Development of Integrated Pest Management Programs for the Red Imported Fire Ant (Hymenoptera: Formicidae)[1]

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Abstract The historic development of integrated pest management (IPM) approaches or programs for the red imported fire ant, *Solenopsis invicta* Buren, are discussed. Initial attempts to eradicate this species in the U.S. failed. In the early 1980's site-specific, goal-oriented approaches were developed by adapting IPM concepts to fire ant problem areas. These programs have evolved over time and, more recently, the concept of managing fire ants on an area-wide or community-wide basis has been demonstrated. Currently, efforts are being made to investigate biological control agents to develop biologically-intensive IPM programs.

Key Words Red imported fire ant, *Solenopsis invicta*, Integrated Pest Management

The red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae), is an exotic pest in areas other than in South America. The discovery, accidental introduction and spread of this species through the southeastern U.S. has been reviewed by Vinson (1997) and Taber (2000). In the U.S., fire ant mound densities are much greater than in South America (Porter et al. 1992) and it has become a pest of major health and economic significance (Vinson 1997, Lard et al. 2001, 2002). Approaches for eliminating problems caused by imported fire ants have changed over time from eradication attempts to programs based on integrated pest management (IPM) concepts.

Range and Impact

There have been several recently published accounts of the history of *S. invicta* in North America (Collins 1992, Williams et al. 2001, Vinson 1997) and its entry into Texas in 1956 (Vinson and Sorenson 1986). *Solenopsis invicta* currently occupies 128 million hectares in 9 southeastern states (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Texas) in the U.S. with limited infestations in Arizona, Oklahoma, Tennessee, New Mexico and California. Infestations also occur in a number of countries in the Carribean including Puerto Rico, the Bahamas, the British and U.S. Virgin Islands, Antigua and Trinidad (Davis et al. 2001). It was detected in New Zealand (pers. com., Amelia Pascoe, Ministry of Ag-

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riculture and Forestry, New Zealand, *www.maf.govt.nz/MAFnet/index/RIFA.html,* English 2001) and Australia (Brisbane) in 2001 (Ryan 2001).

Imported fire ants, which also include *Solenopsis richteri* Forel and hybrids between *S. invicta* and *S. richteri* (Vinson 1997), affect people, livestock and wildlife. They are aggressive and abundant in urban, agricultural and non-agricultural areas, and reduce biological (floral and faunal) diversity in infested areas. Although the exact economic costs of fire ant damage and control are unknown, estimates for the southeastern U.S. have been more than a half billion to several billion dollars per year (Thompson et al. 1995, Thompson and Jones 1996). More recently, the total annual fire ant damages and expenditures for Texas have been estimated to be $1.2 billion (Lard et al. 2001, 2002). In Texas, the impact of the ant on urban "metroplex" areas (Houston, Austin, Dallas, Fort Worth and San Antonio) exceeds $580 million, of which $300 million reportedly is used for treatment expenses. Its ant's impact on agriculture was estimated at $90.6 million.

Historically, each red imported fire ant colony was thought to contain only one queen (monogyne colonies). In the early 1970's, a second form of imported fire ant colonies was reported: the multiple queen (polygyne) form containing two or more inseminated, reproductively active queen ants (Vinson 1997). Worker ants in single queen colonies eliminate additional queens and respond defensively to neighboring colonies to maintain territories. Multiple queen colony worker ants do not display territorial behavior and, consequently, they can produce 3 to 10 times as many ant mounds per area. This form can produce 500 mounds and 50 million ants per hectare. Areas infested with the single queen form normally have 50 to 75 mounds per hectare. Ant mound density in an area relates directly to the economic and ecological impact the ant may have and affects the strategies suitable for their control (Drees and Vinson 1990). Porter et al. (1992) provide a review of the national density of fire ants.

Eradication Attempts

Early attempts to eradicate *S. invicta* and the other exotic fire ant, the black imported fire ant (*S. richteri* Forel), using insecticides like Mirex® (Allied Chemical Corp.) from 1957 through 1977 failed to eliminate these species (Table 1). Carson (1962) discussed these early attempts extensively in her book, *Silent Spring,* resulting in elevated concern of environmental impacts of pesticide use. The possibility of eradicating imported fire ants as a control strategy continues to be debated (Taber 2000), and spot-eradication attempts have begun in certain counties in California (Bowen 2001) and in Brisbane, Australia. In the southeastern U.S., large-scale treatment programs ended with the cancellation of Mirex in 1977.

In the nine years from 1977 through 1986, efforts were directed toward finding a replacement for Mirex. A number of new insecticide classes and products emerged, including hydramethylnon, abamectin compounds and insect growth regulators. State programs, such as that conducted by the Texas Department of Agriculture, continued to experiment with large-scale treatment programs or delivery of insecticides like hydramethylnon bait (Amdro®, American Cyanamid Co., Parsippany, NJ). These were provided either free or at a reduced cost to the general public. The last county-wide treatments of aerially-applied fire ant bait were made in Texas in the early 1980's (Trostle 1984). By the mid-1980's, the concept of eradicating the imported fire ants from the Southeast had been abandoned. There are, however, eradication programs

Table 1. History of control efforts in the U.S.*

1929	Imported fire ant first detected in the northern Mobile area and Spring Hill, AL
1937	First organized control program in Baldwin Co., AL (1-3 oz 48% calcium cyanide dust per mound); 2,000 acres or 800 ha treated
1948	Mississippi spends $15,000 to treat ant mounds with chlordane dust; Alabama and Louisiana provide chlordane to farmers free or at cost
1957	Arkansas conducts 12,000 acre eradication project in Union County, and the city of El Dorado applied heptachlor (2 lb acre) by air; congress appropriates $2.4 million for USDA to begin a federal-state cooperative control and eradication program dedicated to the use of aerial and granular applications of heptachlor and dieldrin (2 lb a.i./acre)
1958	Mandated treatments of regulated items initiated to comply with USDA imported fire ant quarantine regulations
1960	Heptachlor rate lowered to 0.25 lb a.i./acre with 2 applications 3 and 6 months apart
Early 1960's	Growing concerns about the detrimental effects of treatments to wildlife, contamination of food and crops ended the program
1962	Lofgren develops conventional bait formulation; Mirex® developed as an active ingredient: mirex (0.3%) dissolved in soybean oil (14.7%) on impregnated corn grits (85%)
1962-1978	140 million acres treated with Mirex bait by ground and aerial equipment, although many treatments consisted of applications to the same area; thus, approximately 46.6 million acres were actually treated
1967	Feasibility studies were initiated by USDA-ARS in Gainesville, FL to use Mirex to eradicate imported fire ants
Late 1960's	Mirex residues found in environment, non-target organisms and to be toxic to estuarine organisms
1970-1971	U.S. Dept. of Interior bans all Mirex uses; EPA issues notice of cancellation of Mirex
1977	Mirex reported to be a potential carcinogen; EPA cancelled registrations
1978	Amdro® (hydramethylnon with oleic or linoleic acid added to increase oil solubility formulated in soybean oil (20%) on a pregelled defatted corn grit carrier) tested
1980	Amdro registered by EPA for use on pastures, range grasses, lawns, turf, and nonagricultural lands
1983	Prodrone, the first insect growth regulator (IGR) is registered by the EPA
1985	Logic® (fenoxycarb), another IGR, registered by the EPA

Table 1. Continued.

1986	Ascend®/Affirm® (abamectin) registered by the EPA
1986-1995	Site-specific, goal-oriented IPM programs and the Two-Step Method for fire ant management developed and widely adopted
1993-1997	Community-wide fire ant management approaches demonstrated
1995-present	Biological control efforts initiated using importation and release of phorid flies (*Pseudacteon tricuspis* and others) and experimental manipulation of a disease, *Thelohania solenopsae*
1998	Distance®/Spectractide® Fire Ant Bait (pyriproxifen), another IGR, registered by the EPA
1998	Extinguish™ (methoprene), another IGR, registered by the EPA for use in croplands in which other baits can not be applied
2000	Justice®, Eliminator®, Strike® Fire Ant Baits and others containing spinosad (spinosyns A and B combined), a new insecticide class (spinosyn derived from bacterium, *Saccharopolyspora spinosa* Mertz and Yao) registered by EPA
2000	Chipco® FireStar® and TopChoice® (fipronil bait and granular products, a phenyl pyrazole insecticide), approved by EPA
2001	Efforts to demonstrate integration classical biological and insecticide control on an area-wide basis initiated in the southeastern United States

* Modified from Williams et al. (2001).

in certain parts of California and Australia initiated after infestations were discovered in these areas in October 1998 and February 2001, respectively (www.cdfa.ca.gov.ifa, www.dpi.qld.gov.au; S. Mehta, "Aussies getting the dirt on ornery O.C. fire ants" Los Angeles Times Aug. 23, 2002).

IPM Site-Specific, Goal-Oriented Approaches

Integrated pest management (IPM) is a systems approach for the management of insect, mite, disease and weed pests. It encourages the use of a combination of the most compatible and ecologically-sound pest suppression tactics to reduce and maintain pest populations below levels that cause problems. For ants, these strategies include cultural (Drees et al. 2000a), biological (Knutson and Drees 1998), and chemical methods. In contrast to the concept of treating entire counties or states for fire ant eradication, site-specific, goal-oriented management programs for common urban sites where fire ants occur were first described by Hamman et al. (1986) and later refined in Drees and Vinson (1988, 1989, 1991, 1992, 1993). The goal of fire ant IPM became one to prevent or eliminate problems caused by fire ants, rather than elimination of all ants from the ecosystem. The IPM programs developed since Hamman et al. (1986) have been adopted, either directly or with modifications by numerous other state Extension education programs (Oi et al. 1994a, Klein and Thompson

1995). These efforts ultimately resulted in multi-state publications represented by authors with state Cooperative Extension Services, Experiment Stations and the U.S. Department of Agriculture (Drees et al. 1998, 2000b).

Programs developed for urban areas included management options for (1) home lawns and other ornamental turf; (2) homes and buildings; (3) electrical equipment and utility housings; (4) home gardens; (5) compost piles, mulched flower beds, pavement cracks, etc., and; (6) around bodies of water. For agricultural areas (Drees et al. 1998, 1999a), programs were described for (1) cattle production systems, pastures and rangeland; (2) poultry houses, livestock barns and feedlots; (3) field crops and commercial vegetables; (4) fruit and nut orchards, vineyards and blueberry plantings; (5) nursery crops and sod farms (Anon. 1999); (6) fish farms, production aquaculture; (7) apiaries, and; (8) wildlife breeding areas. For ornamental turfgrass areas, a primary habitat of this pest, three treatment options were presented (1) Program 1—The "Two-Step Method"; (2) Program 2—Individual mound treatments, only, and; (3) Program 3—The "Ant Elimination Method." Landscape managers are encouraged to use program combinations. On golf courses, for example, Program 3 would be suitable for high-use areas such as putting greens and tee boxes. In fairways and rough areas, Program 1 may be sufficient.

Program 1—The "Two-Step Method". The two steps involve (1) the broadcast application of a bait product, followed by; (2) treating nuisance mounds with a faster-acting individual mound treatment or with a mound re-treatment of the bait. This approach for managing imported fire ants in areas was first described by Hamman et al. (1986) for ornamental turfgrass and for nurseries in the leaflet developed by H. Collins (Anon. 1988). It was coined "The Two-Step Method Do-It-Yourself Fire Ant Control" (Merchant and Drees 1992, 1993), and later named the "Texas Two-Step Method" (Merchant and Drees 1998, 2000). This method has been popularized throughout the southeastern U.S. through Cooperative Extension Service programs and publications (Bolte 1994, Johnson and Jones 1996, Horton and Gorsuch 1997). Merchant (1995) reported on the high consumer satisfaction after using this approach.

The Two-Step Method provides ant suppression in ornamental turf and non-agricultural lands, including roadsides, for as long as the application sequence is maintained. It is best suited to medium-sized or large areas, and the cost is moderate. However, this approach is not suggested for previously untreated areas with few fire ant mounds (8 per ha or fewer) or where native ants, that might compete with the fire ant, are to be preserved. The goal of this program is to reduce fire ant problems while minimizing the use of individual mound treatments. It does not recommend the use of specific products. As new bait or mound treatment products are developed and marketed, they can be selected to replace older, conventional products. Similarly, some home remedies and products perceived to be "organic" can also be used within the program (Drees and Lennon 1998). Finally, this program also can be suitable for other sites such as pasture and rangeland, provided the products selected are specifically registered for use in these areas.

Program 2—Individual Mound Treatments. This approach is best used in small areas of ornamental turf (usually 0.4 ha or less) where there are fewer than 8 to 12 mounds per ha or where preservation of native ants is desired. This program selectively controls fire ants, but rapid re-invasion should be anticipated. It is unsuitable for heavily-infested areas and generally requires more labor and monitoring than other programs. Individual mound treatments are applied as dusts, granules, granules drenched with water after application, liquid drenches, baits, or aerosol injections.

Non-chemical treatment methods such as hot water mound drenches also may be used (Tschinkel and Howard 1980, Drees et al. 2000b).

Program 3—The "Ant Elimination Method". This program was included to describe programs implemented by many professional pest control companies and landscape maintenance operators. Application of a long-residual contact insecticide to the soil surface eliminates nearly all ant species in treated areas. Its effects are more rapid than the of other programs, and re-invasion of treated areas by migrating colonies and newly-mated queen ants is minimized as long as the contact insecticide remains effective. However, it is more expensive, uses more insecticide and has potentially greater environmental impact (Drees et al. 2000b).

IPM Community-Wide Fire Ant Management and Abatement Programs

Although site-specific IPM approaches were widely adopted and practiced, re-invasion by the ants from neighboring untreated areas has remained a problem for small treated areas such as a treated utility box or a home lot. By treating larger outdoor areas, theoretically, re-infestation is slower and many site-specific ant problems, such as in electrical equipment, can be prevented or reduced. Demonstrations of community treatments using aerial application of bait products were supported by Ciba-Geigy in Moundsville, AL (Taylor et al. 1993) and by American Cyanamid in Junction City, AR in 1993 (Miller et al. 1994). In 1993, County Extension Service agents in Arkansas established "abatement program" employing broadcast applications of bait products (Shanklin et al. 1998). Alternative options for "organizing an area-wide fire ant suppression program" were described in Drees et al. (1996), after which they were termed "community-wide" rather than "area-wide" programs (Drees et al. 2000b). Results and benefits from community-wide fire ant management pilot projects initiated in Texas beginning in 1997 were reported by Drees et al. (1999b) and Riggs et al. (2002). Hooper-Bui et al. (2000) demonstrated increased level and length of fire ant suppression resulting from treating areas larger than single properties. This concept of community-wide fire ant management continues to be promoted and conducted throughout fire ant infested states using one or more of the site-specific goal-oriented programs, although most employ a version of the Two-Step Method that relies on the periodic broadcast application of a bait-formulated insecticide.

Biologically-Intensive IPM

A number of natural enemies of red imported fire ants have been described, and some have been assessed as biological control agents. Several have been marketed as treatments, including certain parasitic nematodes and mites. Parasitic nematodes (*Steinernema* spp.) actively search for and parasitize insect hosts, paralyzing them and completing their life cycles within the host. Species and strains vary in their effectiveness against fire ants. Species tested to date caused ants in treated mounds to temporarily move away from the treated mound, but few colonies were actually eliminated (Drees et al. 1992). The predatory straw-itch mite, *Pyemotes tritici* (Lagreze-Fossat and Montane), that feeds on and paralyzes developing fire ants is not effective when applied as directed, and is potentially hazardous to the user (Thorvilson et al. 1987). These products, which must be applied to individual fire ants mounds, are generally not suitable for large-scale treatment programs and do not persist in the environment (Drees et al. 1996).

Several pathogens are known to infect ants. The fungus, *Beauveria bassiana* (Balsamo Vuillemin), has been evaluated using spores in the laboratory (Siebeneicher et al. 1992) and later in the field (Oi et al. 1994b) with mixed results, although one strain has been marketed for fire ant control. Another approach to using *Beauveria* is the use of mycelial fragments as a bait-formulated biotic insecticide for fire ant control (White et al. 1995). This is currently being field tested (Thorvilson et al. 2002).

Natural enemies of imported fire ants hold promise to provide sustainable suppression as they have been theorized to do in their native habitats of South America (Porter 1998). Candidate organisms for classical biological control approach to imported fire ant selection include the entomopathogen *Thelohania solenopsae* (Microsporidia: Thelohaniidae) and parasitic *Pseudacteon* flies (Diptera: Phoridae). *Thelohania solenopsae* is a microscopic protozoan that infects immature and adult fire ants. Diseased ants, including queens, have shorter life spans, and over a period of several months to a year, the colony declines (Williams et al. 1999). Phorid flies (*Pseudacteon* species) are small flies that parasitize fire ants (Porter 1998). Typically, phorid flies parasitize only 1 to 3% of the ants in a colony, and this alone has little impact on fire ant numbers. The effect of these flies on suppressing ant foraging behavior is theorized to be more important. The presence of only three to four flies is sufficient to disrupt ant activity. Ants attacked by phorid flies spend less time searching for food. Other competitor ant species, not attacked by the phorid flies, could possibly benefit by the greater food resource available to them. Thus, the decline in food collection and increased competition from competitor ants might have a much greater negative impact on a fire ant colony than does death of a small percentage of worker ants actually parasitized. Research is ongoing to determine if *Pseudacteon* spp. can effectively reduce the fitness of fire ant colonies and impart sustained biological control. A number of experimental releases of *T. solenopsae* and the phorid fly, *P. tricuspis,* have been made throughout the southeastern U.S. (Gilbert and Patrock 2002, Williams and Brenner 2001).

Although introduction, spread and conservation of selected species-specific natural enemies of imported fire ants hold promise of providing some level of sustainable biological control of the species introduced to North America, they are unlikely to provide the dramatic levels of control expected by people dwelling in urban areas. Thus, the judicious use of selected insecticide products, even within a biologically-intensive IPM program, will continue. Efforts are currently being undertaken to demonstrate the impact of integrating release and establishment of natural enemies with large-scale broadcast treatments of insecticidal bait products (Williams and Brenner 2001). Development of additional insecticide products that are more cost-effective, target-specific and less detrimental to the user and the environment will continue to improve existing IPM programs.

Summary and Discussion

Many states, beginning with Arkansas in the mid-1990's and including Alabama, Florida, Georgia, Mississippi, Oklahoma, South Carolina, and Texas, have developed specific funding to support imported fire ant research, education and regulatory programs through their land grant institutions (Agricultural Experiment Stations and Cooperative Extension Services). A National Fire Ant Strategy has been developed by the Southern Legislative Conference in collaboration with the U.S. Department of Agriculture, Agriculture Research Service to seek additional state and federal funding. Collaboration between these state and federal agencies has improved dramatically. However, funding remains unstable. Imported fire ants have been in North America since around the 1930's, and there is little likelihood that a single approach will be found to eliminate them. Continued support will sustain development of new technology, help researchers improve biologically-based IPM approaches and allow educators and regulators deliver these advances to people living in infested areas.

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