The *Journal of Cotton Science 11:186–198 (2007)*
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ARTHROPOD MANAGEMENT AND APPLIED ECOLOGY

Species Of Thrips Associated With Cotton Flowers

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ABSTRACT

Cotton (*Gossypium hirsutum* L.) flowers are inhabited by many insect species, including common thrips (Thysanoptera: Thripidae). Thrips species have been hypothesized to increase the severity of hardlock in cotton, but it was unclear if their numbers could be managed using insecticide applications. The objectives of this study were to describe the thrips species and other insects found in cotton flowers and to determine how they are affected by insecticide applications. Population characteristics of the thrips were also investigated, including sex ratio, within-season variability, predator interactions, and rates of accumulation in flowers. White, first-day, flowers were sampled from untreated and insecticide-treated plots in 2 locations from 2003 to 2005. Insecticide treatments consisted of foliar applications of spinosad and either acephate or lambda-cyhalothrin depending on location. *Frankliniella tritici* (Fitch) (eastern flower thrips) was the most common species, and females outnumbered males by approximately 3 to 1. Insecticide treatments consistently reduced thrips numbers by 20 to 90%. *Orius insidiosus* (Say) (minute pirate bug), a predator of thrips, sometimes declined in the floral samples when insecticides were applied. Numbers of thrips and *Orius* sp. fluctuated throughout the season in all treatments. The covariation between thrips and *Orius* sp. was further explored and significant correlations were noted. The rate at which thrips enter flowers after opening was monitored and varied in both the starting (1000 h) and peak (1400 to 1800 h) number of thrips. The average relative humidity from 1700 h on the day before to 1000 h of the next day was negatively correlated to thrips numbers at 1000 h. It appears thrips numbers in cotton flowers can be managed while limiting injury to *O. insidiosus*.

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Thrips (Thysanoptera: Thripidae) are small insects, generally 1.5 mm or less in length. Depending on the species, they range in color from light tan to dark brown, and they possess primitive wings that allow limited flight. Small hairs (setae), which occur on some areas of the body, and the antennae are characteristics that are useful for identifying the species. A survey of the literature indicates most thrips of concern in cotton production belong to the genus *Frankliniella* (subfamily Thripinae). *Frankliniella fusca* (Hinds) (tobacco thrips) is a pest of cotton seedlings, peanuts (Funderburk et al., 1998), and other crops (McPherson et al., 2005; Webb, 1995). Other species, such as *Frankliniella occidentalis* (Pergande) (western flower thrips), *Frankliniella tritici* (Fitch) (eastern flower thrips), and *Frankliniella bispinosa* (Morgan) (Florida flower thrips), occur more often on mature vegetation or flowers.

Thrips can vector plant viruses. For example, *F. occidentalis* (Sakimura, 1963), *F. fusca* (Pappu et al., 1998), and *F. bispinosa* (Avila et al., 2006) are capable of transmitting the tospovirus tomato spotted wilt virus. *F. fusca* has also been shown to transmit *Pantoea ananatis* (Serrano), the bacterium responsible for center rot of onion (Gitiatis et al., 2003). By vectoring the pathogen and establishing infection sites, thrips can increase the incidence of corn ear rot, caused by *Fusarium verticillioides* Sacc. (Nirenberg) (Farrar and Davis, 1991).

Several flower-inhabiting thrips species are present in North Florida. In an 18-month study of 37 wild plant species, 78% of the thrips were adults, and 87% of these adults were from the genus *Frankliniella* (Chellemi et al., 1994). The most common species were *F. tritici*, *F. bispinosa*, *F. occidentalis,* and *F. fusca*. The relative contributions of each species fluctuated substantially during the study. Cotton flowers were not examined, but during the bloom period of June, July, and August, *F. tritici* and *F. bispinosa* were the most common species on wild hosts. The primary influence on *Frankliniella* spp. populations may be the availability of suitable flowers. Populations of *F. occidentalis* increased more rapidly during the spring than other species, possibly because of its wider plant host range. It is an exotic species and was first reported in Georgia in 1981 (Beshear, 1983).

Thrips numbers are affected by predatory insects and parasites. *Orius insidiosus* (Say) (minute pirate bug) is a common predator that can consume 12.5 thrips per day (Tommasini and Nicoli, 1993). If a sufficient number of *Orius* sp. are present in an area, local extinction of flower thrips populations may occur. *Orius* sp. will remain in the area, feeding on extrafloral nectaries or pollen, which is sufficient to allow development and oviposition by *Orius* sp., and prevent the thrips population from rebounding.

A parasitic nematode *Thripinema fuscum* (Tipping & Nguyan) infected *F. fusca* in North Florida. Among *F. fusca* found on peanut, as many as 51 and 67% of females on certain sampling dates were infected, which resulted in sterility. *T. fuscum* infection of *F. tritici* and *F. occidentalis* was less common, occurring in only 2% of individuals, suggesting there is host specificity (Funderburk et al., 2002; Stavisky et al., 2001).

Sex and species differences have been observed in thrips behavior. Males of *F. occidentalis*, *F. tritici*, and *F. bispinosa* are more mobile among plants than females (Ramachandran et al., 2001). Females of *F. occidentalis* spend more time feeding and produce more feeding-associated scars on petunias than males (van de Wetering et al., 1998). On greenhouse-grown pepper plants, movement of *F. occidentalis* was limited, while *F. tritici* and *F. bispinosa* dispersed relatively rapidly (Ramachandran et al., 2001). These species differences in behavior resulted in *F. tritici* and *F. bispinosa* being less susceptible to predation by *Orius* sp. than *F. occidentalis*.

Thrips species also differ in their response to insecticides. *F. occidentalis* populations have been shown to increase following applications of acephate and esfenvalerate, while spinosad causes a population reduction (Reitz et al., 2003). Acephate and esfenvalerate are highly toxic to *F. tritici* and *F. bispinosa*, while spinosad is less effective. In contrast, Eger et al. (1998) found spinosad to be equally effective against all three species. The effectiveness of insecticides on thrips numbers can be complicated by their effect on predators, which probably explains increases in *F. occidentalis* (Reitz et al., 2003). Studebaker and Kring (2000) evaluated several insecticides for both lethal and sub-lethal effects on *Orius* sp., which could affect reproduction. Spinosad had no effect, lethal or sub-lethal, on populations of *Orius* sp. Lambda-cyhalothrin resulted in high mortality, but no sub-lethal effect was observed in survivors. Acephate was not tested in that study, but it is a broad-spectrum organophosphate that affects a large number of arthropods.

Thrips possess only one mandible that is used for cutting into plant tissue and a stylet through which food is drawn. This results in open wounds to the plant, which could allow easier penetration of the tissue by pathogens. Females of *F. occidentalis* have been shown to feed more frequently and intensely than males, resulting in more tissue damage (van de Wetering et al., 1998). Pickett et al. (1988) reported 68% of adult *F. occidentalis* on cotton plants occurred on fruiting structures, and most of these occurred in the flower. This is consistent with the concept that cotton pollen may be preferable to leaves as a food source for some thrips species (Agrawal et al., 1999). Pollen provides a source of protein for egg development, resulting in increased fecundity (Trichilo and Leigh, 1988). In tomato, amino acid analysis showed phenylalanine content to be associated with thrips numbers (Brodbeck et al, 2001). Nectar is also an important resource for attracting pollinators and predatory insects to cotton plants (Wackers and Bonifay, 2004).

Thrips are a frequent problem on cotton seedlings in the United States, resulting in distortion of expanding leaves and small discolored spots. The most common species are *F. occidentalis*, *F. fusca*, and *Thrips tabaci* (Lindeman) (onion thrips). Thrips control is usually achieved using a granular insecticide at planting. In addition, foliar insecticide applications are used if more than 2 to 3 thrips are present per plant and damage is observed (Sprenkel, 2005). Applications of jasmonic acid to cotton seedlings can reduce thrips feeding by 80%, although leaf area is also reduced by 28% (Omer et al., 2001). Thrips feeding is generally not a problem when the plants are more mature; however, severe damage was reported in Turkey by *Frankliniella intonsa* (Trybom) on mature cotton plants (Atakan and Ozgur, 2001a). Although more than 350 thrips were observed per cotton flower, pollination was not adversely affected. Elevated thrips numbers were associated with increased flower shedding, and feeding by larvae resulted in boll abscission (Atakan and Ozgur, 2001a).

In recent years, there has been increasing interest by growers in hardlock of cotton. Hardlock is a failure of the cotton fiber to expand outward from the boll after opening. Affected locules will remain on the plant or be knocked to the ground during harvest. Fiber quality is not usually affected, but yields can be reduced (Wright et al., 2004). Hardlock is associated with the fungus *F. verticillioides* and is believed to infect through the flower on the day of bloom (Marois et al., 2002). Most control strategies have focused on the application of fungicides to flowers and maturing bolls (Marois and Wright, 2004). It has also been suggested flower thrips could be involved in hardlock. If that is the case, reducing their numbers may limit the severity of hardlock.

Previous studies have examined thrips species associated with mature cotton plants. Graves et al. (1987) reported *F. occidentalis* to be the most frequent thrips species in cotton flowers in Louisiana, sometimes numbering more than 100 thrips per flower. They appeared to feed on pollen, and as the flower desiccated, on the calyx surrounding small bolls. *F. intonsa* has been reported to damage cotton flowers and vegetative tissue in Greece (Deligeorgidis et al., 2002) and Turkey (Atakan and Ozgur, 2001a). *Frankliniella schultzei* (Trybom) and *F. occidentalis* have also been reported as pests of cotton flowers and leaves in Brazil (Monteiro, 2001). The objectives of this study are to describe the species of thrips and other insects found in cotton flowers and determine how they are affected by insecticide applications. The interaction of thrips and populations of *Orius* sp. and influence of weather factors on thrips arrival are also explored.

MATERIALS AND METHODS

Prevalent species. To determine the species typically present in cotton flowers, data from untreated control plots (studies described in next section) were used to calculate the mean and standard error of the mean (SEM) for each species in Quincy, FL, (2004 to 2005) and Marianna, FL (2003 to 2005). Because results were similar each year, the data were grouped by location. To determine if these observations were typical of the southeastern United States, or specific to North Florida, samples were taken in other states from 2003 to 2005. Collaborators in Louisiana, Alabama, and South Carolina collected 50-80 cotton flowers from available plots, and sent them to Quincy for identification of insect inhabitants. The Louisiana samples were collected at the Macon Ridge Research Station in Winnsboro (Franklin Co.), LA. The Alabama samples were collected at the Auburn University Gulf Coast Research Station located in Fairhope (Baldwin Co.), AL. The South Carolina samples were collected at the Edisto Research and Education Center in Blackville (Barnwell Co.), SC. Flowers were sampled typically at mid- to late bloom.

Identification of thrips. Vials containing thrips were kept at room temperature until each sample was evaluated. During 2003 and 2004, liquid from the sample was poured into a Petri dish and the flower immersed in the dish to further dislodge any thrips present. The sample was then examined, and the number of insects was recorded. In 2005, the flower was removed and insects were counted while still in the vial. To confirm if this method was effective, flowers were periodically dissected to ensure thrips did not remain within the flowers. Thrips were identified to species based on morphological characteristics (body color, antennae, pigmentation, and ornamentation) (Mound and Kibby, 1998). These characteristics were consistent across the individuals observed. Sex was determined by the presence or absence of the ovipositor, and by abdomen width and curvature. Immature thrips were not identified to species and lumped together. Other commonly found or easily identified insects were classified to order or genus. Insects that were rarely observed were not recorded.

Impact of insecticide treatments on flower inhabiting insects. Two field studies were performed, approximately 65 km apart, at branch locations of the North Florida Research and Education Center NFREC in Quincy (Gadsden Co.) and Marianna (Jackson Co.), Florida. Cultivar DPL 555 Bt/RR (Delta Pine and Land Co.; Scott, MS) was used, and plots were maintained according to the recommendations of the University of Florida Cooperative Extension Service (Wright et al., 2007), unless otherwise noted. Acephate (Orthene 97; Valent U.S.A. Corporation; Walnut Creek, CA) and lambda-cyhalothrin (Karate; Syngenta; Greensboro, NC) were used as needed to control *Nezara viridula* (Linnaeus) (southern green stink bug) and *Euschistus servus* (Say) (brown stink bug).

In Quincy, a fungicide-insecticide study was used to evaluate thrips and cotton yield for 2 yr. The plot design was a randomized complete block design with 4 replications. There were 28 treatments in 2004 and 10 treatments in 2005. Plots were 4 rows (0.9 m between rows) by 9 m long. Control and insecticide-treated plots (with or without fungicide, depending on the year) were sampled for thrips. Other treatments were various rates and timings of fungicide applications, but were not sampled. In 2004, the insecticide treatment consisted of weekly applications of 0.10 kg a.i./ha of spinosad (Tracer; Dow AgroSciences; Indianapolis, IN) on Mondays and 0.56kg/ha acephate (Orthene 97; Valent U.S.A. Corporation) + 0.04 kg a.i./ha lambda-cyhalothrin (Warrior; Syngenta; Greensboro, NC) on Thursdays. In 2005, the rate of lambda-cyhalothrin was lowered to 0.02 kg a.i./ha, and the formulation was changed (Karate; Syngenta). In 2005, 0.9 kg/ha of thiophanate-methyl (Topsin M; Cerexagri, Inc.; King of Prussia, PA) was applied every 2 wk. Diluted treatment compounds were broadcast sprayed at a volume of 103 L/ha.

The study in Marianna examined the effects of insecticides and fungicides on thrips and cotton yield for 3 yr. The site was part of a *Paspalum notatum* (Fluegge) (bahiagrass) rotation, consisting of 2 yr of bahiagrass, 1 yr of peanuts, and 1 yr of cotton. The plots were eight rows in width, with 0.9 m between rows, and 18 m in length. Rows were oriented north to south, and at each end a 6-m wide section of peanuts was planted. Peanuts support large numbers of *F. fusca*, and are commonly planted in proximity to cotton in Florida. It was suspected peanuts could influence the species ratio found in cotton flowers. A randomized complete block design was used with four blocks and four treatments. The treatments were applied during the bloom period and consisted of 1) insecticide (spinosad at 0.07 kg a.i./ha alternated weekly with acephate at 0.9 kg a.i./ha), 2) fungicide (thiophanate-methyl at 1.1 kg a.i./ha applied weekly), 3) insecticide and fungicide, and 4) a non-treated control. Diluted treatment compounds were applied at a volume of 206 L/ha using a High-boy sprayer (John Deere; Moline, Illinois).

Sampling of thrips. Upland (*G. hirsutim* L.) cotton flowers are white on the first day they open, but by evening the fringes of the petals are often pink. On the second day, the petals have changed to a solid dark pink or red color. In this study, white, first-day, flowers were collected and placed in individual 60 ml vials containing 70% ethanol solution in water. Each flower was placed into the vial with the peduncle located at the opening. This allowed the flower contents to fall into the bottom of the vial. Flowers were sampled weekly between 1100 and 1300 h. In Marianna, the two outer rows of each plot were used for sampling, reserving the inner rows for harvest data. To determine if there was interplot interference because of pesticide drift, rows were categorized as insecticide or non-insecticide-treated and whether they were adjacent to an identical or different row. The number of adult thrips was compared between these four categories, and only minor differences stemming from the adjacent row were noted (data not shown). In the study at Quincy, 12 flowers were sampled from two interior rows of each of four control and four insecticide plots. During 2004, the interval between insecticide applications and sampling varied. In 2005, insecticide-only plots were not established, so an insecticide + fungicide treatment was substituted. The interval between treatment sprayings and sampling time was held constant at 2 d. In the Marianna study, 16 flowers were sampled from each of the 16 plots. The interval between insecticide applications and sampling varied between 2 and 6 d. At both locations, treatments were applied on the first week of bloom, and sampling began later that week. Sampling was discontinued in late August, because blooms after that time would not result in harvestable bolls. In 2004, a hurricane prevented sampling on the 5th week, and by the following week the plants had stopped flowering.

Association and covariation between thrips and minute pirate bugs. To determine if thrips and minute pirate bug were associated, the number of flowers containing either thrips or pirate bugs, both species, or neither was calculated. A predicted distribution, generated using a chi-square test, was compared with the observed distribution, and their significance reported. This procedure was performed individually for each year of the studies in Quincy and Marianna. Similar data were obtained each year, so the results are reported by location. Three indexes of species association, Ochiai, Dice, and Jaccard, were calculated. The indexes represent the ratio of samples containing both species (category a) to those containing one or more species (categories a, b and c), and omit samples with neither species present (category d). The equations for these indexes are as follows: Ochiai = $a / [(a + b)(a + c)]^{1/2}$; Dice = $2a / [2a + b + c]$; and Jaccard = $a / [a + b + c]$). All three indexes are included, since using only one can give a biased view of the relationship. Values can range from 0 (not associated) to 1 (always associated). Species covariation was evaluated by correlating thrips and pirate bugs numbers on a per-plot basis for each sampling date. The chi-square test is an indicator of whether there is any relationship between the species, while the covariation determines if their numbers fluctuate similarly over time.

Thrips accumulation in flowers. In 2005, 15 white flowers were sampled at 2-h intervals from 1000 to 1600 or 1000 to 1800 h at the NFREC in Quincy. Sampling occurred on 5 separate days within a 2-wk period. In 2006, this was repeated at two new sites within approximately 300 meters of the 2005 site. At each time interval, 15 flowers were collected from each site. Unlike 2005, the 5 sampling days in 2006 were consecutive, starting 28 July. Thrips were counted as described previously, and sampling was discontinued on several days because of rainwater remaining in flowers following thunderstorms. To determine if weather conditions influenced the rate of thrips arrival in flowers, correlations were performed. Weather data were obtained from the Florida Automated Weather Network (FAWN) for the station located at the NFREC (within 1 km of research plots). Temperature and relative humidity data for each hour from 1600 h of the day prior to sampling through 1800 of the day of sampling were compared with thrips numbers at 1000, 1200, 1400, 1600 and 1800 h. High correlations were noted between thrips at 1000 h and specific time periods for temperature and relative humidity. Regressions were performed comparing the mean temperature from 0800 to 1000 h and mean relative humidity from 1900 (day prior) to 1000 h to thrips numbers at 1000 h.

RESULTS

Prevalent species: Florida sampling sites. The ratio of thrips species and number of individuals present were similar in Quincy and Marianna (Table 1). *F. tritici* was the most common species, and cotton flowers contained an average of 4.9 (Quincy) and 3.1 (Marianna) individuals. Females outnumbered males, by an approximately 3 to 1 ratio. *F. occidentalis* was not found in untreated control plots, although 2 to 3 individuals per 1000 cotton flowers were found in other treatments in 2003 and 2004 at both locations. *F. bispinosa* was not found in Quincy, and only rarely in Marianna (1 thrips per 100 flowers). *F. fusca* was rare (1 thrips per 100 flowers) in both locations. Immature thrips were also present, averaging 0.14 (Quincy) and 0.06 (Marianna) individuals per flower.

Table 1. Mean number of insect inhabitants per cotton flower at locations in Florida, Alabama, Louisiana, and South Carolina from 2003 to 2005

Insect		Quincy, FL[z]	Marianna, FL	Fairhope, AL	Winnsboro, LA	Blackville, SC
Frankliniella tritici	Male	1.25 ± 0.11	0.92 ± 0.05	3.61 ± 0.32	0.68 ± 0.11	1.59 ± 0.20
	Female	3.67 ± 0.22	2.21 ± 0.09	3.67 ± 0.42	1.84 ± 0.21	1.75 ± 0.14
F. bispinosa	Male	0	0	0	0	0
	Female	0	0.01 ± 0.00	0.01 ± 0.01	0	0
F. fusca	Male	0	0	0	0	0
	Female	0.01 ± 0.00	0.01 ± 0.00	0	0	0.01 ± 0.01
F. occidentalis	Male	0	0	0.01 ± 0.01	0.04 ± 0.02	0
	Female	0	0	0	0.07 ± 0.02	0
Thrips palmi	Male	0	0	0	0	0
	Female	0	0	0	0.01 ± 0.01	0
Orius sp.	Adults	0.06 ± 0.01	0.10 ± 0.01	0.08 ± 0.02	0.01 ± 0.01	0.08 ± 0.02
	Immatures	0.04 ± 0.01	0.05 ± 0.01	0.10 ± 0.02	0.01 ± 0.01	0.03 ± 0.01
Immature thrips		0.14 ± 0.03	0.06 ± 0.01	0.61 ± 0.10	0.07 ± 0.02	0.12 ± 0.03
Aphis sp.		3.64 ± 0.33	2.73 ± 0.30	0.33 ± 0.08	5.96 ± 0.91	5.74 ± 1.06
Formicidae		0.28 ± 0.05	0.25 ± 0.03	0.09 ± 0.03	0.89 ± 0.19	0.13 ± 0.04
Forficulidae[y]		0	0	0	0.13 ± 0.05	0
Staphilinidae[y]		0.05 ± 0.01	0.54 ± 0.06	0	0.51 ± 0.22	0.01 ± 0.01

[z] Data were collected from the Quincy location only in 2004 and 2005.

[y] Data were collected in 2005 only.

Orius species were present at both locations. Observed ratios of *Orius* sp. to adult thrips were 1 to 49 Quincy and 1 to 21 in Marianna (Table 1). Although low ratios were often observed, they were not sufficient in cotton to cause localized extinctions of thrips as observed in pepper production (Funderburk et al., 2000). *Aphis* spp. were observed at 3.64 (Quincy) and 2.73 (Marianna) per flower. Members of the family Formicidae were also observed at approximately 2.7 per 10 flowers. They were highly aggregated, and flowers containing ants typically contained 5 or more. Although they were not classified beyond family, at least two species of ants appeared to be present. Members of the family Forficulidae and beetles from family Staphilinidae were not recorded until 2005, because of their previously low numbers. Approximately 5 (Quincy) and 54 (Marianna) Staphilinidae were present per 100 flowers in 2005.

Prevalent species: other southeastern states. Samples from Louisiana, Alabama, and South Carolina were also examined to see if the thrips populations were similar to those in Florida (Table 1). In all locations, *F. tritici* was most commonly collected thrips species, ranging from 2.5 to 7.3 individuals per flower. *F. occidentalis* was rarely observed. Although Louisiana had a mean of 0.11 individuals from 2003 to 2005, 0.31 were present in 2003. One individual of *F. bispinosa* (Alabama) and *Thrips palmi* (Louisiana) was found. The female to male ratios varied considerably by year (data not shown), and ranged from 2 to 1 (Alabama) to 3.7 to 1 (Louisiana) by location. The number of immature thrips also varied considerably, from 0.07 (Louisiana) to 0.61 (Alabama) per flower. *Orius* sp. were present at all locations, and numbered 0.01 (Louisiana) and 0.08 (Alabama and South Carolina) adults per flower.

Impact of insecticide treatments on flower-inhabiting insects. The influence of insecticide treatments on flower-inhabiting insects was examined in Quincy (Table 2) and Marianna (Table 3). Insecticide applications, whether alone or in combination with fungicide, reduced thrips numbers. The reduction in thrips numbers varied depending on location and year. Thrips were reduced by 84 (2004) and 92% (2005) in Quincy, and 32 (2003), 20 (2004) and 36% (2005) in Marianna. The percentage reduction in males did not differ significantly from that of females, so sexes are lumped together as adult thrips. Fungicide applications did not influence thrips numbers (Table 3). Immature thrips were reduced by insecticides by 94 (2004) and 100% (2005) in Quincy (Table 2). The number of immature thrips was not significantly reduced in Marianna (Table 3).

The number of male thrips per female was usually between 0.10 and 0.52 (Table 4). In Quincy, the proportion of males was reduced by about 50% in both years. In Marianna, combining the data from all three years showed an overall significant reduction from 0.48 per female in the control to 0.36 in the insecticide-treated plots. The proportion of males varied considerably during the season (Fig. 1).

Table 2. Mean number of insect inhabitants per 10 flowers by treatment and year in Quincy, FL

Treatments[z]	Number of flowers	Insect inhabitant[y]				
		Adult *F. tritici*	Immature thrips	*Orius* sp.	*Aphis* sp.	*Formicidae*
2004						
Control	**188**	**60.8 a**	**1.9 a**	**1.1 b**	**34.3 a**	**5.1 a**
Insecticide	**190**	**9.6 b**	**0.1 b**	**0.4 b**	**42.5 a**	**0.0 b**
	***P*-value**	**<0.0001**	**0.0002**	**0.0212**	**0.2430**	**<0.0001**
2005						
Control	**288**	**41.7 a**	**1.1 a**	**0.8 a**	**37.8 b**	**1.3 a**
Fung.+Insect.	**280**	**3.2 b**	**0.0 b**	**0.1 b**	**69.1 a**	**0.3 a**
	***P*-value**	**<0.0001**	**0.0077**	**<0.0001**	**<0.0001**	**0.0660**

[y] Numbers from the same year within a column followed by the same letter are not significantly different according to Tukey's Studentized Range Test ($P \leq 0.05$).

[z] Treatments applied from 1st bloom to end of flowering. The insecticide treatment was weekly applications of spinosad (0.10 kg a.i./ha) on Mondays, and acephate (0.56 kg a.i./ha) + lambda-cyhalothrin (0.04 kg a.i./ha) on Thursdays. The fung.+ insect. treatment was the same as the 2004 insecticide treatment, except 0.02 kg a.i. lambda-cyhalothrin was used instead of 0.04 kg a.i., and 0.9 kg a.i./ha thiophanate-methyl (fungicide) was applied every 2 wk.

Table 3. Mean number of inhabitants per 10 flowers by treatment and year in Marianna, FL

Treatments[z]	Number of flowers	Insect inhabitants[y]				
		Adult *F. tritici*	Immature thrips	*Orius* sp.	*Aphis* sp.	*Formicidae*
Averaged across treatments						
2003	1052	38.9 a	1.3 a	1.5 a	14.1 b	0.9 b
2004	1023	27.8 b	0.5 b	0.9 b	18.3 b	2.9 a
2005	1190	14.3 c	0.2 b	1.8 a	54.8 a	2.5 a
P-value		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Averaged across years						
Control	838	31.3 a	0.6 a	1.4 a	27.3 a	2.5 a
Fungicide	803	29.1 a	0.9 a	1.7 a	32.1 a	2.5 a
Insecticide	832	22.4 b	0.6 a	1.2 a	28.5 a	2.0 a
Fung.+Insect.	792	22.9 b	0.4 a	1.3 a	33.2 a	1.6 a
P-value		<0.0001	0.1991	0.0644	0.5239	0.1375

[y] Numbers within a column followed by the same letter are not significantly different according to Tukey's Studentized Range Test ($P \leq 0.05$).

[z] Treatments applied from 1st bloom to end of flowering. Fungicide was thiophanate-methyl (1.1 kg a.i./ha, applied weekly). Insecticide was spinosad (0.07 kg a.i./ha) alternated weekly with acephate (0.9 kg a.i./ha). The Fung. + Insect. treatment was a combination of the fungicide and insecticide treatments listed above.

Table 4. Number of males per female by treatment in Quincy and Marianna, FL

Treatment[z]	Quincy[y]		Marianna[y]
	2004	2005	
Control	0.52 a	0.21 a	0.48 a
Fungicide	---	---	0.47 a
Insecticide	0.25 b	---	0.36 b
Fung.+Insect.	---	0.10 b	0.36 b
P-value	0.0178	0.1574	0.0155

[y] Numbers within a column followed by the same letter are not significantly different according to Tukey's Studentized Range Test ($P \leq 0.05$). Dash indicates missing data. Data from Marianna averaged across 2003-2005.

[z] Treatments applied from 1st bloom to end of flowering. Fungicide was thiophanate-methyl (1.1 kg a.i./ha, applied weekly). Insecticide was spinosad (0.07 kg a.i./ha) alternated weekly with acephate (0.9 kg a.i./ha). The Fung. + Insect. treatment was combination of the fungicide and insecticide treatments listed above.

The number of *Orius* sp. was adversely affected by insecticides in Quincy (Table 2), but not in Marianna (Table 3). Immature Orius were reduced more than adults, and this occurred in both locations (data not shown). The number of *Aphis* spp. was not consistently affected by the treatments in either location. There was also little to no impact on the number of ants in either location. The insecticide treatments appeared to reduce thrips numbers, while having a small impact on other flower inhabitants.

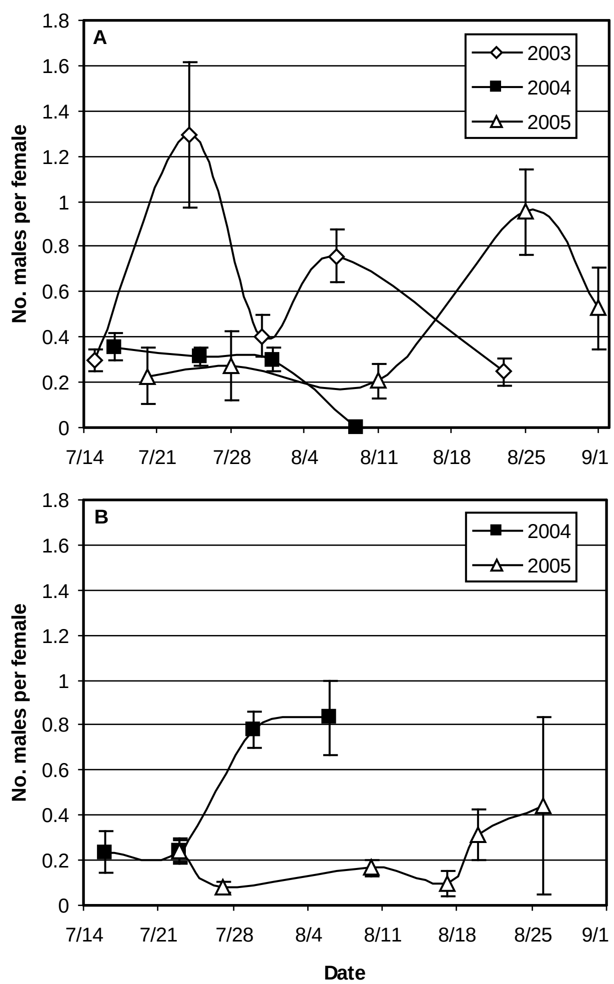

Figure 1. Mean number of males per female in control plots on each day of sampling at Marianna (A) and Quincy (B). Standard error of the mean (SEM) indicated by brackets.

Changes in thrips numbers during the growing season. The number of thrips observed varied considerably during the growing season (Fig. 2a). At later sampling dates at Marianna in 2003 and 2005, thrips numbers were approximately 2x and 3x, respectively, higher than earlier in the season and were likely associated with a declining number of white flowers available in the field. The overall seasonal trend was similar in both of these years, although 2005 had fewer thrips. In 2004, flowering stopped unusually early (data not shown), preventing continued sampling. This was preceded by a drastic decline in thrips numbers, from approximately 4.5 to 0.1 per flower. Thrips number in Quincy also varied considerably during the season (data not shown).

Association and covariation of thrips and *Orius* sp. Populations of *Orius* sp. also fluctuated during the growing seasons (Fig. 2b). In Marianna, control and insecticide plots generally showed similar fluctuations during the growing season for each year (data not shown). In 2005, there was a rapid increase in the number of *Orius* sp. present during the last two sampling dates. On the last two sampling dates of that year, numbers of *Orius* sp. were approximately 5 times higher than earlier in the season (0.30 vs. 0.06 per flower). Obvious relationships between thrips and *Orius* sp. (Fig. 2) were not apparent.

To determine if thrips and *Orius* sp. were associated, the actual and observed distribution of flowers containing both, only one, or neither species was calculated using a chi-square (Table 5). The number of flowers containing both thrips and *Orius* sp. was higher than predicted (Tables 5 and 6) in both Quincy and Marianna. Species association indexes were low and ranged from 0.06 and 0.30. Species covariation, the tendency of both species to fluctuate together over time, was evaluated by correlating thrips and *Orius* sp. on a per-plot basis for each sampling date. Correlations as high as r = 0.50 were noted when data were separated by location and year (data not shown). Aggregating the data by location provided lower correlations, but greater significance (Table 6). Data suggest that thrips and *Orius* sp. are associated, but not strongly in cotton flowers.

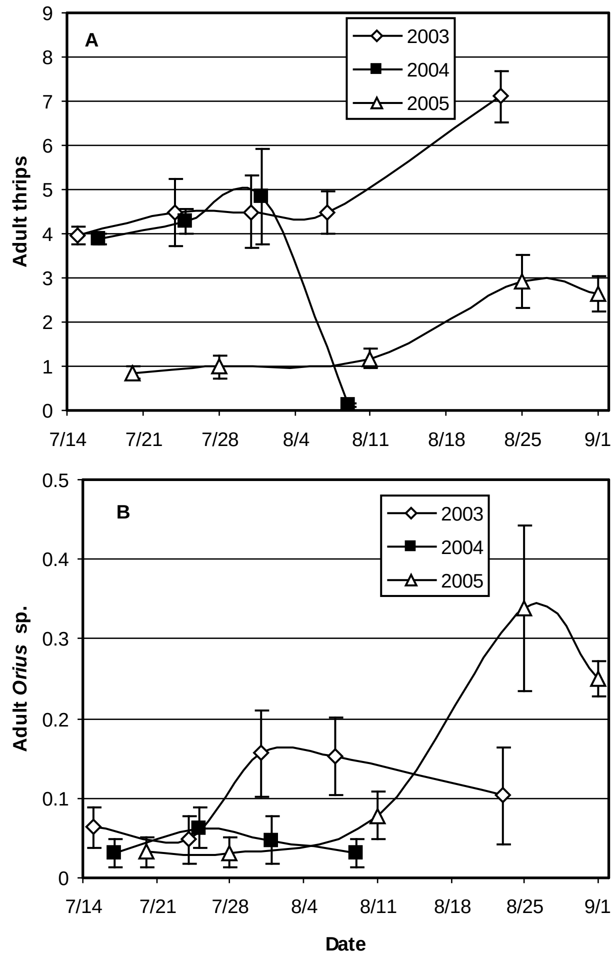

Figure 2. Within-season variation in A, adult thrips and B, adult *Orius sp*. (minute pirate bug) numbers in Marianna control plots.

Thrips accumulation in flowers. Flowers opened at approximately 0900 h, and thrips were present by 1000 h (Fig. 3). On most days in 2005, there were 2 thrips or less found in flowers at the first sampling time of 1000 h. In 2006, flowers at the 1000 h sampling time typically had 6 thrips per flower. There was considerable variation in the rate

Table 5. Occurrence of adult thrips and *Orius* sp. in flowers

Location	Number of flowers	Distribution[z]	Thrips + *Orius* sp.	Thrips alone	*Orius* sp. alone	Neither present
Quincy	946	Observed	29	472	8	437
		Predicted	20	481	17	428
Marianna	3265	Observed	248	2062	46	909
		Predicted	202	2102	86	869

[z] Generated using a chi-square.

of arrival, as well as the size and time of maximum population, among days (data not shown). On most days, thrips numbers increased steadily until 1400 h. At that time, the flowers typically contained a mean of 8 (2005) or 18 (2006) thrips. There was considerable variation in thrips numbers among days, and it is suspected that this was because of weather conditions. Temperature, relative humidity, solar radiation, wind speed, and rainfall were compared with the number of thrips present. In 2006, relative humidity from 1900 h on the day before sampling to 1000 h of the day of sampling was strongly negatively associated with the number of thrips present in flowers at 1000 h (adjusted $r^2 = 0.61$, $P = 0.0046$) (Table 7). Temperature (°C) from 0800 to 1000 h on the day of sampling was positively associated with thrips numbers in 2006 (adjusted $r^2 = 0.28$, $P = 0.0667$). Incorporating both temperature and relative humidity did not improve the model (adjusted $r^2 = 0.56$, $P = 0.0232$), and the temperature term became negative. Relative humidity and temperature were not significantly associated with thrips numbers in 2005. It is possible variations in the total thrips population during sampling in 2005 obscured the role of weather. The sampling dates also showed narrower ranges of temperature (27.6 to 29.4 °C) and relative humidity (76.0 to 83.3%) in 2005 than in 2006 (26.6 to 30.5 °C and 66.3 to 84.7%). The narrower weather variable ranges in 2005 may have been insufficient to influence thrips numbers.

Other weather variables were also evaluated (data not shown). Solar radiation was not predictive of thrips numbers, possibly because of its limited ability to penetrate the plant canopy in early morning. Wind speed was relatively low (0 to 11 km/h) on most days and was not correlated with thrips numbers. Rainfall also occurred during the dates sampled, and on one occasion was associated with slightly reduced thrips numbers, although this was only temporary.

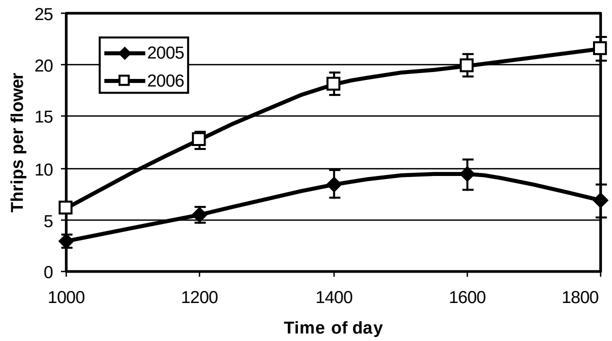

Figure 3. Mean number of adult thrips per white flower in Quincy, FL. Standard error of the mean (SEM) indicated by brackets.

Table 6. Interspecific association and covariance of thrips and *Orius* sp.

		Quincy, FL	Marianna, FL
	Species association[z]		
Relationship		Positive	Positive
P-value		<0.01	<0.001
Index	Ochiai	0.21	0.30
	Dice	0.11	0.19
	Jaccard	0.06	0.11
	Species covariance[z]		
r		0.35	0.13
P-value		0.0014	0.0065

[z] Species association was calculated for each sampling date on a per flower basis, and species covariance was calculated for each sampling date on a per plot basis.

DISCUSSION

Cotton flowers contain valuable resources for insects, and some organisms are likely to utilize them, in spite of control measures that are attempted. Flower inhabitants interact through competition and predation, and their populations can fluctuate

Table 7. Relationship of mean temperature (T) from 0800 to 1000 h and relative humidity (RH) from 1900 (of preceding day) to 1000 h to thrips numbers at 1000 h in Quincy, FL

Year	No. days	Equation	r^2	adj.-r^2	*P*
2005	5	thrips = 82.93826 − (T*2.88495)	0.1719	-0.1041	0.4877
2005	5	thrips = -8.83217 + (RH*0.12930)	0.0149	-0.3134	0.8449
2005	5	thrips = 74.90710 − (T*3.71156) + (RH*0.33889)	0.2602	-0.4795	0.7398
2006	10	thrips = -45.69035 + (T*1.83749)	0.3601	0.2801	0.0667
2006	10	thrips = 47.46459 – (RH*0.46845)	0.6543	0.6111	0.0046
2006	10	thrips = 61.03958 − (T*0.32780) − (RH*0.51750)	0.6586	0.5611	0.0232

for unknown reasons. Based on its prevalence on vegetable crops and wild hosts in the Quincy area before 2003 (Chellemi et al., 1994; Funderburk et al., 2000), *F. occidentalis* was expected to be a common species in cotton flowers. In this study, it was uncommon in 2003 and almost non-existent in 2004 and 2005. It may be that the ratio of flower thrips species found in cotton flowers is closer to an approximation of the species found in the surrounding area rather than being a unique ecological niche. If that is the case, fluctuations may occur in the ratio of thrips species.

Species composition could influence predators that feed on thrips. Previous work has suggested *Orius* sp. feeds preferentially on *F. occidentalis* relative to *F. bispinosa* and *F. tritici* (Reitz et al., 2001). This is probably because of the increased activity levels noted in *F. tritici*, which requires increased effort for predators (Reitz et al., 2001). Under certain conditions, predation may influence the species ratio. The most common species may face greater pressures as predator and parasite populations adjust themselves to better exploit their prey. It is possible this may prevent any one species from comprising a persistent majority.

Having mostly one thrips species in a field simplifies pest management. Reitz et al. (2003) determined that effects of insecticides varied according to thrips species in pepper production. Spinosad was effective against *F. occidentalis*, but not against *F. tritici*. In contrast, esfenvalerate and acephate reduced populations of *F. tritici* and *F. bispinosa*, but resulted in higher populations of *F. occidentalis*. This suggests that the spinosad component of the insecticide applications in the present study may not have been as important as other components; however, the high proportion of *F. tritici* in thrips populations occurred in multiple locations in the Southeast and was present in plots not sprayed with spinosad.

Insecticide applications generally resulted in fewer males compared with females in the plots, and this could be relevant from a management perspective. Thrips are haplodiploid, with males being haploid and females being diploid (Pearsall, 2002). Sexual reproduction between male and female thrips results in exclusively female offspring, because sex is determined by ploidy level. Females also reproduce parthenogenically, which results in exclusively male offspring. Decreasing the number of males available for mating might increase the likelihood of parthenogenic reproduction, resulting in fewer female offspring being produced. The reason for a reduction in males in the insecticide plots is unclear. Males tend to disperse more readily than females (Ramachandran et al., 2001), suggesting they would re-colonize the insecticide plots faster than females. This is the opposite of what was observed. Research on tomato has shown males are more likely to occur in the upper portion of the plant canopy (Reitz et al., 2002). This increases their exposure to insecticide applications compared with females, which are more evenly distributed throughout the canopy. Greater exposure to spraying may explain the lower proportion of males in insecticide-treated plots.

Alternating applications of spinosad and acephate in Marianna did not appear to harm populations of *Orius* sp., but *Orius* sp. are highly mobile and may have re-colonized the plots after treatment. Spinosad is generally thought to be relatively non-toxic to *Orius* sp. (Ramachandran, 2001; Reitz et al., 2001). Insecticide applications reduced *Orius* sp. in Quincy, but it is unclear if this was because of the particular insecticides used or the frequency of application. Because *Orius* sp. were very low in all treatments, it is difficult to draw a clear conclusion from the results in Quincy. Previous research in field pepper has shown that thrips suppression occurs at 1 *Orius* sp. to 200 thrips, and several days after reaching 1:40, localized near-extinction of thrips occurred (Funderburk et al., 2000). That did not occur in this study, possibly because the particular thrips species present. *F. tritici* is more mobile, and more likely to evade *Orius* sp. than is *F. occidentalis* (Reitz et al., 2001). A positive association between thrips and *Orius* sp. was observed. In a predatory relationship, a positive association suggests *Orius* sp. fluctuates in response to thrips numbers. In contrast, a negative association would result if *Orius* sp. caused a localized depression in thrips numbers. If both of these scenarios occur, then the observed relationship would appear weak.

In this study, the mean number of thrips declined each year in all treatments. In 2004, thrips numbers were lower than 2003 primarily because of a sharp decline during the fourth week of bloom. The reason for that decline is unclear, but it preceded the unusually early end of flowering. Nitrogen concentration in plant tissue influences both thrips feeding (Brodbeck et al., 2001) and flowering (Gerik et al., 1998). It is not known if declining nitrogen availability within the plant led to reduced phenylalanine content, causing thrips to emigrate in search of better hosts (Brodbeck et al., 2001). Low nitrogen availability might also have caused premature termination of flowering in 2004 (Gerik et al., 1998), although this seems unlikely considering the abruptness with which this sequence occurred. A possible reason for the declining thrips numbers each year is planting date. Because of weather and technical problems, planting dates were slightly later each year, with the onset of flowering ranging from 20 June in 2003 to about 5 July in 2005. Thrips populations are at their peak on native host flowers in the spring, but decline rapidly in May (Chellemi et. al, 1994). It is possible delayed planting of cotton resulted in more of a gap in food availability between the wild spring-hosts and the cotton flowers, which reduced thrips numbers. It is also possible that various parasites and predators that are more suited to *F. tritici* may have built to levels that effectively reduced population. *T. fuscum* infects 40-80% of *F. fusca* females in North Florida, but fewer than 2% of *F. occidentalis* and *F. tritici* (Funderburk et al., 2002; Stavisky et al., 2001). There may be other parasites, which more commonly affect *F. tritici*.

The observed increase in thrips numbers per flower during the day is consistent with previous studies. In Turkey, *F. intonsa* was shown to follow a similar pattern (Atakan and Ozgur, 2001b). Red flowers (day after bloom) were found to contain their highest numbers of thrips at 0530 h, after which their numbers fell steadily until 1130 h. This dispersal coincides with the opening of new white flowers, which were shown to accumulate between 20 and 200 individuals. The authors also suggested red flowers could serve as a refuge from insecticide applications. In British Columbia, *F. occidentalis* dispersal could occur if wind speed was less than 15 km/h, although it was most common in the absence of wind (Pearsall, 2002). Wind suppressing thrips movement was not observed in this study, possibly because wind speeds did not exceed 16 km/h and was typically below 8 km/h (data not shown). The association of lower temperature and relative humidity before 1000 h with higher thrips numbers was unexpected. Toapanta (2001) reported that the duration of generations of *F. occidentalis* and *F. fusca* was determined by growing degree days, with warmer temperatures resulting in faster maturity. Higher morning temperatures in this study decreased thrips movement, possibly because the temperatures encountered were above the optimum. Low humidity may result in less dew on the plants, allowing thrips to move more easily within the plant canopies.

Thrips control in cotton flowers had not been reported previously, and its potential effectiveness was unknown. Insecticide applications reduced total thrips numbers by approximately 28 to 92% depending on the year and location. This study demonstrates insecticide applications are an effective strategy for reducing thrips numbers in cotton flowers. The reduction in thrips numbers was associated with reduction in hardlock severity (Mailhot et al., 2007).

ACKNOWLEDGEMENTS

We thank Cotton Inc. and Cerexagri for financial support, Drs. Kathy Lawrence, John Mueller, and Boyd Padgett for providing flower samples, and Dr. Joe Funderburk and Julie Stavisky for advice in working with and identifying thrips.

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