA populations throughout the southern United States.

There are many reasons why decapitating flies offer promise as a biological control of fire ants. Some of these reasons include their (1) specificity for IFAs,[40,48–50,56–58] (2) function over seasons, geography, and climate,[35,45,47,59] and (3) effects on fire ant behavior.[51,53,55] It is unclear what the total impact that decapitating flies will have on IFA populations. However, since the ants have developed specific defensive behaviors to the flies, these behaviors probably reflect the capacity of the flies to negatively affect IFA colony survival.[40]

INFECTION WITH PROTOZOA

The microsporidium *T solenopsae* (Microsporida: Thelohaniidae) is an obligate, intracellular pathogen that causes the slow demise of a fire ant colony (Fig 3A and B). It is one of the most common pathogens in fire ants in Brazil and Argentina.[60,61] In 1996 during a survey for pathogens in IFA colonies in the United States, *T solenopsae* was discovered in IFA workers in Florida, Mississippi, and Texas.[36] The IFA field colonies that were infected with *T solenopsae* succumbed faster than uninfected colonies.[62,63] Laboratory studies showed that IFA colonies with single and multiple queens infected with *T solenopsae* lost 85% to 100% of immature stages and had high queen mortality.[39,64,65] During a 2-year field study in Florida, there was a maximum reduction of 63% in IFA populations infected with *T solenopsae,* and the pathogen spread to more than 85% of fire ant nests; however, the true field impact of this disease on IFA populations may not be apparent, because IFA reinfestations may occur during the slow decline of infected colonies.[65] Sustained field infections of *T solenopsae* have only occurred in polygynous fire ant populations (D. H. Oi and D. F. Williams, unpublished data, January 2002).

T solenopsae is transmitted transovarially (vertical transmission) from the queen to its offspring.[66,67] Horizontal transmission between colonies also occurs and has been accomplished in both the laboratory and field by inoculating uninfected colonies of IFAs with brood from infected colonies.[39] All stages of IFAs are infected by *T solenopsae*.[66,67]

Figure 3. A, Light microscopic view (×40) of a cyst of the imported fire ant (IFA) disease (*Thelohania solenopsae*) in the abdomen of a parasitized worker. B, Phase-contrast microscopic view (×630) of spores of *T solenopsae* occurring as typical octet in abdominal contents of a parasitized IFA. C, Larger, heavier, and healthy IFA queen (left) compared with *T solenopsae*-infected queen (right).

This disease directly affects IFA colonies by weakening the queens so that they eventually stop the production of new offspring.[36] Infected queens weighed 50% less than normal ones (Fig 3C). The advantages of *T solenopsae* as a biological control agent[33] include (1) debilitation of queens, (2) specificity for IFAs, (3) self-sustaining infections, and (4) lower relative tolerance to chemical pesticides.[68]

Imported fire ant colonies have been inoculated with *T solenopsae* in 10 states (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, and Tennessee). Available data suggest sustained infections in at least 4 of these states (Florida, Louisiana, Mississippi, and South Carolina). Additional studies and inoculations of *T solenopsae* are under way. The widespread use of *T solenopsae* could result in a long-term, environmentally safer suppression of IFAs.

During recent examinations of IFA colonies in Florida, another natural occurring protozoan disease of IFA was discovered. The disease is caused by a *Mattesia* spp and was named yellow head disease due to the yellow-orange color of the heads of infected ants (Fig 4).[18] Yellow head disease has been found in 8% of the IFA colonies surveyed and throughout Florida in both multiple-queen and single-queen fire ant colonies. The disease probably occurs in other states but to date has been observed only in Florida and Mississippi (R. Pereira, oral communication, May 2002). Although the actual impact on IFAs has not been determined, there have been cases where mortality of infected ants has occurred. Therefore, this disease has promise as a biological control agent for IFAs.[33]

PARASITIC ANTS

Solenopsis daguerrei (Santschi) is an ant parasite of IFA colonies in South America. This parasite produces no worker caste and is totally reliant on its host colony for its care. Having no worker caste, only reproductive males and females represent this species.[69] *S daguerrei* parasites enter IFA colonies, attach (yoke) themselves to fire ant queen(s) (Fig 5A and B), and divert resources from the IFA colony. In addition, the IFA workers feed and maintain the immature stages of *S daguerrei*. Field studies of the impact of *S daguerrei* on IFAs have been conducted in Buenos Aires Province, Argentina, and indicate that *S daguerrei* causes detrimental effects on IFA colony growth, the number of sexual reproductives produced, and the number of host queens in multiple queen colonies.[70–72]

S daguerrei could be useful as a biological control agent for IFAs; however, major hurdles must be overcome. Research with this organism by scientists in the United States (under quarantine) and Argentina[73] showed that this parasite is difficult to rear in the laboratory and to introduce into IFA colonies. Additional studies are required before these insects can be introduced into the United States.

FUTURE BIOLOGICAL CONTROL RESEARCH

It is unlikely that IFAs can be completely eradicated from the United States. However, technology using chemicals and/or

Figure 4. An imported fire ant reproductive (right) with a yellow head as a result of the yellow head disease (*Mattesia* sp). The color reflects the presence of thousands of spores of the protozoan.

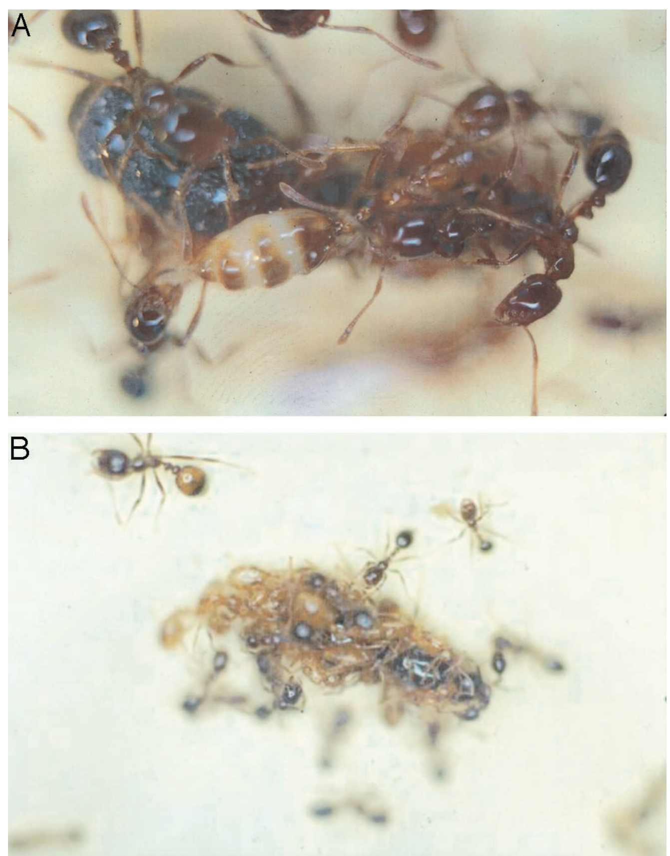


Figure 5. A, The parasitic ant (*Solenopsis daguerrei*) attached to an imported fire ant (IFA) (*Solenopsis invicta*) queen. B, Several orange-colored parasitic ants attached to one IFA queen, which is almost invisible.

natural control agents could eventually maintain populations at low levels if an integrated approach is used for control. Current methods using only chemicals for IFA control, including the ones we have previously reviewed in this journal, are not sustainable.[4] An integrated pest management program for the IFAs using self-sustaining biological control agents is critical for the future. The USDA-ARS recently initiated an integrated pest management project on the areawide suppression of fire ants, using chemicals baits and biological agents for control. This is the first time that a large-scale integrated approach using chemicals in conjunction with self-staining biological control agents has been used against fire ants. A Web site describing the project and information related to fire ant biology and natural enemies can be found at www.ars.usda.gov/fireant/. The discovery, development, and use of effective biological control agents for IFAs will not only lower populations but also reduce the amount of pesticides needed for their control and decrease their potential health risks to humans. Integrated control programs could save millions of dollars annually by reducing pesticide use that will benefit human health, decrease costs to agriculture, and improve the environment. Biological control agents could also help prevent the spread of IFAs into susceptible states located on the edge of present IFA infestations.[33]

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