

IMPACT OF THE RED IMPORTED FIRE ANT UPON COTTON ARTHROPODS

A Thesis

by

RODRIGO ROGELIO DIAZ GALARRAGA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2003

Major Subject: Entomology

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ABSTRACT

Impact of the Red Imported Fire Ant upon Cotton Arthropods. (May 2003)

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Inclusion/exclusion field experiments demonstrated that the red imported fire ant, *Solenopsis invicta* Buren, did not affect the abundance of 49 groups of insects and spiders collected in pitfall traps. However, arthropod diversity was significantly greater ($H' = 2.829$) in exclusion plots relative to inclusion plots ($H' = 2.763$). Moreover, this study demonstrated that *S. invicta* can have an important impact upon cotton arthropod communities, including key predator species. Densities of ground beetles (Carabidae), spiders, lacewings (*Chrysoperla* spp.), and minute pirate bugs (*Orius* spp.) were significantly lower in the presence of *S. invicta*. However, populations of aphidophagous insects such as *Hippodamia* spp. and *Scymnus* spp. increased with cotton aphid (*Aphis gossypii* Glover) density early in the season. Abundance of cotton aphids was ca. 5× greater in inclusion plots, likely due to protection and tending by *S. invicta*. This increase was observed early in the season, though aphid populations did not reach economic levels. Predation of sentinel bollworm [*Helicoverpa zea* (Boddie)] and beet armyworm (*Spodoptera exigua* Hubner) eggs increased 20-30%, when *S. invicta* was present. Most predation of sentinel beet armyworm egg masses, measured via direct nocturnal observations, was due to *S. invicta* (68%) and cotton fleahopper [*Pseudatomoscelis*

seriatus (Reuter)] (21%) in plots with *S. invicta*, and by the mite *Abrolophus* sp. (52%), spiders (13%) and minute pirate bug (13%) in plots without *S. invicta*. The frequencies of minute pirate bug, cotton fleahopper, *S. invicta* and native ants in beat bucket samples did not accurately reflect the frequency with which they were observed feeding on sentinel noctuid eggs. Overall, the results of these studies demonstrated that *S. invicta* was associated with declines in the abundances of minute pirate bug, spiders, and lacewing and with an increment in cotton aphid populations, though they did not reach the economic threshold. Moreover, *S. invicta* significantly increased predation of bollworm and beet armyworm eggs. All together, the results suggested that *S. invicta* has a net positive impact on cotton pest management.

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CHAPTER I

INTRODUCTION

The red imported fire ant, *Solenopsis invicta* Buren, presumably arrived in the port of Mobile, Alabama, from Brazil between 1933 and 1945 (Callcott and Collins 1996). Since that time, it has spread at a rate of 1.47×10^5 ha per yr, and is now established in more than 114 million ha, in 670 counties in 11 states in the US and Puerto Rico (Callcott and Collins 1996). Recently, *S. invicta* expanded into, California and New Mexico, and its spread seems to be restricted only by cold temperatures and low humidity (Korzukhin et al. 2001). *S. invicta* preferentially inhabits disturbed areas in general (Taber 2000). Several biological factors including a venomous sting and its aggressive foraging activity in human-inhabited areas make fire ant an important pest.

S. invicta is a powerful competitor compared to other invertebrates species. Porter and Savignano (1990) provide a list of characteristics that contribute to the success of fire ants: (1) preference for disturbed habitats; (2) tolerance of a wide range of temperatures; (3) use of a wide variety of food resources; (4) workers highly variable in size; and, (5) colonies with a high reproductive capacity.

The impact of *S. invicta* in agricultural landscapes is the subject of debate because the uncertainty of impacts. On one hand, *S. invicta* can have negative impacts

This thesis follows the style and format of the Journal of Economic Entomology.

such as feeding on seed and plants of corn, citrus, okra and soybeans, damaging harvesting equipment, and interfering with the activities of agricultural field workers (Taber 2000). On the other hand, *S. invicta* is an aggressive predator, reducing populations of ticks, chiggers, boll weevil, the sugar cane borer, and corn earworm (Vinson 1997), and their mounds enrich pasture soils with micronutrients (Showler and Reagan 1987).

Cotton, *Gossypium hirsutum* L., is the most important field crop in Texas with ca. 2.27 millions ha cultivated in 2002 (Texas Agricultural Statistical Service 2003). However, pest management in cotton is a prime example of over-reliance of chemical control of pests, leading to unsustainable cotton production:

“The history of cotton insect control has been marked by waste, misery, death and destruction. Yet we seem incapable of learning from a pattern of disaster” (Van den Bosch 1978).

Due to many problems associated with sole reliance on chemical pest control, cotton pest management has evolved in recent decades to an integrated approach where biological control, cultural control and crop management play crucial roles. Biological control of pests in cotton is mainly exerted by a complex of generalist predators that prevents potential pests from causing economic loss (Sterling et al. 1989). Indeed, the evaluation of predators in crop systems is a high priority for scientists developing IPM strategies:

“ To better understand the value of endemic biological control agents, more research is needed to measure and quantify their mortality effects on pests. The rates at which predators consume prey will help to establish their efficiency as mortality agents. Once these efficiencies are understood, sampling the

number of predators relative to prey will be more useful in making pest management decisions” (Frisbie et al. in 1989).

S. invicta has been recognized as important predator in southern United States cotton. *S. invicta* is a generalist predator, feeding on pests as well as natural enemies. Early in the season, *S. invicta* protect cotton aphids from predation, mainly by lady beetles and syrphids, allowing aphid populations to increase (Kaplan and Eubanks 2002). Later in the season, *S. invicta* may control important pests such as boll weevil and bollworms (McDaniel and Sterling 1982, Fillman and Sterling 1983).

Thus, the presence of *S. invicta* in cotton fields presents a dilemma: Do *S. invicta* favor or disrupt biological control of pests? To date, most available studies address only the impact of *S. invicta* on a few temporary pests. Consequently, there is a need to understand their role during the entire cotton season, including the roles of other predators and the levels of pest control achieved. The objectives of this research were to assess the impacts of *S. invicta* upon cotton aphid, bollworm and beet armyworm, and on cotton insect diversity with emphasis on key predator species.

CHAPTER II

EFFECT OF THE RED IMPORTED FIRE ANT, *Solenopsis invicta* Buren (HYMENOPTERA: FORMICIDAE), ON ARTHROPOD AND KEY PREDATORS COMMUNITIES IN COTTON

Introduction

The red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae), is a polyphagous predator whose prey includes pest and beneficial insects making its presence in cotton fields controversial. According to Whitcomb et al. (1972), *S. invicta* preys on other insects and generally reduces arthropod diversity, thus affecting ecosystem stability. However, after being present for decades in the southern United States, *S. invicta* has become an important food web component. According to Vinson (1994), *S. invicta* have the potential to become a keystone species and possibly the dominant regulator of insect populations. Invasive ants such as *S. invicta* may displace other important predators in agroecosystems, either via intraguild predation or competition for prey (Risch and Carrol 1982).

Though its role in agroecosystems is not entirely clear, *S. invicta* is currently targeted by control efforts. Insecticide bait products are routinely used to reduce fire ant populations, and quarantine areas are established in Texas to slow their spread. Recently, phorid flies [*Pseudacteon tricuspis* Borgmeier (Phoridae)] were released in Central Texas as *S. invicta* biological control (USDA-ARS 2003). However, Vinson (1994)

suggested that *S. invicta* suppression could potentially lead to outbreaks of species previously suppressed by a complex of natural enemies, which *S. invicta* has supplanted. For example, *S. invicta* displaced other ants such as *Monomorium minimum* (Buckley), *Pheidole* spp., and *Pogonomyrmex barbatus* (F. Smith) (Cook 2003), making the polygyne form of *S. invicta* the most common fire ant species in Texas (Porter et al. 1991). However, no pest outbreaks associated with this displacement have been documented.

S. invicta impacts on cotton insect diversity are important if populations of predators and parasitoids of cotton pests are reduced. Using D-Vac® samples and pitfall traps, Sterling (1979) failed to detect impacts on predator populations in east Texas cotton. However, Reilly and Sterling (1983) found positive relationships between *S. invicta* numbers and cotton aphid (*Aphis gossypii* Glover), damsel bug (*Nabis* spp.), cotton fleahopper [*Pseudatomoscelis seriatus* (Reuter)] and minute pirate bug (*Orius* spp.), and concluded that *S. invicta* may eliminate cues such as exuviae, excreta and honeydew used by natural enemies of these species. Lofgren (1986) and Vinson (1994) listed reports of *S. invicta* predation on beneficial and other insects in different crops and ecosystems. Eubanks (2001) found negative correlations between densities of *S. invicta* and 16 of 16 herbivores and 22 of 24 natural enemies encountered in cotton and soybean fields. More recently, Eubanks et al. (2002) reported that fire ant densities were negatively correlated with the abundance of 12 of 13 natural enemies in cotton fields sampled in 1999, and 8 of 8 sampled in 2000.

The role of *S. invicta* predation and the potential impacts of its suppression in cotton agroecosystems are not well understood. Therefore, the main objectives of this research were to evaluate the impacts of *S. invicta* on cotton arthropod diversity and abundance, with special emphasis on species of predatory insects and spiders.

Materials and Methods

Study site. The study was conducted in a ca. 50 ha cotton field on the Texas A&M Stiles Farm Foundation in Williamson County, TX. Standard agricultural practices were used during the season. Eight plots of 3 ha each, arranged in two rows of four plots, were outlined in the cotton field. Four alternating plots were treated with broadcast applications of S-methoprene fire ant bait (Extinguish®, Wellmark International, Bensenville, IL) at a rate of 1.12 kg/ha during fall of 2000 and once with hydramethylnon fire ant bait (Amdro®, Ambrands, San Ramon, CA) at a rate of 1.68 kg/ha in early spring of 2001 to eliminate *S. invicta* (hereafter “exclusion plots”). The remaining four plots were left untreated (hereafter “inclusion plots”). Both bait products are known to be highly specific to ants and degrade within 2-3 days in the field, and were therefore expected to have minimal effects on other arthropods. The sampling area consisted of a subplot of 25 m by 25 m in the center of each plot. Foliar insecticides were not applied in subplots.

Ground dwelling arthropods. *S. invicta* foraging on the ground was sampled in exclusion and inclusion plots using bait vials containing one piece of candy (Jolly Rancher®, Hershey Foods' Jolly Rancher Candy Co., Golden, CO) and one piece of cat

food (Purina Cat Chow®, Nestle, St. Louis, MO). Sixteen vials were placed on the ground in each plot, ca. 15 cm distant from the base of a cotton plant, early in the morning when *S. invicta* were foraging. Vials were collected after one hour and the number of *S. invicta* captured was recorded. Other ground-active arthropods were sampled by placing one pitfall trap at each corner of each subplot. Pitfall traps consisted of a large cup (12 cm height × 9.7 cm diameter) with an internal funnel (7.5 cm height × 9.2 cm diameter) leading to a small collecting cup (5 cm height × 7.5 cm diameter) containing ethylene glycol (LowTox® antifreeze, Prestone, Danbury, CT). Samples were collected weekly from May 3 to August 3, 2001, which covered most of the cropping season. Samples were not taken on May 11 and June 7 due to heavy rainfall. Pitfall trap samples were processed in the laboratory using a mesh with 500-micron openings to separate soil. All arthropods were preserved in 70% alcohol and sorted and identified to family or ordinal level with the aid of a dissecting microscope and the keys of Borror et al. (1989).

Large numbers (> 1630 per trap) of false chinch bug, *Blissus* sp. (Lygaeidae), were attracted to pitfall traps during mid-July, and were excluded from calculations of diversity and evenness indices to avoid bias. Similarly, *S. invicta* was excluded from calculations of diversity and evenness indices because they were deliberately eliminated from exclusion plots.

Canopy-dwelling predators. Ten species of canopy-dwelling predators were sampled weekly from June 20 to August 3 using the beat bucket technique (Knutson and Wilson 1999), which consists of shaking cotton plants inside a 5 gal white plastic bucket

and counting all recovered predatory insects. Fifteen “stations” located in a diagonal transect were sampled per subplot. A sample of three consecutive plants was taken early in the morning (8:00-10:00 am) at each station. Predators that were recorded included minute pirate bug, cotton fleahopper, *S. invicta*, crab spider (Thomisidae), jumping spiders (Salticidae), “other” spiders, bigeyed bug (*Geocoris* spp.), green lacewing (*Chrysoperla* spp.), lady beetles (*Hippodamia* spp., *Coleomegilla* spp., *Coccinella* spp., others), damsel bug, and *Scymnus* spp.

Statistical analysis. Diversity indices of arthropods in exclusion and inclusion plots were calculated using all identified families of arthropods from pitfalls traps. The Shannon-Weiner diversity index (H') was calculated as $H' = -\sum p_i \times \ln(p_i)$ where p_i is the proportion of individuals of the i^{th} family relative to total families (Magurran 1998). The Shannon evenness index (E) was calculated as $E = H' / \ln(S)$, where S is the number of families identified (Magurran 1998). The diversity index H' was compared between exclusion and inclusion plots using a t -test (Magurran 1988), which yields non-unitary degrees of freedom. Cumulative mean arthropod numbers (per order or family) collected in pitfall traps were compared between exclusion and inclusion plots via t -tests (Zar 1999). The numbers of ants in bait vials and the predators collected in beat bucket samples were compared between exclusion and inclusion plots via repeated measures ANOVA (Zar 1999). Mean numbers of ants in bait vials per date in exclusion plots were compared against a hypothesized mean of zero using one-sample t -tests (Zar 1999). The relative abundances of predators, estimated as the total numbers of a given predator

species relative to the total of all predators, were compared between inclusion and exclusion plots via χ^2 -tests (Zar 1999).

Results

Ground-dwelling arthropods. The insecticide baits applied to exclusion plots were effective in reducing the number of foraging *S. invicta* to near-nil levels ($P < 0.001$) (Fig. 1). Moreover, the mean number of *S. invicta* per vial differed significantly from zero on only two of eight sampling dates (Fig. 1). The total numbers of arthropods collected in pitfall traps in exclusion and inclusion plots, were 13,871 and 18,325 respectively, and represented 57 orders or families (Table 1). Ground beetle (Carabidae) densities were ca. $2\times$ ($P = 0.010$), spider wasps (Pompilidae) about $3.5\times$ ($P = 0.042$), false crab spiders (Philodromidae) about $4\times$ ($P = 0.031$), and jumping spiders (Salticidae) about $2\times$ ($P = 0.048$) greater in exclusion plots relative to inclusion plots. Densities of wolf spiders (Lycosidae), the most abundant spider family, did not differ between treatments ($P = 0.066$). Difference in mean densities was not significant ($P > 0.058$) for the remaining 49 groups of arthropods (Table1).

Arthropod diversity was significantly greater ($H' = 2.829$) in exclusion plots relative to inclusion plots ($H' = 2.763$) ($t = -1.99$; d.f. = 5837.97; $P < 0.025$). Similarly, evenness appeared to be greater in exclusion ($E = 0.384$) versus inclusion ($E = 0.329$) plots.

Canopy-dwelling predators. Season long, a total of 1,278 *S. invicta* were collected in the cotton canopy in inclusion plots, while 29 *S. invicta* were collected in

exclusion plots ($P < 0.001$) (Fig. 2a). The densities ($P \leq 0.016$) and relative abundances ($P \leq 0.001$) of cotton fleahopper and lady beetles were significantly greater in inclusion plots versus exclusion plots (Fig. 2b, c, Fig. 3). In contrast, the densities ($P \leq 0.001$) and relative abundances ($P \leq 0.001$) of spiders and minute pirate bugs were greater in exclusion versus inclusion plots (Fig. 2d, e, Fig. 3). The season-long composition of spiders in exclusion plots was jumping spiders 4.5%, crab spiders 26.5% and “other spiders” 69.0%, while the corresponding numbers in inclusion plots were 4.1%, 26.4% and 69.5% (data not shown).

Scymnus spp., damsel bug, bigeyed bug and green lacewing were the least frequently collected predators in beat bucket samples (Fig. 4). Bigeyed bug densities ($P < 0.015$) (Fig. 4a) and relative abundance ($P < 0.001$) (Fig. 3) were significantly greater in inclusion versus exclusion plots. In contrast, green lacewing densities ($P < 0.013$) (Fig. 4c) and relative abundance ($P = 0.05$) (Fig. 3) were significantly greater in exclusion compared with inclusion plots. Seasonal densities and relative abundance of damsel bug did not differ between exclusion and inclusion plots (Fig. 4b, Fig. 3). *Scymnus* spp. densities did not differ between exclusion and inclusion plots (Fig. 4d), while relative abundance was greater in inclusion plots ($P < 0.001$) (Fig. 3).

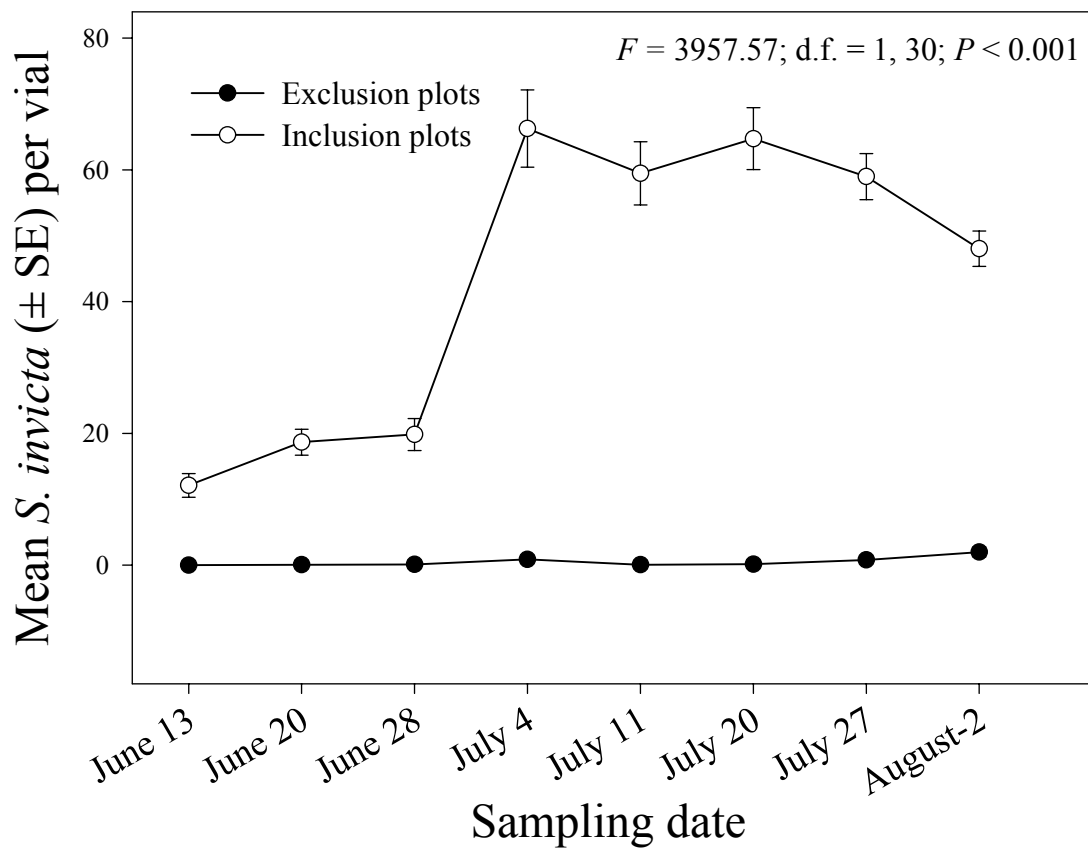


Fig. 1. Mean numbers of *S. invicta* per bait vial in *S. invicta* exclusion and *S. invicta* inclusion plots, Williamson Co., Texas, 2001. Exclusion plots were treated with fire ant bait to eliminate *S. invicta*, while inclusion plots were left untreated. Mean number of *S. invicta* was not significantly different from zero on all dates ($t = 1.83$; d.f. = 64; $P \geq 0.071$) except July 4 ($t = 2.37$; d.f. = 64; $P = 0.021$) and August 2 ($t = 2.57$; d.f. = 64; $P = 0.012$).

Table 1. Mean (\pm SE) cumulative abundance of arthropods per pitfall trap in plots with and without *S. invicta* between May and August, 2001, Williamson Co., Texas. Degrees of freedom = 6.

Order: Family	with <i>S. invicta</i>	without <i>S. invicta</i>	<i>t</i>	<i>P</i>
Collembola: Entomobridae	70.75 \pm 33.29	41.25 \pm 20.02	0.76	0.476
Orthoptera: Acrididae	69.50 \pm 40.22	19.50 \pm 2.99	1.24	0.302
Orthoptera: Gryllidae	226.25 \pm 20.73	181.00 \pm 23.63	1.44	0.200
Blattaria: Blattidae	0.25 \pm 0.25	0.25 \pm 0.25	0.00	1.000
Dermoptera: Carcinophoridae	1.50 \pm 0.87	2.25 \pm 0.75	-0.65	0.537
Hemiptera: Tingidae	0.00 \pm 0.00	0.25 \pm 0.25	-1.00	0.391
Hemiptera: Miridae	27.00 \pm 4.69	40.50 \pm 11.00	-1.13	0.302
Hemiptera: Nabidae	0.50 \pm 0.29	0.50 \pm 0.29	0.00	1.000
Hemiptera: Anthocoridae	1.50 \pm 0.96	0.75 \pm 0.25	0.76	0.477
Hemiptera: Reduviidae	1.25 \pm 0.63	2.50 \pm 1.26	-0.89	0.409
Hemiptera: Berytidae	0.25 \pm 0.25	0.00 \pm 0.00	1.00	0.356
Hemiptera: Lygaeidae	1683.50 \pm 1246.18	2489.25 \pm 1587.90	-0.40	0.704
Hemiptera: Cydnidae	3.50 \pm 2.02	3.50 \pm 2.84	0.00	1.000
Hemiptera: Thyreocoridae	4.00 \pm 1.22	7.25 \pm 1.25	-1.86	0.113
Hemiptera: Pentatomidae	17.00 \pm 10.74	23.75 \pm 15.27	-0.36	0.730
Homoptera: Cicadellidae	17.25 \pm 1.65	13.50 \pm 3.97	0.87	0.417
Homoptera: Aphididae	4.75 \pm 3.09	1.00 \pm 0.70	1.18	0.315
Thysanoptera	0.50 \pm 0.29	0.00 \pm 0.00	1.73	0.182
Neuroptera: Chrysopidae	0.75 \pm 0.48	0.50 \pm 0.50	0.36	0.730
Coleoptera: Carabidae	29.75 \pm 6.99	61.75 \pm 4.97	-3.73	0.010
Coleoptera: Staphylinidae	14.00 \pm 1.47	17.25 \pm 7.08	-0.45	0.680
Coleoptera: Scarabaeidae	15.25 \pm 3.30	16.00 \pm 3.34	-0.16	0.878
Coleoptera: Elateridae	4.00 \pm 0.71	6.00 \pm 2.38	-0.81	0.471
Coleoptera: Coccinellidae	6.75 \pm 1.49	3.50 \pm 1.19	1.70	0.140
Coleoptera: Mordellidae	1.00 \pm 0.40	0.25 \pm 0.25	1.57	0.168
Coleoptera: Tenebrionidae	5.75 \pm 1.18	5.25 \pm 1.10	0.31	0.768
Coleoptera: Meloidae	15.00 \pm 5.31	17.75 \pm 6.57	-0.33	0.756
Coleoptera: Anthicidae	20.00 \pm 5.31	17.25 \pm 5.04	0.38	0.720
Coleoptera: Chrysomelidae	19.00 \pm 8.95	7.50 \pm 2.78	1.23	0.295

Table 1 (cont.).

Order: Family	with <i>S. invicta</i>	without <i>S. invicta</i>	<i>t</i>	<i>P</i>
Coleoptera: Curculionidae	1.50 ± 0.65	2.75 ± 0.75	-1.26	0.253
Coleoptera: Phalacridae	14.50 ± 3.62	10.25 ± 3.68	0.82	0.442
Diptera	59.00 ± 10.50	86.50 ± 13.64	-1.60	0.161
Lepidoptera	9.00 ± 2.86	8.50 ± 2.87	0.91	0.906
Parasitic Hymenoptera	16.25 ± 1.89	14.25 ± 3.065	0.60	0.599
Hymenoptera: Halictidae	23.25 ± 5.75	35.75 ± 5.17	-1.62	0.157
Hymenoptera: Apidae	0.75 ± 0.25	0.00 ± 0.00	3.00	0.058
Hymenoptera: Mutillidae	2.75 ± 0.25	3.00 ± 0.91	-0.26	0.302
Hymenoptera: Pompilidae	1.75 ± 0.63	4.50 ± 0.87	-2.57	0.042
Hymenoptera: Vespidae	0.25 ± 0.25	0.25 ± 0.25	0.00	1.000
Hymenoptera: Formicidae	2025.00 ± 355.88	172.25 ± 31.70	5.19	0.013
Araneae: Dictynidae	8.25 ± 2.29	11.50 ± 3.84	-0.73	0.495
Araneae: Linyphiidae	17.75 ± 2.25	12.00 ± 1.22	2.24	0.391
Araneae: Araneidae	0.25 ± 0.25	0.00 ± 0.00	1.00	0.391
Araneae: Corinnidae	1.25 ± 0.63	1.00 ± 1.00	0.21	0.839
Araneae: Gnaphosidae	20.75 ± 4.17	14.75 ± 1.49	1.35	0.224
Araneae: Hahniidae	23.25 ± 5.75	35.75 ± 5.17	-1.62	0.391
Araneae: Lycosidae	72.25 ± 6.90	73.75 ± 13.35	-0.10	0.066
Araneae: Miturgidae	1.75 ± 0.63	0.50 ± 0.29	1.81	0.121
Araneae: Oxyopidae	3.00 ± 0.71	4.00 ± 0.71	-1.00	0.356
Araneae: Philodromidae	1.25 ± 0.95	5.50 ± 1.19	-2.79	0.031
Araneae: Salticidae	6.00 ± 2.94	15.00 ± 2.12	-2.48	0.048
Araneae: Tetrangathidae	0.25 ± 0.25	0.25 ± 0.25	0.00	1.000
Araneae: Theridiidae	0.00 ± 0.00	0.25 ± 0.25	-1.00	0.391
Araneae: Thomisidae	0.25 ± 0.25	0.00 ± 0.00	1.00	0.391
Araneae	0.25 ± 0.25	0.50 ± 0.50	-0.45	0.670
Acari	10.50 ± 1.55	4.00 ± 1.68	2.84	0.030

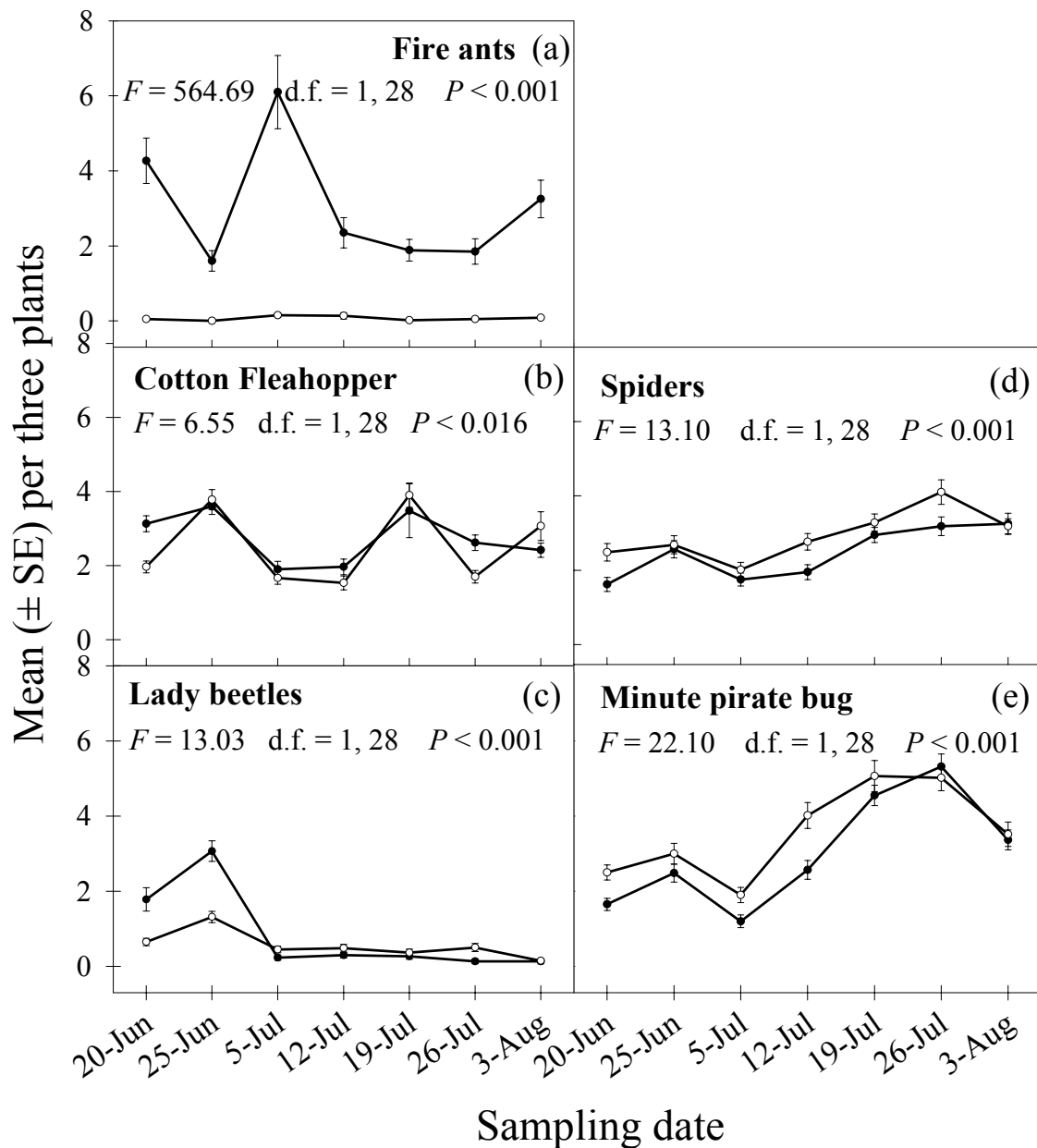


Fig. 2. Mean numbers of the predators most frequently collected in beat bucket samples, Williamson Co., Texas, 2001.

Lines with filled circles correspond to *S. invicta* inclusion plots and lines with empty circles to *S. invicta* exclusion plots. Exclusion plots were treated with fire ant bait to eliminate *S. invicta*, while inclusion plots were left untreated.

(a) *Solenopsis invicta* Buren. (b) *Pseudatomoscelis seriatus* (Reuter). (c) *Hippodamia* spp., *Coleomegilla* spp., *Coccinella* spp., other coccinellidae. (d) Salticidae, Thomisidae, other families. (e) *Orius* spp.

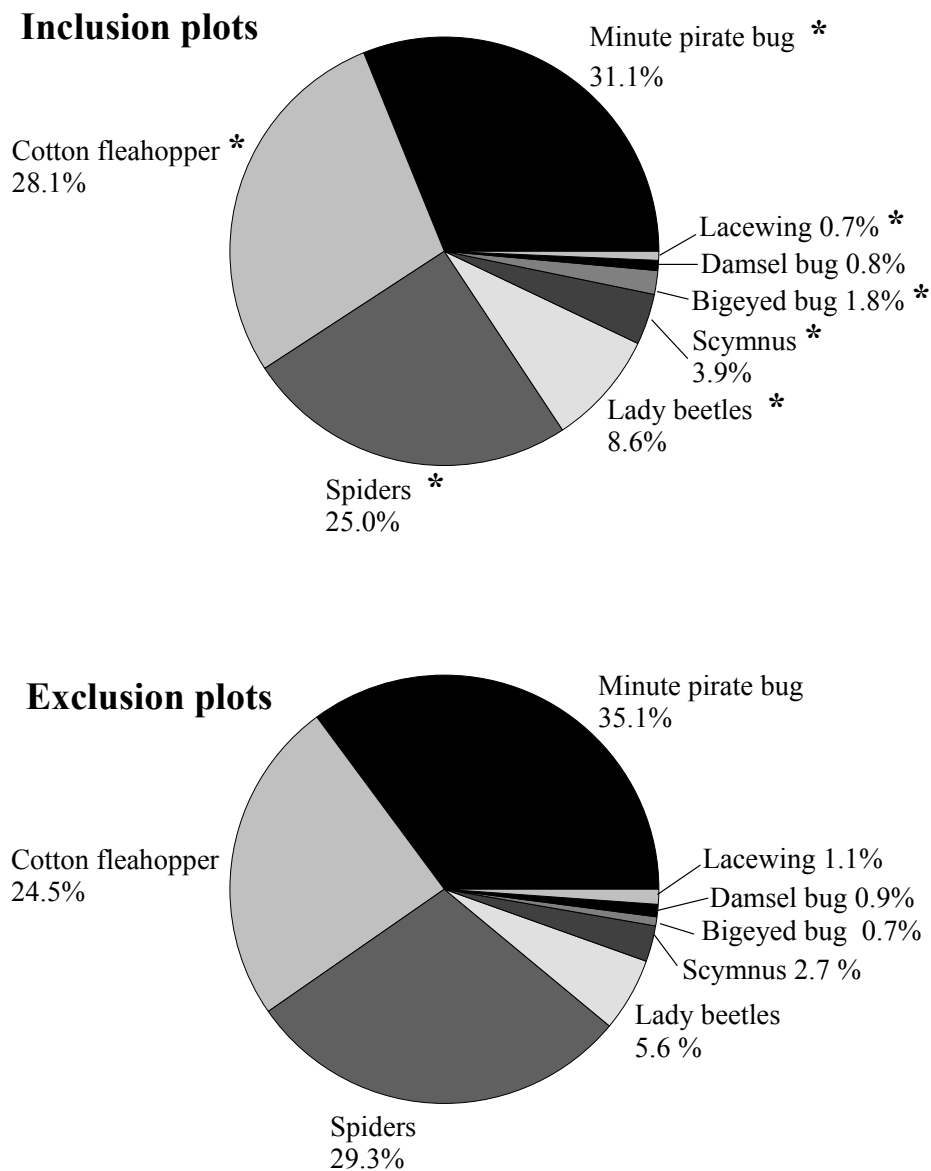


Fig. 3. Relative abundance of predators collected during June to August using beat bucket samples in *S. invicta* inclusion and *S. invicta* exclusion plots, Williamson Co., Texas, 2001. Exclusion plots were treated with fire ant bait to eliminate *S. invicta*, while inclusion plots were left untreated. χ^2 -tests were performed: minute pirate bug, $\chi^2 = 17.5$; d.f. = 1; $P < 0.001$; cotton fleahopper, $\chi^2 = 10.8$; d.f. = 1; $P < 0.001$; spiders $\chi^2 = 13.9$; d.f. = 1; $P < 0.001$; lady beetles, $\chi^2 = 31.0$; d.f. = 1; $P < 0.001$; *Scymnus* spp., $\chi^2 = 7.86$; d.f. = 1; $P < 0.001$; bigeyed bug, $\chi^2 = 18.0$; d.f. = 1; $P < 0.001$; and, lacewing, $\chi^2 = 5.21$; d.f. = 1; $P = 0.05$.

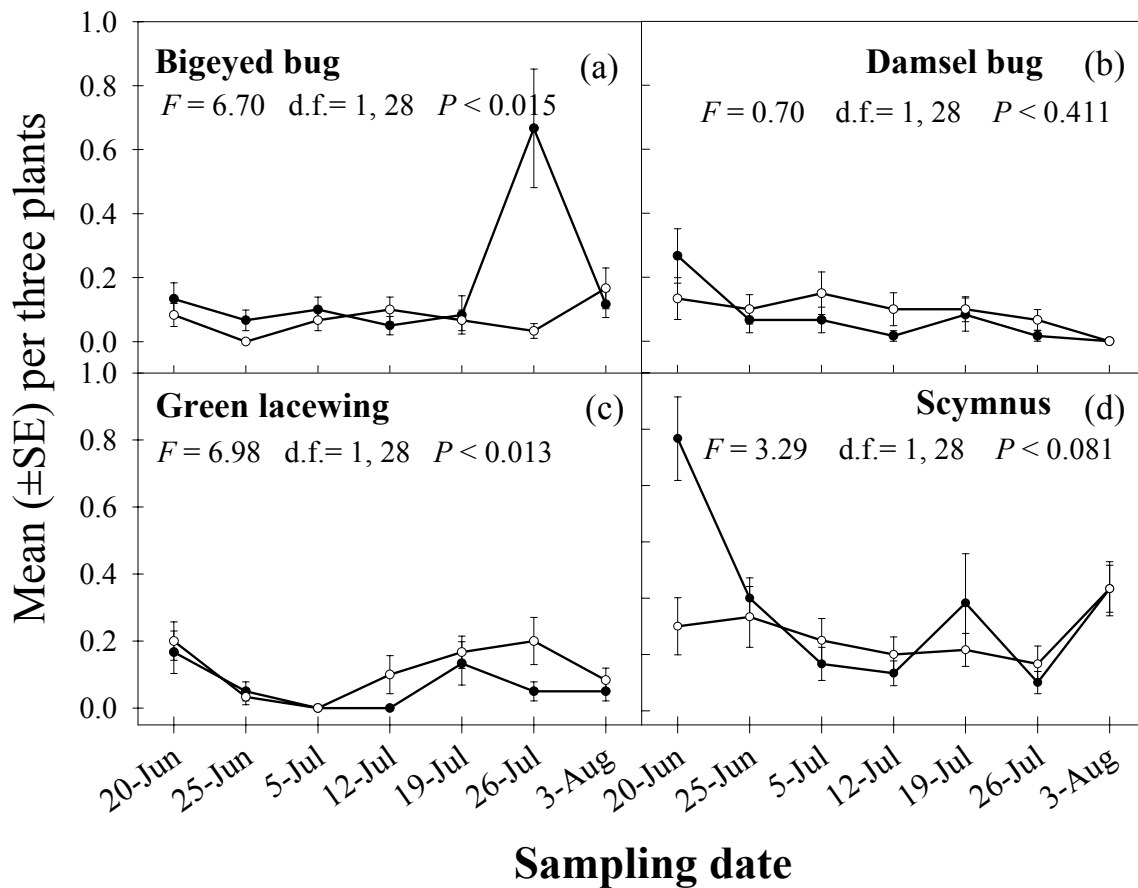


Fig. 4. Mean numbers of the less abundant predators collected in beat bucket samples, Williamson Co., Texas, 2001. Lines with filled circles correspond to *S. invicta* inclusion plots and lines with empty circles to *S. invicta* exclusion plots. Exclusion plots were treated with fire ant bait to eliminate *S. invicta*, while inclusion plots were left untreated. (a) *Geocoris* spp. (b) *Nabis* spp. (c) *Chrysoperla* spp. (d) *Scymnus* spp.

Discussion

The results of this study demonstrated that *S. invicta* had a significant impact upon arthropod diversity, and density of several important predators in cotton. The presence of *S. invicta* significantly reduced the density of false crab (Philodromidae) and jumping (Salticidae) spiders and ground beetles (Carabidae) among ground-dwelling arthropods, and significantly reduced densities of minute pirate bug, spiders and green lacewing among canopy-dwelling predators. Lady beetle densities increased in the presence of *S. invicta*, likely due to a greater abundance of cotton aphids (*Aphis gossypii* Glover) (Homoptera: Aphididae) (see fig. on p. 33). These results suggest that while some arthropods, including important predator species, are impacted by *S. invicta*, most others are not significantly affected by this species, and some predators such as lady beetles may benefit from population increases of prey such as cotton aphid.

Ground dwelling arthropods. Previous work showed that *S. invicta* are aggressive predators that strongly impact distribution and abundance of arthropod populations in different ecosystems (Reagan et al. 1972, Whitcomb et al. 1972, Howard and Oliver 1978, Porter and Savignano 1990, Gotelli and Arnett 2000, Eubanks 2001, Eubanks et al. 2002, Morrison 2002, Cook 2003). In this study, the diversity of arthropods was greater and more evenly distributed in the absence of *S. invicta*, indicating that its presence negatively affected ground-dwelling arthropod assemblages. In contrast, *S. invicta* affected the abundances of only six of fifty-five recorded arthropod families.

Ground beetle numbers were lower in inclusion plots, and this was likely intraguild predation and competition for prey. Other studies found similar effects of *S. invicta* on ground beetle assemblages (Brown and Goyer 1982, Lee et al. 1990, Eubanks 2001, 2002). In addition, *S. invicta* and ground beetles share foraging areas and prey, including small invertebrates such as lepidopteran and coleopteran larvae, crickets, slugs, collembolans, and seeds (Best et al. 1977, Vogt et al. 2001).

The numbers of jumping (Salticidae) and false crab (Philodromidae) spiders were significantly lower in the presence of *S. invicta*, which may have been due to competition for prey. Moreover, jumping spiders actively predate on ants (Jackson et al. 1998, Clark et al. 2000, Jackson and Daiqin 2001), while the reverse is unlikely due to high mobility of jumping spiders (R. D., pers. observ.). Common prey of *S. invicta* and jumping spiders include fleahoppers, boll weevil, bollworm, tobacco budworm, and cotton leafworm (Breene et al. 1993, Taber 2000).

Canopy dwelling predators. Spider densities were higher in the absence of *S. invicta*, which may have been due to competition for prey and/or intraguild predation of spider egg sacs by *S. invicta*. Eubanks et al. (2002) suggested that spiders are more affected by *S. invicta* competition than by intraguild predation, while other studies suggest that spiders are not affected by *S. invicta*. Sterling et al. (1979) reported that the densities of nine families of canopy-dwelling spiders were not affected by *S. invicta*. However, samples were taken on only two dates and thus did not reflect season-long patterns. Other studies show that *S. invicta* do not affect spider densities in pastures, and wooden and grassy fields (Howard and Oliver 1978, Porter and Savignano 1990).

Riechert and Bishop (1990) suggested that spiders may have more refuges to escape predation in these spatially complex environments. Though studies addressing direct predation on spiders by *S. invicta* are not available, egg sac predation is likely because its intrinsic vulnerability to predator attacks (Guarisco 2001).

Minute pirate bug was the most abundant predator season-long, and was more abundant in the absence of *S. invicta*. According to Sansone et al. (1997), minute pirate bug is a key predator of bollworm eggs due to its abundance and predatory capacity. Previous studies suggested that minute pirate bug densities are negatively (Eubanks 2001) or positively (Eubanks et al. 2002) correlated with *S. invicta* density in cotton. The results reported in this study suggest that *S. invicta* may reduce densities of minute pirate bug via intraguild predation or competition for prey.

Early in the season, density and relative abundance of lady beetles was higher in the presence of *S. invicta* than in its absence. The results of previous studies showed that lady beetles densities could be negatively (Eubanks 2001, Eubanks et al. 2002, Kaplan and Eubanks 2002) or not (Sterling et al. 1979) correlated with *S. invicta* densities. However, in a study related to this one, cotton aphid densities significantly increased early in the season in the presence of *S. invicta* (see pg. 38, Fig. 5), probably because of tending and guarding (Kaplan and Eubanks 2002). Lady beetles have chemical and behavioral adaptations that reduce predator attacks (Vinson and Scarborough 1989, Völkl 1995). Thus, ladybeetles densities likely increased in response to higher cotton aphid densities in the presence of *S. invicta* (see pg. 38, Fig. 5) and adaptations to avoid predation by *S. invicta*.

Cotton fleahopper can be a serious cotton pest early in the season, and may be a key predator of bollworm and budworm in mid and late season (McDaniel and Sterling 1982). Fleahopper densities were (marginally) higher throughout the season, and its abundance relative to other predators was higher in the presence of *S. invicta*. Similar to this study, Sterling et al. (1979) found significantly more fleahopper nymphs in cotton in the presence of *S. invicta*. The greater abundance of cotton fleahopper in the presence of *S. invicta* may be explained by their high mobility, which can facilitate the escape from ant predation, and a lower density of important predators such as spiders (Breene et al. 1989, 1990; Nyffeler et al. 1992) in the cotton canopy.

Several studies in Texas cotton fields demonstrate that bigeyed bug, lacewings, *Scymnus* spp., and damsel bugs occur in low numbers compared with other natural enemies (Sterling et al. 1979, Pyke et al. 1980, Knutson and Wilson 1999). Lacewing densities were significantly lower in the presence of *S. invicta*, suggesting that *S. invicta* preys on immature lacewings as suggested by Tedders et al. (1990). It is unclear why bigeyed bug populations were higher in the presence of *S. invicta*. Damsel bug and *Scymnus* spp. densities were not affected by the presence of *S. invicta* throughout the season, though the latter was relatively more abundant in the presence of *S. invicta*. *Scymnus* spp. population peaks coincided with cotton aphid peaks in the presence of *S. invicta* (see pg. 38, Fig. 5) suggesting that densities of this predator increased with aphid densities.

Conclusion. Though the densities of predators such as ground beetles, spiders and minute pirate bugs were lower in the presence of *S. invicta*, it is unclear whether

reductions in their densities negatively impacts biological control of cotton pests. On the other hand, *S. invicta* predation of important pest such as boll weevil (Fillman and Sterling 1983), cotton fleahopper (Breene et al. 1990), bollworm (Nueslly and Sterling 1994) and beet armyworm (see Chapter III) may compensate the effects of intraguild predation. The results of several studies demonstrate that *S. invicta* is an important predator in crops in southern United States (Reagan et al. 1972, Sterling 1978, McDaniel and Sterling 1979, McDaniel et al. 1981, Breene et al. 1989, Vogt et al. 2001, Woolwine and Reagan 2001). While *S. invicta* can cause damage to some crops (Lofgren 1986, Shatters and Vander-Meer 2000), it is important to consider its role as a key predator in agroecosystems. Finally, cotton growers should take advantage of the beneficial effects of *S. invicta* while minimizing their negative impacts because *S. invicta* suppression is presently uneconomical.

CHAPTER III

EFFECT OF THE RED IMPORTED FIRE ANT, *Solenopsis invicta* Buren (HYMENOPTERA: FORMICIDAE) ON COTTON APHID POPULATIONS AND PREDATION OF BOLLWORM AND BEET ARMYWORM (LEPIDOPTERA: NOCTUIDAE) EGGS

Introduction

The red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae), arrived in the US between 1933 and 1945 from Brazil, and currently is found in >114 million ha in the southern states (Callcott and Collins 1996). Mass foraging, a venomous sting, territoriality, large colony sizes, and alate dispersal are among the biological factors facilitating its range expansion (Showler and Reagan 1987).

Cotton, *Gossypium hirsutum* L., is the most important field crop in Texas with ca. 2.3 million ha cultivated in 2002 (Texas Agricultural Statistical Service 2003). Cotton fields are colonized by foraging *S. invicta* workers from colonies outside cotton fields, and by immigrant queens after mating flights (Lopez et al. 1996). Within its geographic range, *S. invicta* is among the key insect predators present in cotton (Sterling 1978, McDaniel and Sterling 1982, Fillman and Sterling 1983) and according to Lopez et al. (1996) may be the most important species of *Solenopsis* in US cotton agroecosystems because of its distribution, abundance, and predatory aggressiveness. The impacts of *S. invicta* in agricultural landscapes were reviewed by Lofgren (1986),

and include predation on beneficial insects, pest arthropods and wildlife, and crop damage.

Cotton aphid, *Aphis gossypii* Glover (Homoptera: Aphididae), is a common pest of cotton in the US. According to Henneberry et al. (2000), damage is due to direct feeding on leaves, which reduces yield, contamination of lint by honeydew and growth of associated fungi, and transmission of more than 50 plant viruses. *S. invicta* is known to interact with cotton aphids. For example, Reilly and Sterling (1983) found a positive association between cotton aphids and *S. invicta* densities in east Texas cotton, while Sterling et al. (1979) suggested that *S. invicta* tends cotton aphids on cotton early in the growing season. In a recent study, Kaplan and Eubanks (2002) found that *S. invicta* enhanced cotton aphid survival and density in the field by interfering with predators.

In contrast to their apparently positive influence on cotton aphid populations, *S. invicta* is known to prey on eggs and larvae of lepidopteran insects, including pests species such as bollworm [*Helicoverpa zea* (Boddie)], tobacco budworm [*Heliothis virescens* (F.)], velvetbean caterpillar (*Anticarsia gemmatilis* Hubner) and soybean looper [*Pseudoplusia includens* (Walker)] (Lofgren 1986). Using radioactively tagged eggs, McDaniel and Sterling (1979, 1982) found that *S. invicta* was the most common predator of tobacco budworm eggs on cotton plants in east Texas cotton, and *S. invicta* workers were observed preying on third and fourth instar larvae. Nuessly and Sterling (1994) found that predation of radioactively tagged bollworm eggs was higher toward the top of cotton plants, and that *S. invicta* was responsible for 86% of egg mortality attributable to specific arthropods. Furthermore, management of sugarcane borer

(*Diatraea saccharalis* Fabricius) in Louisiana partially depends on the predatory activity of *S. invicta* (Reagan 1981).

S. invicta is present during most of the cotton growing season, thus interacting with pests whose damage is in many cases restricted to portions of the season. The objectives of this research were to assess the influence of *S. invicta* on cotton aphid population dynamics early in the season, and evaluate its importance as a predator of bollworm and beet armyworm (*Spodoptera exigua* Hubner) later in the season.

Materials and Methods

Central Texas. The study was conducted in 2001 in a cotton field located on the grounds of the Texas A&M Stiles Farm Foundation in Williamson Co., TX. The important cotton pests at this location are thrips (*Frankiniella* spp.), cotton fleahopper [*Pseudatomoscelis seriatus* (Reuter)], and cotton aphids early in the season, and bollworm and boll weevil (*Anthonomus grandis* Boheman) late in the season. Standard agricultural practices were used during the cropping season.

Eight plots of 3 ha each, arranged in two rows of four plots, were outlined in a > 50 ha cotton field. Four alternating plots were treated with broadcast applications of S-methoprene (Extinguish®, Wellmark International, Bensenville, IL) fire ant bait at a rate of 1.12 kg/ha during fall of 2000 and once with hydramethylnon (Amdro®, Ambrands, San Ramon, CA) fire ant bait at a rate of 1.68 kg/ha early in spring of 2001 to eliminate *S. invicta* present in each plot (hereafter “exclusion plots”). The remaining four plots were left untreated (hereafter “inclusion plots”). Both bait products are known to be

highly specific to ants and degrade within 2-3 days in the field, and therefore were expected to have minimal effects on other arthropods in the study plots. The sampling area consisted of a 25 m by 25 m subplot in the center of each plot; foliar insecticides were not applied to subplots. *S. invicta* foraging on the ground was sampled in each plot using vials (45 ml) containing a piece of candy (Jolly Rancher®, Hershey Foods' Jolly Rancher Candy Co., Golden, CO) and a piece of cat food (Purina Cat Chow®, Nestle, St. Louis, MO). Sixteen vials were placed on the ground, ca. 15 cm distant from the base of a cotton plant, early in the morning when *S. invicta* workers were foraging. Vials were collected after one hour and the number of *S. invicta* was recorded.

Cotton aphid dynamics. Cotton aphid populations were sampled from June to August using a modified key leaf technique (Hardee et al. 1994). Sampling consisted in counting aphids on leaves as follows: i) all leaves during first three weeks after planting; ii) fourth fully expanded leaf from the terminal during 4th through 6th week after planting (fourth leaf to pinhead square); iii) first main stem green leaf about one-third the distance from the terminal during 7th through 9th week after planting (pinhead square to first-bloom); and iv) first main stem green leaf above the first basal fruiting branch during the remainder of the season (first bloom to end of season). Ten sampling stations, each consisting of five consecutive plants, were sampled per subplot, starting in one corner of the subplot and crossing diagonally to the opposite corner.

Bollworm predation. This experiment was conducted between the first week of June and the first week of August, which corresponds to the period when bollworms infest cotton in central Texas (Lopez et al. 1995). One single sentinel bollworm egg was

placed on a terminal leaf of each of 25 plants, per subplot. Plants with sentinel eggs were in a single row and separated at least by 2 meters from each other. Each egg was handled using a fine brush, and glued to leaves with gum arabic (Tragacanth Powder, Across Organics, NJ). Five randomly selected eggs per subplot were surrounded by a ring of Tangle foot® (The Tanglefoot Co., Grand Rapids, MI) to correct for loss of eggs due to factors other than predation. The proportion of lost surrounded eggs was subtracted from the totals of eggs placed on plants, and subsequent analyses used corrected totals. Presence or absence of eggs was recorded after 24 hours. This experiment was repeated on 18 different days beginning ca. 9:00 am on each day.

Beet armyworm predation. Night observations were made to identify predator species and determine timing of predation events on lepidopteran eggs. During the summer, in Central Texas insect activity in cotton fields is greatest during the cooler hours of the day, from 6:00 pm to 7:00 am (R.D. pers. observ.). Thirty-six beet armyworm egg masses (each 40-50 eggs) were deployed one per plant each night between 6:00 to 7:00 pm. Each egg mass was then observed for a period of five seconds every 15 minutes. Predators feeding on egg masses were identified to genus in the field, and the frequencies and timing of predatory events were scored for a period between 7:00 pm and 1:00 am. A predation event was recorded when a predator was seen eating/removing eggs from egg masses. This experiment was repeated thrice in exclusion plots and thrice in inclusion plots between July 12 and August 1.

Statistics. The mean numbers of *S. invicta* in baited vials and mean aphids per leaf were compared between exclusion and inclusion plots via repeated measures

ANOVA (Zar 1999). In addition, mean numbers of *S. invicta* in baited vials in exclusion plots were compared against a hypothesized mean of zero using one-sample *t*-tests to confirm whether *S. invicta* was eliminated from these plots. The proportions of bollworm eggs absent per plot after 24 h were arcsine transformed and plot means were compared via two-way (treatments, dates) ANOVA. In this case, the treatment \times date interaction was significant ($F_{\text{treatment} \times \text{date}} = 1.95$; d.f. = 1, 17; $P = 0.021$), therefore, comparisons were made within individual dates using χ^2 - tests (Zar 1999).

North Texas. The study was conducted in 2002 at the Texas A&M University Research and Extension Center, Dallas, because a severe thunderstorm destroyed the cotton field in the Texas A&M Stiles Farm planted for this experiment. Among the important pests are thrips, cotton aphid, cotton fleahopper, bollworm and beet armyworm. Standard agricultural practices were used during the season.

Exclusion plots consisted of six contiguous plants from which *S. invicta* was excluded by applying a 6 cm band of Tangle Foot® to the base of each plant. Tangle Foot® was applied during the warmest part of the day (2:00 – 3:00 pm) when ants were not foraging on plants. Inclusion plots consisted of six contiguous plants without Tangle Foot®. Sixteen exclusion and 16 inclusion plots were outlined within a 4 ha cotton field.

Bollworm predation. One bollworm egg was placed in the upper canopy of one cotton plant per plot. Each egg was handled using a fine brush and glued to leaves with gum arabic. Eggs were recorded as either present absent after 24 h. This experiment was repeated on six dates between July 22 and August 7, 2002.

Beet armyworm predation and predator abundance. One beet armyworm egg mass (40-50 eggs) was placed in the upper canopy of one cotton plant per plot. Observations were conducted as described above (Central Texas, *Beet armyworm predation*). This experiment was repeated six times each in exclusion and inclusion plots between July 22 and August 7, 2002. The densities of ten predator species [*Hippodamia* spp., *Orius* spp., cotton fleahopper, lacewings (*Chrysoperla* spp.), spiders (Thomisidae, Salticidae, Others), damsel bugs (*Nabis* spp.), big eyed bugs (*Geocoris* spp.), *S. invicta* and native ants] present in the canopy of the two cotton plants immediately adjacent to the plant harboring the beet armyworm egg mass were recorded by taking beat bucket samples at the end of the experiment (~ 1:00 am). These data were used to assess beet armyworm egg disappearance rates, correlate predator density (as per beat bucket samples) with egg disappearance rate, and assess predator activity on cotton plants. Egg masses were recorded as either present or absent 24 h after being placed on plants.

Statistics. The proportions of bollworm eggs and beet armyworm egg masses absent after 24 h were arcsine transformed and compared between plots using two-way (treatment, dates) ANOVA (Zar 1999). Frequencies of predators collected in beat bucket samples and predators observed feeding on beet armyworm egg masses were compared using log-likelihood ratios with Yates' correction for continuity (Zar 1999). Mean numbers of *S. invicta* in exclusion plots were compared against a hypothesized mean of zero using one-sample *t*-tests to confirm whether *S. invicta* was eliminated from these plots.

Results

Central Texas. The ant bait treatments were effective in substantially reducing *S. invicta* populations in exclusion plots ($P < 0.001$) (Fig. 1). Moreover, the mean number of *S. invicta* per vial differed significantly from zero on only two of eight sampling dates (Fig. 1).

Cotton aphid densities were significantly higher in inclusion plots relative to exclusion plots ($P < 0.001$) (Fig. 5). Overall, cotton aphid densities were ca. 5.5× higher in inclusion plots (Fig. 5).

Significantly fewer bollworm eggs were present in inclusion relative to exclusion plots after 24 h on 14 of 18 dates ($P \leq 0.05$) (Fig. 6). Overall, twice as many bollworm eggs (58.5 ± 0.1 %) were absent in inclusion plots relative to exclusion plots (28.2 ± 0.1 %) after 24 h.

Forty-seven predation events on beet armyworm egg masses were observed in inclusion plots versus 69 events in exclusion plots during 18 h of observations in each plot type. Most predation events in inclusion plots were by *S. invicta* (~2/3) and cotton fleahopper (~1/5), followed by other predators (Fig. 7). In contrast, the majority of predation events in exclusion plots were by a mite (~1/2), *Abrolophus* sp. (Acari: Erythraeidae), followed by spiders, minute pirate bug and cotton fleahopper (each <1/8) (Fig. 7). *S. invicta* was the first predator to arrive at egg masses (~70 min.) in inclusion plots, and recruits removed all eggs in a mass within 15-30 min. In contrast, *Abrolophus* sp. arrived first at egg masses (~150 min.) in exclusion plots, and fed on one or two eggs for ca. 1 h.

North Texas. Beat bucket samples demonstrated that *S. invicta* was effectively excluded from foraging in the canopy of exclusion plots (Fig. 8, 9). Mean *S. invicta* densities in inclusion plots were 0.80 ± 0.14 ants per sample while in exclusion plots they were 0.04 ± 0.03 ants per sample and not significantly different from zero ($t = 1.46$; d.f. = 6; $P \geq 0.164$).

Bollworm egg disappearance in inclusion plots (62.5 ± 4.0 %) was significantly greater than in exclusion plots (42.5 ± 8.3 %) after 24 h ($F_{\text{treatments}} = 6.93$; d.f. = 1, 5; $P = 0.046$; $F_{\text{date}} = 1.80$; d.f. = 1, 5; $P = 0.266$). Beet armyworm egg mass disappearance in inclusion plots (38.5 ± 5.0 %) was significantly greater than in exclusion plots (9.4 ± 2.7 %) after 24 h ($F_{\text{treatments}} = 20.07$; d.f. = 1, 5; $P = 0.007$; $F_{\text{date}} = 0.55$; d.f. = 1, 5; $P = 0.7384$). Minute pirate bug, cotton fleahopper, spiders, and *S. invicta* were the most frequently collected predators in beat bucket samples in inclusion plots (Fig. 8). The proportions of minute pirate bug and cotton fleahopper were significantly greater in beat bucket samples compared to direct observations, while the reverse was true for *S. invicta* and native ants ($P \leq 0.05$) (Fig. 8). Similarly, minute pirate bug, cotton fleahopper, and spiders, but not *S. invicta*, were the most frequently collected predators in beat bucket samples in exclusion plots (Fig. 9). The proportion of minute pirate bug was significantly greater in beat bucket samples relative to direct observations ($P < 0.05$) (Fig. 9).

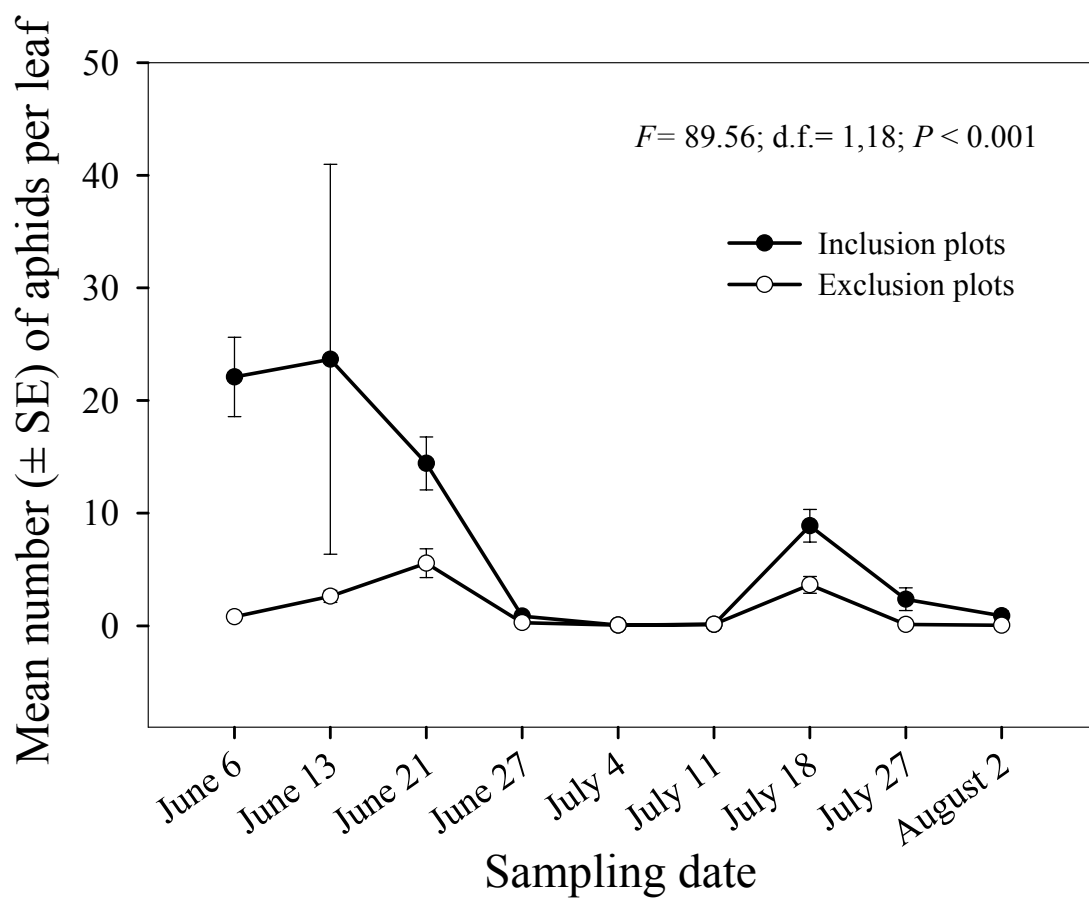


Fig. 5. Mean number of *Aphis gossypii* per cotton leaf in *S. invicta* inclusion and *S. invicta* exclusion plots, Williamson Co., Texas, 2001. Exclusion plots were treated with fire ant bait to eliminate *S. invicta*, while inclusion plots were left untreated.

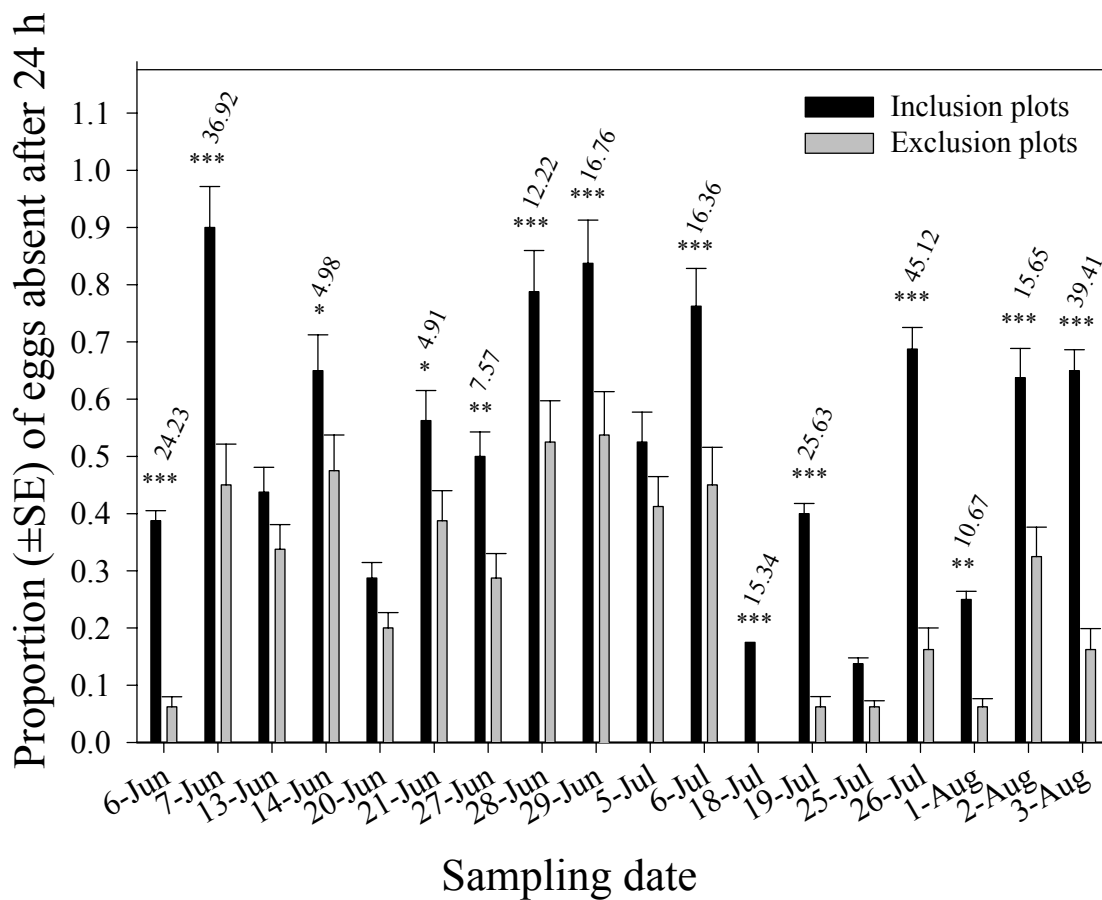


Fig. 6. Proportion of bollworm eggs absent after 24 h in *S. invicta* inclusion and *S. invicta* exclusion plots, Williamson Co., Texas, 2001. Individual dates were compared using χ^2 tests, and χ^2 values are inset, and all have one degree of freedom. *, $P < 0.05$; **, $P < 0.025$; ***, $P < 0.0001$. Exclusion plots were treated with fire ant bait to eliminate *S. invicta*, while inclusion plots were left untreated.

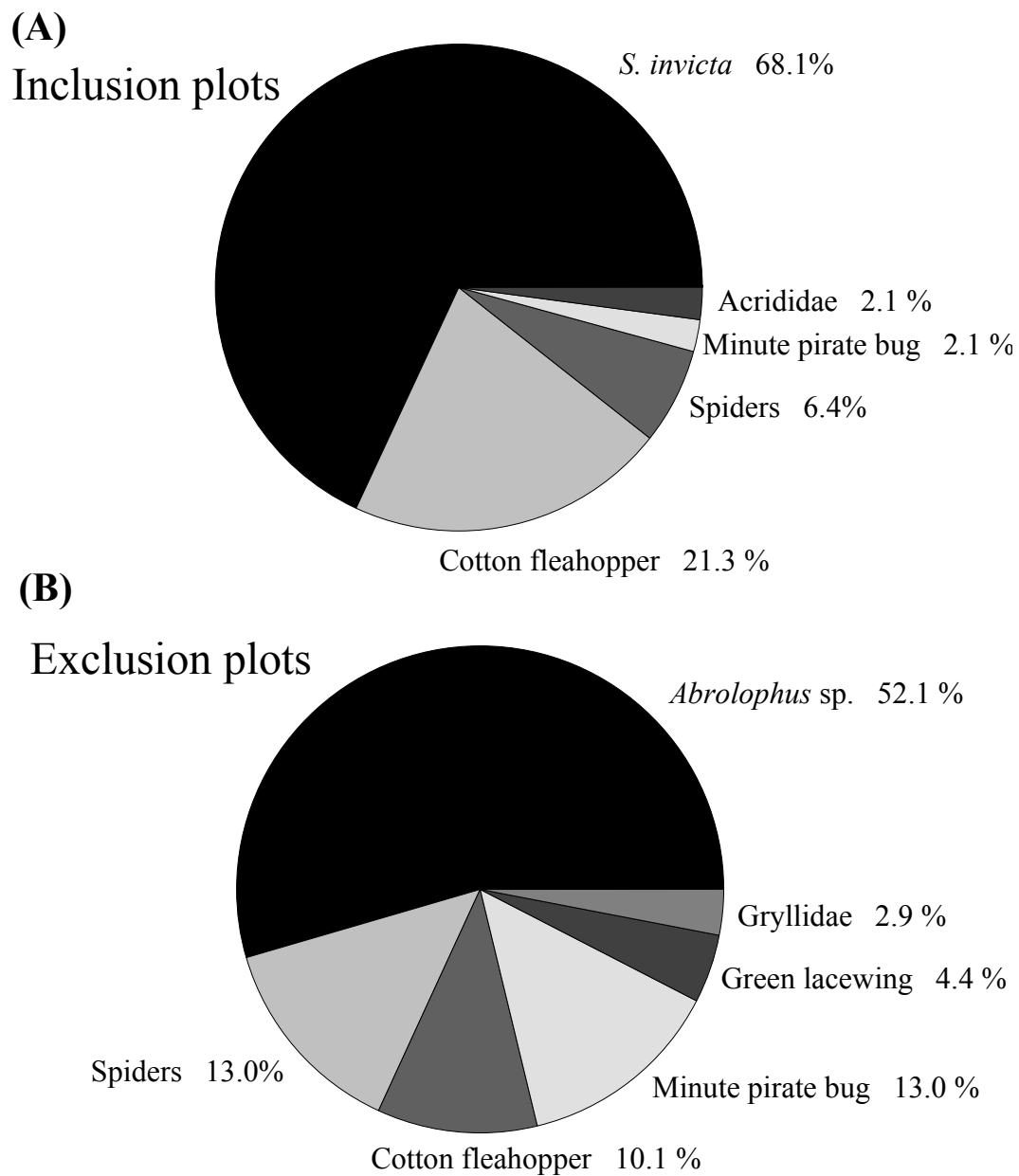


Fig. 7. Proportions of observed predation events on beet armyworm eggs corresponding to individual predator species, Williamson Co., Texas 2001. (a) *S. invicta* inclusion plots (n=47). (b) *S. invicta* exclusion plots (n=69). Exclusion plots were treated with fire ant bait to eliminate *S. invicta*, while inclusion plots were left untreated.

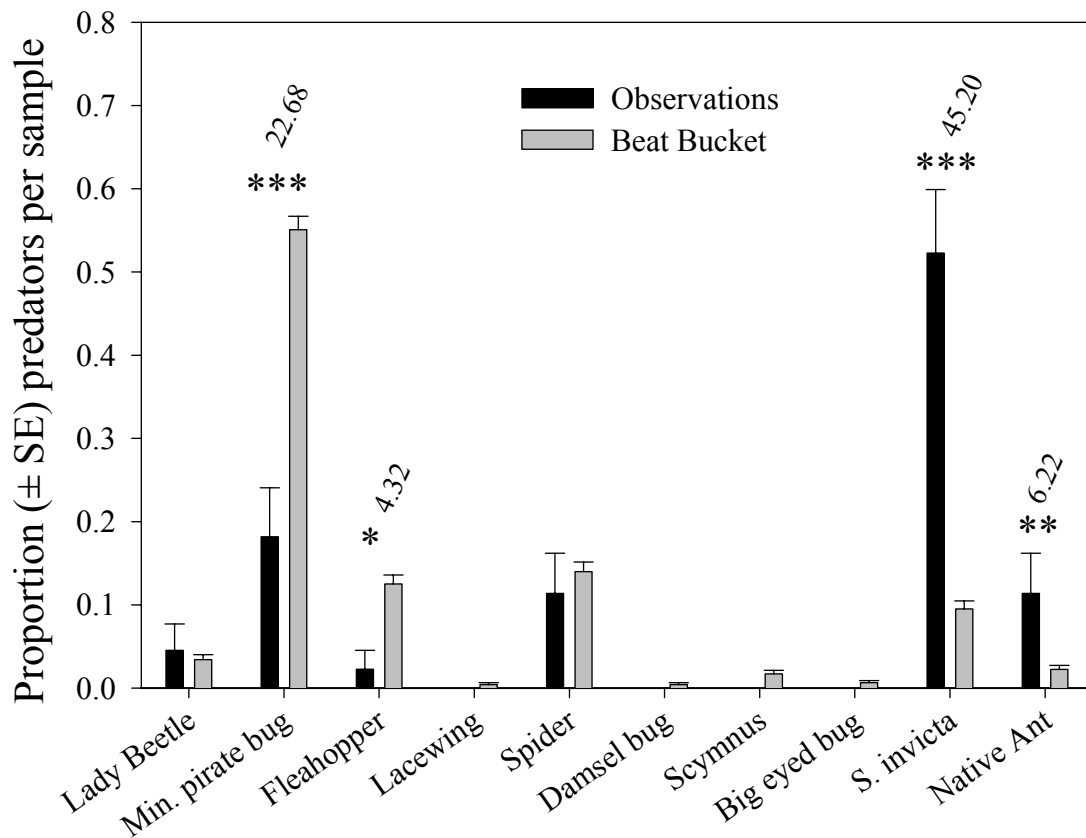


Fig. 8. Relative frequencies (shown as proportions) of predators observed in *S. invicta* inclusion plots based on beat bucket samples ($n = 96$) and visual observations of sentinel egg predation ($n = 44$), Dallas, Texas, 2002. Inclusion plots consisted of six contiguous plants. Proportions were compared using log-likelihood ratio-tests. G values are inset, and all have one degree of freedom. *, $P < 0.05$; **, $P < 0.025$; ***, $P < 0.0001$.

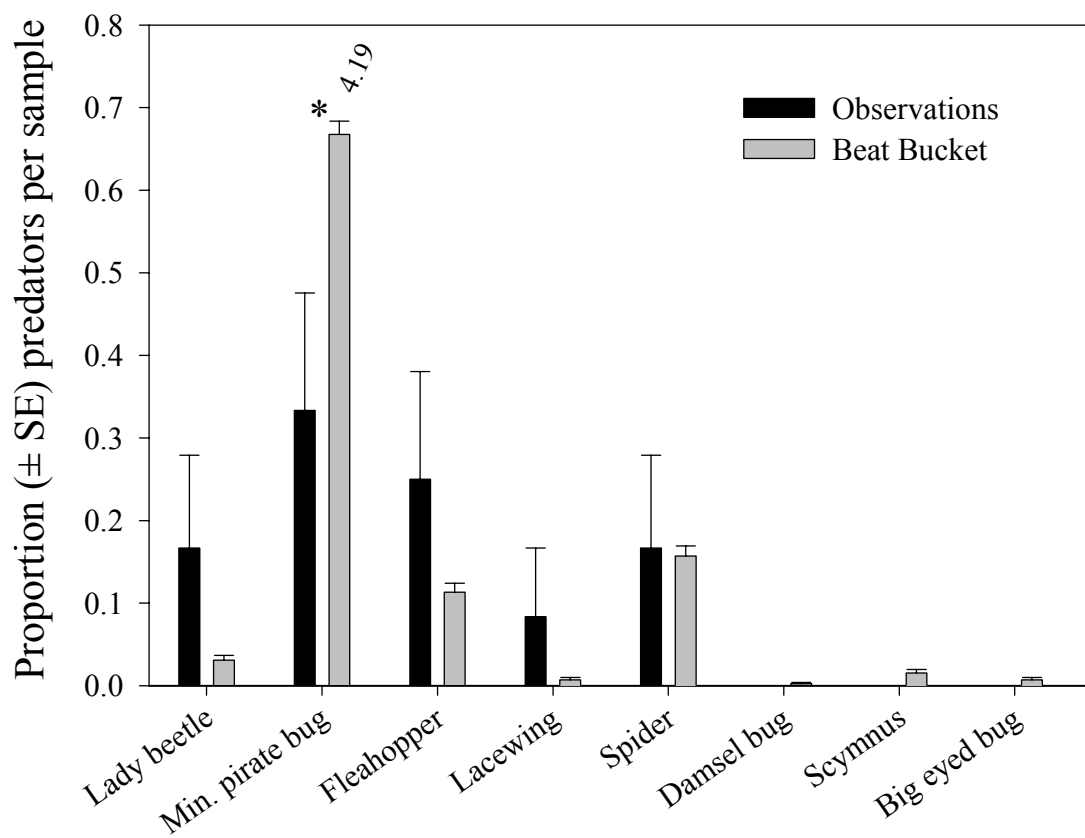


Fig. 9. Relative frequencies (shown as proportions) of predators observed in *S. invicta* exclusion plots based on beat bucket samples ($n = 96$) and visual observations of sentinel egg predation ($n = 37$), Dallas, Texas, 2002. Exclusion plots consisted of six contiguous cotton plants treated with a band of Tangle Foot® at their base to exclude *S. invicta*. Proportions were compared using log-likelihood ratio-tests. G -values are inset, and all have one degree of freedom. *, $P < 0.05$.

Discussion

The results of this study show that *S. invicta* positively influences the population growth rate of cotton aphid populations though these did not reach economic levels, and that it is an important predator of bollworm and beet armyworm eggs. Specifically, this study showed that cotton aphid populations were favored by *S. invicta* early in the season, and that *S. invicta* increased predation of bollworm and beet armyworm eggs by 20-30% during mid and late-season. Moreover, on the basis of direct observations, the results suggest that *S. invicta* is the most frequent predator of beet armyworm eggs in cotton fields, and that its density estimates are not correlated with frequency of observed predation. Overall, the results suggested that *S. invicta* has a net positive effect in cotton agroecosystems.

Influence on cotton aphid populations. Previous studies showed that *S. invicta* is associated with numerous honeydew-producing homopterans, and that these associations are characterized by a variety of positive outcomes on homopteran populations (Scarborough 1984, Michaud and Browning 1999, Helms and Vinson 2002, Kaplan and Eubanks 2002, Hill and Hoy 2003). Nevertheless, negative outcomes had been reported in other ant-homopteran interactions (Way 1963, Sakata 1994, 1995; Offenberg 2001). The increase in cotton aphid densities suggests a net positive balance between tending and guarding versus predation by *S. invicta*, though aphid densities did not reach the economic threshold level of 50 aphids per leaf (Moore et al. 2002). Beat bucket samples demonstrated that lady beetles responded numerically to aphid increase early in the season (see pg. 19, Fig. 2), consequently, they could prey on aphid

populations despite the protection of *S. invicta*. In a similar study, Kaplan and Eubanks (2002) reported that cotton aphid densities were 1.7× more abundant in plots with high (3.5 ± 0.3 ants per six cotton plants) versus low (1.8 ± 0.3 ants per six cotton plants) *S. invicta* densities. In contrast, Scarborough (1984) found in greenhouse bioassays that *S. invicta* did not directly affect the density of cotton aphids. Further research is necessary to elucidate which factors, e.g. honeydew removal, protection from natural enemies, or direct predation by *S. invicta* more strongly affects cotton aphid population dynamics.

Predation on bollworm and beet armyworm eggs. Disappearance of noctuid eggs in cotton fields is largely attributed to predation by predators with chewing mouthparts such as ants and ladybeetles (Whitcomb and Bell 1964, McDaniel and Sterling 1982). In this study, *S. invicta* was the most important predator of bollworm and beet armyworm eggs in both years. Presence of *S. invicta* led to increased rates of disappearance of bollworm and beet armyworm eggs by 20-30% and 27%, respectively. Several studies show that *S. invicta* is an active predator of noctuid eggs (McDaniel and Sterling 1979, 1982; Agnew and Sterling 1982, Nuessly and Sterling 1986, 1994), larvae (McDaniel et al. 1981, Stewart et al. 2001) and pupae (Ruberson et al. 1994). Furthermore, nocturnal observations confirmed that *S. invicta* was responsible for 68 % of beet armyworm egg masses predation. Nocturnal observations also showed that *S. invicta* was the first to encounter beet armyworm egg masses, and recruited workers quickly removed all eggs. The mite *Abrolophus* sp. was the most frequent predator in the absence of *S. invicta* during 2001. However, this mite consumed few eggs, one or two eggs over periods of 2-3 h. Whitcomb and Bell (1964) found that the mites *Erythraeus*

sp. and *Balaustium* sp. preyed on bollworm eggs and only three egg shells were dislodged during 31 feeding observations. In contrast, *S. invicta* consumed or removed entire egg masses (40-50 eggs) in short periods of time (ca. 15-30 min).

Comparisons of beat bucket samples and nocturnal observations during 2002 suggested that *S. invicta* is underrepresented, while minute pirate bug and cotton fleahopper are over-represented, in beat bucket samples relative to their corresponding egg encounter frequencies. Minute pirate bug and cotton fleahopper were the most common predators in beat bucket samples, yet were infrequently observed preying on eggs. In contrast, *S. invicta* was less common in beat bucket samples, yet were the predator most frequently observed preying on eggs.

Other field studies confirm that *S. invicta* reduces numbers of eggs and immatures of important pests in different crops. In soybeans, *S. invicta* reduced egg densities (Brown and Goyer 1982) and preyed on larvae (Elvin et al. 1983) and pupae (Lee et al. 1990) of velvetbean caterpillar, and are important predators of southern green stink bug, *Nezara viridula* (L.) (Ragsdale et al. 1981, Krispyn and Todd 1982, Stam et al. 1987). In cowpea, *S. invicta* reduced egg densities of *Leptoglossus phyllopus* (L.) (Abudulai et al. 2001) and preyed on pupae of cowpea curculio, *Chalcodermus aeneus* Boheman (Russell 1981). In peanuts, Vogt et al. (2001) found that most *S. invicta* food items were rednecked pea-nutworms, *Stegasta bosqueella* Chambers. *S. invicta* in sugarcane is recognized as a controlling agent of sugarcane borer, *Diatrea saccharalis* F., and their presence is promoted through conservation practices (Adams et al. 1981, Fuller and Reagan 1988, Bessin and Reagan 1993). Finally, *S. invicta* added 44 % to boll

weevil predation in cotton fields (Agnew and Sterling 1981). Thus, *S. invicta* clearly plays an important role as a natural enemy of key pests in field crops.

Conclusion. Though the presence of *S. invicta* in cotton fields led to an increase in cotton aphid populations early in the season, they were also shown to be important predators of noctuid eggs. Moreover, this study showed that *S. invicta* may be the most important predator of bollworm and beet armyworm eggs in cotton fields considering behavioral factors such as mass foraging, recruitment and aggressiveness. The predatory role of *S. invicta* is increasingly relevant in recent years because beet armyworm is becoming a persistent and serious pest in southeastern and mid-southern states, especially in regions under boll weevil eradication programs (Ruberson et al. 1994, Parajulee and Slosser 2000). Their widespread distribution, high densities and frequent predation of key pests make *S. invicta* an important component of cotton agroecosystems. Thus, proper management of *S. invicta* populations should be encouraged so that their negative impacts can be ameliorated and their positive effects enhanced. Future research should focus on developing techniques to minimize the increase in cotton aphid populations early in the season and enhance *S. invicta* predatory activity later in the season.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

The cotton industry plays important roles in the economies of Texas, the United States, and other countries. Pest losses reduce the profitability of cotton production. Texas cotton production is mostly affected by thrips, cotton aphid, cotton fleahopper, bollworm and beet armyworm. Currently, transgenic cotton varieties are available that protect plants from bollworm and tobacco budworm, and other lepidopteran pests. However, growers still rely on insecticide applications for control of thrips, cotton aphids, cotton fleahopper and lygus bug. Moreover, outbreaks of beet armyworm are a concern due to wide-scale applications of malathion in efforts to eradicate the cotton boll weevil. Even though cotton insect pest management is rapidly changing, natural enemies remain important components of cotton pest management and thus warrant conservation and encouragement

Generalist predators have some unique features absent in specialists. For example, they can have immediate impacts on immigrant pests, and reduce the rate of pest resistance evolution to transgenic crops (Symondson et al. 2002). *S. invicta* is the most abundant generalist predator in southern US cotton fields and their predatory activity can strongly influence populations of some cotton insect pests.

The results of the first year of study demonstrate that *S. invicta* did not affect the abundance of 49 groups of ground-dwelling insects and spiders collected in pitfall traps.

However, cotton fields with *S. invicta* had lower densities of ground-active predators such as carabids, and canopy-dwelling spiders, green lacewing and minute pirate bugs. Populations of aphidophagous insects such as lady beetles and *Scymnus* spp. increased apparently due to the availability of cotton aphids early in the season. The results suggested that a greater abundance of aphids in the presence of *S. invicta* increased convergent lady beetle movement into cotton, which contributed to suppression of aphid densities below economic thresholds.

The foraging activity of *S. invicta* increased during the season both years of study. This was particularly important in the context of pest predation. Though *S. invicta* tended and guarded cotton aphids early in the season, aphid populations did not reach damaging levels. Later in the season, aphid populations decreased apparently due to predation by lady beetles and other predators, fungal diseases, and abiotic factors such as heavy rain. The results of both years of study demonstrated that *S. invicta* is an important predator of bollworm and beet armyworm during most of the cropping season. Therefore, the increase of *S. invicta* foraging activity during mid and late season enhances to their predatory role at a critical time.

Ants of various species play important roles in pest management in different crops. Beneficial predatory ants include at least seven ant genera: *Oecophylla*, *Dolichoderus*, *Anoplolepis*, *Wasmania*, and *Azteca* in the tropics, *Solenopsis* in the tropics and subtropics, and *Formica* in temperate regions (Way and Khoo 1992). Attempts to control the spread of *S. invicta* in different ecosystems have failed, and its control or suppression may aggravate pest problems (Long et al. 1958; Hensley et al.

1961; Reagan et al. 1972; Adams et al. 1981). Cotton growers in the southern US should take advantage of this ant through conservation practices when its impact is beneficial. If future research confirms the net benefit of *S. invicta* to cotton pest management, then methods to manage of *S. invicta* densities and their impact should be developed.

More studies are needed to understand the ecology of *S. invicta* in cotton fields. Some areas of study that merit consideration include the impacts of tillage practices on mound density, nutritional ecology and food dynamics of colonies during the cropping season, impacts of insecticides on foraging activities, and effects of crop rotations on ant populations.

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APPENDIX

Impact of the red imported fire ant, *Solenopsis invicta* Buren, on cotton aphids and aphidophagous insects.

This appendix describes the outcome of a failed field study and makes a number of recommendations for future similar studies.

Description. During summer of 2001 we observed an increase in the densities of cotton aphids in plots with *S. invicta*. This increase could be explained by at least two hypotheses: a) tending of *S. invicta* has direct beneficial effect on the cotton aphid survival and reproduction, and b) guarding of *S. invicta* from aphidophagous arthropods significantly increases cotton aphid survival.

We conducted an inclusion/exclusion experiment in the field to evaluate the interaction between *S. invicta*, aphids and natural enemies. We used an experimental cotton field located in the Research Farm at Texas A&M University in College Station, Texas. Cages with “windows” that selectively allowed free movement of natural enemies into and out of the cages were used for this experiment.

In the first week of May and July of 2002, cotyledon stage plants were manually cleaned of all insects and inoculated with adult cotton aphids (4 aphids per seedling) from a laboratory colony. Forty cylinder-shaped cages with stainless steel wire frames, and fine polyester mesh netting (diameter 32 cm; height 35 cm) (“Fiber-Air Sleeve”, Kleen Test Products, Milwaukee, Wis. USA) were placed over groups of aphid-inoculated

plants (3-7 seedlings per cage). The cage mesh had an irregular fine weave, with pores small enough to allow air flow, but excluded all aphid predator and parasitoids. The aphid populations were allowed to increase for 18 days free of natural enemies and other herbivores. The cages were opened every 4-5 days and any herbivores and natural enemies were manually removed.

Eighteen days after cage deployment, ten cages were randomly allocated to each of three treatments: 1) aphids only, with mesh cages retained to prevent insect migration and allow aphid population growth unaffected by natural enemies (ants were previously eliminated using diatomaceous earth); 2) aphids plus *S. invicta*, with fine mesh cages containing a “window” (dimensions: 6 cm height) at the base of the frame, covered with a medium-mesh screen (pores 1.5 mm x 1.5 mm), which allowed *S. invicta* to move in and out of cages, but excluded lady beetles (*Hippodamia convergens*); 3) aphids plus *S. invicta* plus natural enemies, with fine mesh cages containing a window (dimensions: 6 cm height) covered with a coarse-mesh screen (pores 8mm x 8mm), which allowed *S. invicta*, *H. convergens* and other aphidophagous arthropods to move in and out of cages; and 4) no-cage control, to determine if the presence of the mesh cage influenced aphid population growth, natural enemy efficacy, or plant growth. Replicates were blocked by initial aphid density to control statistically for any influence of initial aphid abundance on treatment effects.

Sampling techniques. Non-destructive sampling techniques were used to estimate the number of nymphal and adult cotton aphids, the number of intact aphid mummies, the number of consumed aphid mummies (mummies that were severely

damaged from coccinellid feeding but were dislodged from the leaf), and the total leaf area in each cage. All nymphal, adult and mummified aphids and *S. invicta* on the upper and lower surfaces of all leaves were counted every 3-5 days for 24 days.

Problems presented and potential solutions. During this experiment fire ant workers were found entering cages, mainly from the soil underneath the cage. Also, cotton aphid parasitoids were able to enter through the fine mesh. Therefore, it was difficult to have parasitoid- and ant-free cages.

Since *S. invicta* is very difficult to eliminate from underneath the plant, having “potted” plants in the field may help to control ants. The insect trap coating (Tangle foot®) kept ants from crawling on the plants only for two days; ants placed several pieces of dirt and /or soil on the surface and thus had access to the plant.

The size of the window was large, which made it difficult to completely seal cages. Consequently, it is recommended to have smaller windows (e.g. 8cm × 15cm) to facilitate checking and repair during sampling.

VITA

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Professional interest

The implementation of effective programs of Biological Control as key tool in Integrated Pest Management (IPM). The intensive use of agrochemicals has created among other things, insect resistance, environmental hazards, secondary pests and reduction of natural enemies. These negative consequences only can be avoided through careful implementation of IPM strategies.

Education

B.S. 1999. Major: Agronomy. Escuela Agricola Panamericana, Zamorano, Honduras.

2001-2003 Texas A&M University, College Station

- Sampling and identification of natural enemies in cotton fields and evaluation of its impact upon cotton key pests
- Evaluation of impact of transgenic crops on pest and natural enemies
- Lab experience in rearing lepidopteran pests for experiments
- Identification of beneficial insects collected in different types of traps

1996-1999: Escuela Agricola Panamericana, El Zamorano, Honduras

- Research assistant in the Department of Entomology
- Sampling, collecting, rearing, releasing and evaluating natural enemies of corn's mayor pest in Honduras
- To plan and develop experimental designs for research projects. Thesis: "Biological Control of corn earworm (*Helicoverpa zea* (Boddie)) in sweet corn produced in Zamorano"
- Theoretical and practical training in the production and management of agronomic crops, vegetables, fruits, forest and ornamentals in the tropics
- Theoretical and practical training in the processing and merchandising of agricultural products including fruits, vegetables and ornamentals
- Assisted local farmers in developing crop systems in agronomy, forestry, horticulture and animal science