POPULATION DYNAMICS AND WITHIN PLANT DISTRIBUTION OF *Frankliniella* SPECIES AND *Orius insidiosus* AND THEIR IMPACT ON COTTON HARDLOCK DISEASE

By

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To my father, Mr. E. A. Osekre, whose toil and sacrifices made this milestone possible

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Cotton hardlock, associated with *Fusarium verticillioides*, has become a very important disease of the crop, reducing yields significantly yearly in the Southeastern region of the US. The disease manifests in the failure of the fiber to fluff out as the boll opens at maturity and locks like wedges of an orange when broken apart. Thrips have been associated with the disease as vectors. Field studies were carried out to determine the relationship between thrips population fluctuations and the disease in two locations, Quincy and Marianna, Florida. Four species of *Frankliniella* thrips namely *F. bispinosa, F. fusca, F. occidentalis* and *F. tritici* were identified on the crop in both locations but *F. tritici* constituted >98% of the adult population. No association was found between thrips and the disease.

Field estimation of the relationship between thrips and a predatory minute bug, *Orius insidiosus* and the predatory role of this bug against the thrips on the crop were also conducted. No relationship was found between them and the predator was found not to effectively suppress the population of the thrips.

Field evaluation of applications of an insecticide and a fungicide for control of the disease showed the former rather than the latter offered better management of the disease. The

insecticide applications tend to significantly reduce thrips population which invariably led to a reduction in the disease and thereby led to increase in yield in most cases. These results demonstrate that thrips may be playing little or no role in the epidemiology of the disease and therefore lend support to the idea that, insecticides alone or combinations of insecticides and fungicides applications can be used to manage the disease.

CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

Cotton

Cotton belongs to the genus *Gossypium*, which contains a great diversity of plant species ranging from herbaceous perennials to small trees. This genus contains 49 species distributed throughout most tropical and subtropical regions of the world. Cotton is not native to the USA. Its centers of diversity include northwestern Australia, northeastern Africa, the Arabian Peninsula, and western and northern Mexico. The Spanish were the first non-native people to experiment with cotton culture, having done so in Florida in 1556 (Smith and Cothren 1999). The most cultivated species of cotton in the world include *Gossypium hirsutum* L. and *Gossypium barbadense* L. (also referred to as "New World" species), accounting for >97% of the world fiber production. Cotton fibers of the *G. hirsutum* species range from 2 to 3 centimeters in length, whereas *G. barbadense* cotton produces long-stable fibers up to 5 centimeters in length (Smith and Cothren 1999). In Florida and the southeastern parts of the US, "upland cotton" is the main type grown. Cotton is a very important crop serving many purposes, including being a major natural fiber crop for cloth, providing edible oil and as a product for livestock food.

Reproductive growth of cotton commences about 4 to 5 weeks after sowing, with the formation of floral buds in the apical part of the plant. This is followed in several weeks by flower opening (anthesis) which is usually followed shortly by the dehiscence of anthers soon after the petal open, and the start of fruit (boll) development although high humidity or cool temperatures can delay this by 2 to 3 hours. Floral buds appear first as small, green, pyramidal structures known as squares. The first floral organs to be initiated are the sepal, followed by petals, stamens, and carpel (Smith and Cothren 1999). The length of time between the first appearance of a given square (i.e., pinhead square size) and anthesis (white flower stage) is

approximately 25 days (Tharp 1965). Flowering in cotton follows a predictable pattern, and is affected by environmental factors. Low night temperatures (below $32^{O}C$) cause flowering at a lower node as do longer photoperiods, e.g., 14-hour versus 8-hour days (Mauney 1968). The first flowers to open are usually at main-stem nodes 6 or 7 and at the first position along a fruiting branch. About 3 days elapse between the opening of a flower on a given fruiting branch and the opening of another. The same relative position on the next higher fruiting branch is usually separated by about 3 days (known as the vertical flowering interval). On the other hand, the time interval for the development of two successive flowers on the same branch is about 6 days (horizontal flowering interval). Upland cotton (*G. hirsutum*) flowers are creamy white on the day of flowering, but petals turn pink-red the following day and abscise at the base 1 or 2 days later while Pima cotton (*G. barbadense*) flowers are yellow at anthesis but also turn pink.

Cotton flowers open at or near dawn and remain open only a single day. Anthesis is usually followed shortly by the dehiscence of anthers soon after the petals open. Cotton can undergo self pollination in the absence of insect pollinators, and this process occurs shortly after anthesis; but when pollinators such as *Bombus* sp. are present, cross pollination can be significant (i.e., up to 50-80%). Fertilization, which is primarily determined by temperature, could occur in as little time as 12 hours following pollination, or it can be more than 24 hours. Temperature is the primary determining factor (Smith and Cothren 1999).

Flowering continues until defoliation or when an unfavorable condition such as frost occurs. Cotton naturally sheds some squares and young bolls and commonly sheds about 60% of its squares and young bolls under typical crop growing conditions (Smith and Cothren 1999).

Cotton yield potential is significantly affected by various factors which initiate premature shedding of squares and young bolls (Smith and Cothren 1999). Excessive shedding of squares

or bolls can result in significantly altered plant morphology by effectively increasing vegetative growth. However, flowers are typical not shed (Smith and Cothren 1999). The typical development rate of cotton requires an average of 32 days in the Southeast to 50 days in the West from emergence to squares (floral bud) initiation, with the appearance of first white blooms three weeks later. Cotton yield is a combination of two major components: boll number and boll size or lint per boll.

Some Innovations in Cotton Production

Technologies in breeding and biotechnology have been applied in cotton to address pest problems as well as environmental concerns. The introduction of novel changes in *Bt* endotoxins and improved formulations resulted in the release in 1996 by Monsanto of *Bt* cotton that produces the Cry1Ac protein. Recent technologies have led to the release of Bollgard II and Widestrike II "*Bt* cotton" that express Cry2Ab and a combination of Cry1Ac & Cry1F proteins, respectively. These are effective against important lepidopterous insect pests of the crop. Umbeck et al. (1987) and Perlak et al. (1990) noted that the most important development in cotton production was the use of genetic engineering to manipulate the cotton plant to express *Bt* endotoxin at levels that control lepidopterous pests. The use of the *Bt* cotton has contributed to the reduced number of sprays of chemical pesticides, reduced labor cost and time, reduced production cost, reduced environmental pollution and reduced risk in cotton production. Another significant development was the incorporation of a gene conferring resistance to glyphosate in cotton (Roundup Ready).

Diseases of Cotton

Several diseases affect cotton wherever the crop is grown. Important diseases of cotton include *Verticillium* wilt, *Alternaria* leaf spots, cotton root rots and cotton boll rots, and diseases caused by nematodes. Diseases reduce cotton yields, increase the cost of production and

processing and reduce the value of fiber and seed. Boll rots have in recent times been recognized as a group of very important diseases of cotton contributing significantly to yield losses in the crop. *Fusarium* spp. and *Alternaria* spp. are among the most common pathogens associated with boll rots wherever the disease occurs in the USA.

Cotton Boll Rots

Many of the organisms in the boll rot complex are probably responsible for discolored fibers in the harvest. This may occur if infestation occurred near to boll maturity or if the infection is confined to a single locule. The soilborne fungi which cause boll rot have been observed to survive on plant debris (Bell 1999).

In the USA, *Fusaria* are reported to have replaced *Collectotrichum* spp. as the most common boll rot fungi (Bagga and Rannay 1969). In infecting bolls, the first fungi to attack the aging boll directly are *Collectotrichum* spp. and *Diplodia gossypium* (Watkins 1981, Hillocks 1992). As the bolls near dehiscence, *Fusarium*, especially *F. semitectum*, and *Alternaria* spp. also may penetrate the bolls directly, although these pathogens more commonly enter through wounds or lesions first caused by *Collectotrichum*. *Fusarium* spp., *Diplodia* spp. and other fungi have been associated with a progressive basal type of rot where bracts are infected first, followed by invasion through nectaries and base of boll (Bell 1999).

Fusarium spp., among the most common isolated fungi boll rots, have been noted to have the capability to infect bolls about 35 days or older. Diseased bolls become dark brown with a white to salmon-pink overgrowth of the fungus. As bolls age beyond 40 days they become progressively more susceptible to attack by several fungal pathogens (Bell 1999). Immature fiber exposed by injuries to the boll can be deteriorated by more than 100 different fungal species (Hillocks 1992). Infection with *Fusarium* spp. can occur through the flower and that infection can be found on flower parts as well as seed at 20, 40 and 53 days after flowering (Marois,

Wright, Mailhot, unpublished data). This suggests that two possible ways by which *Fusarium* infection can occur are infection through the flower as the pollen tube grows down the pistil, and infection through wounds on developing bolls created by insects.

Most boll rot fungi produce airborne spores that come to rest on the bolls, bracts, or exposed fibers. The spores germinate and proceed to ramify through boll parts. Bracts tissue often dies before other boll parts and may serve as an important means of entry to the boll. The boll fungi apparently grow and sporulate prolifically on flowers, squares, and bolls that are shed from the plant and fall on the ground (Bell 1999). An average of more than 1 million conidia of *Fusarium* have been found per shed flower and square in Louisiana, and large numbers of both *Diplodia* and *Fusarium* were found in air samples collected over cotton fields (Snow and Sanders 1979). In an initial survey of boll rots in the cotton fields in the delta region of Louisiana and Mississippi in 1996, McLean and Lawrence (1998) isolated *Fusarium* spp. and *Alternaria alternata* from diseased bolls with a frequency of 18 and 11%, respectively.

Studies conducted in the USA by Sparnicht and Roncardi (1972) showed that *Fusarium* spp. do not penetrate directly through the pericarp. Under humid conditions, bolls decayed by *F. moniliforme* are known to be covered initially with a white or grey mycelium, which disappears when the fungus sporulates. Conidia are produced in large numbers on the surface of the bolls and have a pink color in mass. *Fusarium* species can be carried internally on cotton seed (Hillocks and Brettell 1993) and persist in the seedling or the soil surface and therefore provide a reservoir of inoculum to infect the lower bolls. Also, it appears that isolates of *F. moniliforme* and other *Fusaria* may be present in the vascular tissue of the healthy plants, becoming damaging only under certain conditions.

Boll Rots and Hardlock

There seems to be different types of boll rots. Hillocks and Brettell (1993) indicated that discoloration of the seed cotton caused by the growth of microbial contamination occurred in the field under three distinct circumstances. One such circumstance involves incomplete boll rot, where the boll is able to open normally but one or more locules fail to fluff out due to fungal or bacterial infection, which is known as “tight lock” (hardlock) in the USA. In this type, locks of infected bolls often fail to fluff (tight locks) or are only partially fluffed and stained. The poorly fluffed locks are often knocked to the ground during harvest. Hardlock is the condition in which individual locules within a boll remain compact and fail to open normally (Marois et al. 2002). When picked and ginned, the stained fiber results in lower fiber grades and, thus, decrease the value of the crop. Usually *Fusarium* spp. and *D. gossvina* infecting at the cracking stage may cause "tight-lock”.

Insects and Boll Rots

Numerous arthropods are recognized as pests of cotton in the United States, but generally fewer than 25 are considered key pests of the crop (Newsom and Brazzel 1968). Many of these pests have been persistent problems causing economic losses in cotton for over a century, in spite of the application of management strategies. The susceptibility of cotton plants to arthropod pests varies considerably across and within the various production regions of US.

Insects occasionally transmit boll rot pathogens as well as provide wound for them to enter the boll (Watkins 1981, Hillocks 1992). Thrips have been associated with hardlock by creating wounds or entry points for the causal agent of the disease. The large amount of inoculum produced and carried in the environment and on plant debris suggests that even though the pathogen is seed-borne, that means of pathogen transmission could not be important in the epidemiology of the disease. Thus thrips role in the epidemiology of the disease is a matter of

concern especially where it is known that *Fusarium sp.*, which is associated with the disease, usually infects through wounds created by insects.

Thrips

Thrips, especially those belonging to the *Frankliniella* spp., are also considered important insect pests notably on seedling cotton. Several species of thrips, including tobacco thrips, *F. fusca* (Hinds), flower thrips, *F. tritici* (Fitch), and the western flower thrips, *F. occidentalis* (Pergande) have been noted to cause considerable damage to cotton. These thrips species commonly occur throughout all US cotton production regions. The adults are anthophilic (Cho et al. 2000, Hansen et al. 2003) and inhabit the flowers of many of cultivated and uncultivated plants (Chellemi et al. 1994). *Frankliniella* spp. are the most abundant thrips on crops and the surrounding plant community in our agroecosystem (Salguero-Navas et al. 1991).

Thrips species generally have population characteristics that include vagility, a short generation time, polyphagy, a tendency towards parthenogenesis, and possibly a competitive breeding structure that promotes aggregation and exploitation of localized optimal conditions (Mound and Teulon 1995). They have piercing-sucking, multi-purpose mouthparts. They use these to pierce leaves, flowers, seeds, pollen grains, and fruit, as well as to suck open liquids such as nectar, water, or insect secretions (Kirk 1997). This way of causing damage to plant parts give some unique characteristic symptoms including streaks and discoloration of the petals, with dark flowers showing light streaks and light flowers showing dark streaks on such plants after damage (Pfleger et al. 1995). Adult and larvae damage cotton plants, but the larval stages are considered to cause more significant injury. Thrips damage is most severe when feeding occurs in the apical meristem of the plant terminal, and the apical bud is destroyed, especially at the seedling stage. High densities of thrips occasionally are found during the flowering stage, but

plants of this age usually are considered to tolerate thrips populations without any substantial yield loss (Graves et al. 1987).

Biology of Thrips

Adult thrips are approximately 1 to 2 mm in length and generally appear in various colors ranging from yellowish-brown to dark brown. Thrips are haplodiploid (males are haploids while females are diploids). Flower thrips are believed to overwinter as sexually mature females in soil and protected places of a plant such as curled leaves. The life cycle consists of the egg, larva, prepupa, pupa and adult. Female adult thrips live up to 30 days and lay 2 to 10 eggs per day (Toapanta et al. 1996). Their development is affected by temperature. At 20^{o}C, development from egg to adult takes approximately 19 days, reducing to 13 days at 25^{o}C. The female inserts eggs into soft plant tissues, including flowers, leaves, stems and fruit using its ovipositor. The eggs hatch into larvae, which consist of two instars that feed and develop on the leaves, flowers and fruit. The prepupal and pupal stages often complete their development on the ground or growing medium, but pupation can also take place on the plant or in the soil. The pupa is a non-feeding stage during which the wings and other adult structures develop.

Thrips and Cotton Hardlock

Some insects are known to vector plant diseases and *Frankliniella* thrips are widely recognized as one of the most important vectors of plant diseases. In contrast, Lewis (1973) noted that there is limited information evidence to support the claim that thrips can vector bacteria and fungi. He listed four economically important bacteria that had been found on the bodies of thrips but considered the impact of thrips as disease vectors to be minor. Marullo (1997) also reported that some thrips species have been shown to feed on fungal spores, but fungi appear to be an uncommon food source for species of thrips in the family Thripidae. Bell (1999), however, noted that most fungi, apart from *Diplodia* sp., usually do infect only after the

boll wall have been breached, either by insect damage or by preventing rupture of the suture. Thrips are believed to vector hardlock (Marois and Wright 2004) through similar means. Thrips have been associated (as vectors) with several important plant diseases such as tomato spotted wilt.

Four species of *Frankliniella* thrips known to help vector hardlock are found in Florida. These species in northern Florida are three native species, including *F. bispinosa, F. fusca,* and *F. tritici,* and a non-native species *F. occidentalis*. The role of thrips in the epidemiology of hardlock has not been investigated. The determination of the role of thrips in the epidemiology of the disease would go a long way to identify control strategies for the disease.

One way to determine the impact of thrips on the disease epidemiology is to evaluate the impact of the thrips population fluctuations on the disease. There is the need to, first of all, even determine the abundance of the various *Frankliniella* thrips in this region and follow their population fluctuations during the cotton growing season since the occurrence of thrips species depends on various factors. Thrips species composition on cotton varies during the production season within a given region and is influenced by environmental conditions and alternate host in field borders (Leonard et al. 1999**)**. Even though the role of thrips in the spread of the disease has caught the attention of some researchers, there is little information and research on the impact of population dynamics and within-plant distribution of *Frankliniella* spp. on the disease spread and severity. Additionally, since the disease is associated with the bolls (which develop from the flowers), there is the need to determine the aggregation pattern of thrips on the various plant parts to identify the temporal aggregation of the insects on the plant parts. Results from these studies would show the relationship between thrips and hardlock. These issues are addressed in chapter 2, with the objectives to determine the most abundant *Frankilniella* species occurring

during the cotton growing season, their aggregation pattern on the various plant parts, and the impact of their population fluctuations on the disease. This may provide a clue to the development of appropriate management strategies for thrips and subsequent management of cotton hardlock.

Control of Boll Rots (Hardlock)

Cotton production in Florida had seen steady increases in volume over the years until 2001 when consistent declines were recorded. One of the reasons accounting for the yield decline in recent times has been the emerging severity of hardlock disease. Hardlock was very severe in the Florida Panhandle in 2002, and the average yield of cotton was reduced from a five year average of 730 kg/ha to only 388 kg/ha, due almost entirely to hardlock (Marois and Wright 2004).

Cotton diseases have been managed by the use of pesticides. Insecticides rather than fungicides are mostly employed to manage boll rots as fungicides are often not effective. Bell (1999) explained that fungicide applications generally do not control the disease because of the huge amounts of inoculum produced by the pathogens in inaccessible places. It seems the key for effective control involves the reduction of early season inoculum, avoiding over-fertilization, improving air circulation in the plant canopy as well as applying insecticides. Marois et al. (2002), however, reported about the effectiveness of fungicides to reduce hardlock by noting that, in 2002 yields were almost doubled by bloom time application of fungicides in a Florida study.

Insecticide and insect-resistant cultivars have been used to decrease boll rots by reducing insect wounds necessary for the entrance of certain fungal pathogens. The association of thrips to hardlock underscores the need to search for effective control strategies to control thrips to manage the disease. Thrips control using insecticides appears possible. The stage of the plant at which pesticides are applied seems important for effective thrips control. Leser (1985) and Carter

et al. (1989) noted that successful management of thrips is usually accomplished primary at planting with insecticides treated seed or soil applied systemic insecticide. However, since hardlock affects the bolls, this control strategy recommended by Leser (1985) and Carter et al. (1989) is not applicable. But, the report by Marois et al. (2002) about the effectiveness of fungicides to manage hardlock coupled with the reported successes in the management of boll rots with insecticides underscores the need to explore the possibility of the use of insecticides or in combination with fungicides to manage hardlock. This would allow for consideration of the various pesticide combination options that could be used to manage the disease. This was addressed in chapter 4, with the objective of evaluating a fungicide and an insecticide for the management of the disease.

Hardlock Management Using Natural Enemies of Thrips

Even though chemical methods appear to be the immediate and widely used strategies to control pests, biological control has often been quite effective. *Orius insidiosus* (Say) (Heteroptera: Anthocoridae) is a natural enemy of thrips even though there have been controversies about their effectiveness in the control of thrips. In managing hardlock, there is the need to consider various options and the use of natural enemies is one option worth considering.

Local population of *F. fusca* were reported to have been near extinction in peanut by parasitism from *Thripinema fuscum* when levels of parasitism reach 60 to 90% during late spring or early summer (Funderburk et al. 2002). In that report, Funderburk et al. (2002) noted that population of *F. fusca* remained extinct until harvest of the peanut crop. *O. insidiosus* has been reported to effectively suppress thrips population in greenhouses (Tavella et al. 1996). Some successes of this predator against *Frankliniella* thrips in field pepper have also been reported (Funderburk et al. 2000). But, it must also be stated that there has been varying degree of effectiveness of the predator against *Frankliniella* species. And, some researchers have also

argued that the predator could not be effective against thrips (Mound and Teulon 1995). There was the need to evaluate the effectiveness of *O. insidiosus* in suppressing thrips population so that this strategy could also be considered in the management of cotton hardlock disease, if found effective. This was investigated in Chapter 3, by determining the effectiveness of the predator against thrips.

O. insidiosus

O. insidiosus adults are small (about 3 mm long). Wings extend beyond the body tip. Nymphs are wingless, yellow-orange to brown in color. Both adults and nymphs feed by sucking juices from prey through the sucking mouthpart (rostrum). They are common on many agricultural crops and on pasture lands. They are commonly found in flowering plants and weeds during spring and summer when plant juice abounds. Their life cycle follows egg, nymphal and adult stages, with the nymph developing through five stages. Both mature adult and immature stages feed on many small prey including thrips, spider mites, insect eggs, aphids, and small caterpillars. Females lay 2 to 3 days after mating and can lay up to 300 eggs within plant tissue. Eggs take about 3 to 5 days to hatch, and development from egg to adult takes a minimum of 20 days under optimum conditions. Adults live about 35 days. They overwinter as an adult in leaf litter both inside and outside a farm.

Objective of the Study

The overall objectives of these studies were to determine the impact of the population dynamics of thrips and their within-plant distribution on the disease epidemiology and to evaluate the potential of using insecticides and/or fungicides, or using natural enemies (*O. insidiosus*) of thrips in managing the disease.

CHAPTER 2
POPULATION DYNAMICS OF *FRANKLINIELLA* THRIPS

Introduction

The Thysanoptera are opportunistic species exploiting intermittent occurring environments. Thrips in the genus *Frankliniella* (Thysanoptera: Thripidae) are ubiquitous, polyphagous pests of vegetables, fruits and ornamental crops (Hansen et al. 2003). An even greater concern with *Frankliniella* thrips is the ability of some species to transmit many different pathogens. Not only do *Frankliniella* species feed on many species of host plants, they are able to feed in different microhabitats within a particular host plant (Kirk 1997, Mound 1997). A complex of *Frankliniella* species occurs throughout northern Florida and the southeastern USA (Eckel et al. 1996, Chellemi et al. 1994, Puche et al. 1995). All of these species are highly anthophilic (Cho et al. 2000) and inhabit flowers of a variety of cultivated and uncultivated plants (Chellemi et al. 1994).

Several researchers have undertaken studies on some aspects of the ecology and chemical response behavior of thrips (Salguero-Navas et al. 1991, Lewis 1997, Michelakis and Amri 1997, Pearsall and Myers 2000, Ramachandran et al. 2001, Hansen et al. 2003, Whittaker and Kirk 2004). It is also worth noting that most of the innovative research on thrips that had been done over the years had centered on population dynamics and biology of thrips on crops other than cotton. Salguero-Navas et al. (1991), Chellemi et al. (1994), Fritche and Tamo (2000), Funderburk et al. (2000), Pearsall and Myers (2000), Ramachandran et al. (2001), and Hansen et al. (2003) have all reported on such studies. A few other researchers both within and outside USA have, however, looked at the population dynamics of thrips on cotton (Graves et al. 1987, Pickett et al. 1988, Atakan et al. 1998, Atakan and Ozgur 2001). These studies have looked at the population abundance of *Frankliniella* species thrips at various times of the year.

Temporal Abundance of Thrips

The effect of time on thrips abundance in flowers has been reported by a few workers, with slight variations. Gangloff (1999) reported that the effect of time of day on thrips abundance was never great. Continuing, he noted that numbers of all stages of thrips generally climbed steadily throughout the day and were lowest between 0200 and 0600 hours. Atakan and Ozur (2001) found thrips numbers peaked around 1200 hours; and Tappan (1986) and Kiers et al. (2000) also recorded peak numbers around 1200 hours and thereafter declined.

Seasonal Abundance of Thrips

Despite their similarity in appearance and their overlapping host ranges, thrips species display different population dynamics (Cho et al. 2000, Ramachandran et al. 2001, Baez 2002, Reitz 2003). Reitz et al. (2003) reported that, in north Florida, *F. occidentalis* can be found year round and it is the most common species from winter to early spring when it is displaced by the increasingly abundant *F. tritici* and *F. bispinosa*. They explained that although *F. tritici* is extremely abundant throughout the central and eastern parts of the US, it does not persist in central and southern Florida where *F. bispinosa* is the only abundant species. Factors such as interspecific competition and differences in their ability to escape predation by *Orius* may be important.

In their study on tomato in north Florida, Salguero-Navas et al. (1991) found large populations of *F. occidentalis*, *F. tritici*, and *F. fusca* between late April and early June, with greatest densities during May. They added that densities were low on other dates, especially during fall. In explaining this trend, they indicated that population trends of thrips species were apparently unrelated to crop phenology or the number of flowers per plant. Thus, in their study, they found that the larvae were more aggregated than adults. They added that colonization behavior of the tomato flower by *F. occidentalis* was different than that observed for *F. tritici*

and *F. bispinosa*. Toapanta et al. (1996) reported that low numbers of thrips were recorded during the winter, but increased rapidly during early spring, while Chellemi et al. (1994) reported the greatest number of *F occidentalis*, *F. tritici*, and *F. bispinosa* occurring in May when adults were found in the flowers of many wild plant species.

Reitz (2003), who conducted studies in northern Florida, reported that thrips rapidly colonize plants soon after the onset of flowering in early September, and that population peaked in mid-September and declined until the end of the month, and *F. tritici* was the predominant species. No *F. fusca* was collected in that month. Stavisky et al. (2002), who also conducted their studies on tomato in north Florida, reported that the population of thrips increased in early May on tomato, peaked in mid-May, and declined in early June.

Lewis (1997) reviewed the scientific literature relating to periods of intense flight activity or "mass flight" of thrips. On this aspect, Salguero-Navas et al. (1991) and Funderburk et al. (2000) observed that such flights by *F. occidentalis*, *F. tritici* and *F. bispinosa* are typical in the Florida geographical region during late April and early May when the adults disperse in large numbers from wild hosts and colonize crop fields. There are reported variations in the colonization behavior of the various *Frankliniella* spp. on various crops and there is the need to study these behaviors in different crops. This chapter addresses the thrips species abundance on cotton in the summer/fall season.

Within Plant Distribution of Thrips

Although it has been argued that seasonality is more important than host plant phenology in determining abundance of thrips (Salguero-Navas et al. 1991), host plant phenology also plays an important role in *Frankliniella* population dynamics, with the younger plants being able to support greater densities than older plants. On the thrips preferred position in terms of foliage, some workers found significantly more *F. tritici* and *F. bispinosa* adults in the upper canopy than

in the lower canopy. Gillespie and Vernon (1990) noted that these differences were as a result of differential aggregation of the sexes of thrips spp. in the canopy. Terry (1997) also noted that the greater proportion of males observed in the upper canopy in his study may be related to aggregations. Males tend to aggregate in certain locations for mating, and females tend to remain in the flowers after mating. Females outnumbered males by greater than a 4 to1 ratio in *F. occidentalis* (Hollingsworth et al. 2002).

Spatial Abundance of Thrips

Scientific literature shows that, generally, the adults and larvae of *F. occidentalis* are most abundant in flowers of a variety of plants (Gonzales and Wilson 1982, Pickett et al. 1988) but there have been reported variations in the pattern of distribution. Tavella et al. (1996) showed that 96% of adult and larval *Frankliniella* spp. occurred in the flowers of greenhouse grown pepper (*Capsicum anuum* L.). But, while Higgins (1992) found the majority of *F. occidentalis* adults in the flowers of greenhouse-grown pepper and cucumber (*Cucumis* sativa [L.]), he observed that the majority of larvae were found on the leaves. Studies by Funderburk et al. (2000) and Ramachandran et al. (2001) showed similar patterns reported by Tavella et al. (1996). The leaves are preferred as a more stable source of food for developing larvae in some species (Funderburk et al. 2002). Young leaves are exploited by adults when the flowers are scarce (Teulon et al. 1991, Toapanta et al. 1996). The aggregation of thrips species in host plants seems to vary among the species and host plants, with little information of these variations in cotton. The aggregation patterns of the various species on the plant parts were investigated in this chapter.

Sex Distribution in Thrips

On male to female distribution and ratio, Pearsall and Myers (2000) reported that the sex ratio of 20 to 30% males was in accordance with the results of studies by Lewis (1973), who

suggested that males would be expected to make up approximately 20% of the population in species such as western flower thrips in which reproduction is arrhenotokous. Gangloff (1999) reported that significantly fewer females and immature thrips occurred on onion foliage with flowers and buds compared with flowers with and without pollen. He also noted that fewer males were found on foliage compared with flowers. However, Salguero-Navas et al. (1991) indicated that sample location on plants did not influence density estimates of *F. fusca,* and movement behavior of this species may differ from that of *F. tritici* and *F. occidentalis*.

Variations in sex aggregation of thrips within the vegetative and reproductive structures need further investigations on various crops. Thus these variations emphasize the need to study the population dynamics of thrips on various crops, and how host plant architecture; fruiting and surface structures influence the within-plant distribution of these thrips. Additionally, quantifying the within-plant distribution of *Frankliniella* thrips is important for the development of reliable and cost effective sampling protocols – the basis for all decision-making in IPM programs (Atakan et al. 1996).

Furthermore, thrips are believed (Marois and Wright 2004) to spread *F. verticillioides* (until 1998, was known as *F. moniliforme*) which is associated with hardlock in cotton by infecting flowers. It is estimated that the disease reduced cotton yield in the Panhandle of Florida by about 50-60% in 2002 (Wright et al. 2003). There is little information on the impact of thrips densities on the epidemiology of the disease. This can be evaluated by determining the impact of population dynamics of thrips in field cotton to establish if there is any relationship between the insects and the disease. This is based on the premise that high thrips numbers would lead to more damage than low thrips numbers and therefore create more entry points for infection by the causal agent of the disease. Information on the population dynamics of thrips and their within-

plant distribution may contribute to the understanding of the role thrips play in the spread of this disease. This may provide a clue to the development of appropriate control strategies for thrips and subsequent control of cotton hardlock. The hypotheses to be tested in this study were:

a) more adult and larval thrips occur in the flowers than on the leaves

b) more adult and larval thrips occur in the upper than the lower canopy

c) periods of peaked thrips populations in the flowers would result in high *Fusarium* infection, leading to high incidence of hardlock.

Materials and Methods

Field Plots

Two separate field experiments were conducted to investigate the above hypotheses.

Cotton (DPL-555 BG/RR) was sown on two fields at the North Florida Research and Education Center (NFREC), Quincy, FL, during the summer/fall 2005; one each at the Front Office Block (FOB) and Walshfield sites. In 2006 and 2007 summer/fall, only one field was maintained in Quincy at the Walshfield site. NFREC branch at Marianna (approximately 64 kilometers from Quincy) was included as a second location. The Quincy fields were part of a cotton-peanut-bahiagrass rotation study while the Marianna field had previously only bahiagrass maintained on it. Cotton plants were grown according to normal production practices recommended by the University of Florida Extension Services unless otherwise stated. Cotton rows were planted in a north-south direction. The field in each site consisted of four blocks in a randomized complete block design. Each field measured 100.6 m x 14.6 m with block size of 18 m x 14.6 m and between block distance of 4.6 m. Blocks consisted of 16 rows of plants, with a row spacing of 0.9 m. Planting was done after the application of 5-10-15 (N-P-K) fertilizer at 225 kg/ha three days prior to planting. In 2005, insecticides (Karate – Thiophanate methyl - and Orthene) were applied in 190 liters/ha of water, with a gas pressurized mechanical sprayer to

control southern green stink bugs (Nezara viridula (L)) and brown stink bugs (Euschistus servus (Say)) on August 11 and August 26 in Quincy. Dimethoate at 0.28 liters/A was also applied on September 9 to control aphids that year. Apart from these, no pesticides were applied again in that year and none were applied throughout the study period in 2006 and 2007 in both locations.

Thrips Sampling

During the first four weeks after seedlings had emerged, above-ground parts of 40 plants (10 plants from each block) from each field were randomly collected weekly into separate 1.9-L plastic containers containing 70% ethyl alcohol and taken to the laboratory for processing. Thrips were extracted and adult species and their sexes were determined and counted under a stereomicroscope at 40x based on their taxonomic features. Larval thrips were counted as a group. From the fifth week onward, two leaves from the upper, middle, and lower canopies of 40 plants (10 plants from each block) from each field were sampled and subjected to the same laboratory procedure described above. One each of cotton square, white flower and boll from 40 plants from each field were also collected and put into separate 60 ml wide-mouth “HDPE” sample bottles containing 70% ethyl alcohol. Another set of flowers (one flower each from the upper and lower canopies – two flowers from each plant) from 40 plants from each field were separately put into sample bottles. The flowers were inverted when being placed in the sample bottles such that insects inhabiting them got dislodged and dropped to the bottom of the bottle. These were taken to the laboratory for processing. Extracted insects in each bottle were also treated as described above, with respect to identification, sexing and counting. Flowers were randomly checked under the stereomicroscope to make sure all thrips were extracted.

Thrips Population Dynamics on Hardlock Severity

On the day of sampling each week, 100 white flowers from 100 plants (one from each plant) from each field (25 flowers from each block) were tagged with ribbons of different colors

to identify the day of each week. At the time of assessing hardlock, only 40 open bolls for a given tagging date (between 8 to12 bolls from each block) were used for the assessment. Tags with dates having <40 open bolls as a result of severe boll or flower abortion were not included in the assessment of hardlock. In addition, the general hardlock severity for the season was determined by rating 40 randomly selected plants (10 plants from each block) in each field. The total number of locules with hardlock was divided by the total number of locks in all the bolls on all 40 plants, giving a percent index for each field. Hardlock was assessed two weeks before harvesting was done. Yield was also obtained by harvesting bolls after evaluating for hardlock.

Data Analysis

The data were subjected to analysis using SAS (8.1) GLM procedure and analysis of variance performed at the 5% probability level. Tukey's procedure was used to separate means, and linear regression analysis was used for the relationship between thrips and hardlock.

Results

Population Dynamics of *Frankliniella* Thrips

Frankliniella spp., *F. bispinosa*, *F. fusca*, *F. occidentalis* and *F. tritici* were recorded in both Quincy and Marianna. However, *F. tritici* accounted for >98% of the adult thrips population at both locations. At both locations, relatively high densities of *F. fusca* were recorded on the leaves only during the first four weeks and declined greatly and the population nearly became extinct after that period (Figs. 2-1, 2-2 and 2-3). Very low densities of *F. bispinosa* and *F. occidentalis* were recorded in 2005 and 2006 and no *F. bispinosa* were recorded in 2007 in both locations. Generally, all but *F. fusca* were recorded on cotton squares in both locations and their respective densities per square per week were <1 throughout the sampling period (Figs. 2-4, 2-5 and 2-6). Likewise, weekly mean densities of *F. occidentalis*, *F. bispinosa*, and larval thrips per leaf and flower were <1 during the entire life of the plant. Adult thrips inhabited the leaves when

there were no flowers but preferred the latter to the former when blooming began. Thrips population began to increase rapidly on the plants with the onset of bloom, peaking around mid-season which also coincided with peak bloom (Figs. 2-7, 2-8 and 2-9). In both locations, peak densities of adult *F. tritici* in flowers occurred around late July to mid-August (Figs. 2-7, 2-8 and 2-9). The highest weekly mean densities of adult *F. tritici* recorded per leaf were 0.28, 0.28, and 0.33 in 2005, 2006 and 2007, respectively in Quincy while 0.93 and 0.33 per leaf were recorded in 2006 and 2007, respectively in Marianna. Mean densities of 26.8, 19.6 and 18.28 per flower of this species were recorded in the flowers in 2005, 2006, and 2007, respectively in Quincy while 33.7 and 24.18 were recorded in 2006 and 2007 in Marianna. Only adult *F. tritici* and larval thrips were recorded on the bolls, and their densities per boll per week were <1 (Figs 2-10, 2-11 and 2-12). More larval thrips than adult *F. tritici* occurred in the bolls in 2006 and 2007 in both locations.

Within Plant Distribution of *Frankliniella* Thrips

Adult thrips preferred the flowers to other parts of the plant. There were significant differences ($P < 0.0001$) in the mean densities of *F. tritici* on various parts of the plant. Their mean densities in the flowers, over time, were significantly more than that on the leaves, squares and bolls (Tables 2-1, 2-2 and 2-3). On the contrary, significant differences in the mean densities of larval thrips in the various plant parts were mixed. In certain weeks the mean densities of *F. bispinosa* and *F. occidentalis* were significantly higher in the flowers than in any other plant part; otherwise no significant differences were observed for the rest of the sampling period. Only adult *F. tritici* and larval thrips were found in all parts of the plants. With a few exceptions, >90% adult thrips occur in the flowers during blooming, with varying proportions on the leaves, squares and bolls (Tables 2-4, 2-5, 2-6, 2-7 and 2-8). More larval thrips inhabited the leaves at the initial stages of bloom but this proportion declined in favor of the flowers with time.

Significantly ($P < 0.0001$, $F_{2, 948} = 7.38$) more adult *F. tritici* were found in the upper canopy than the mid- and lower canopies in Marianna in 2006 and ($P = 0.0346$, $F_{2,828} = 1.91$) in 2007 (Tables 2-9 and 2-10). A similar trend was observed in Quincy. However, no significant differences were observed between the mid- and lower canopies. There were no significant differences in the mean densities of *F. occidentalis* in the canopies in both locations. There was significantly ($P = 0.0062$, $F_{2,828} = 2.4$) more larval thrips in the upper canopy than the other two canopy levels in both 2006 and 2007 in Marianna; but mixed results were obtained in Quincy. There was also significantly ($P < 0.0001$, $F_{1,312} = 9.35$) more adult *F. tritici* in the upper than the lower flowers in Quincy in 2006 and ($P < 0.0001$, $F_{1,232} = 10.19$) in 2007 (Table 2-11). Similar observations were made in Marianna ($P <0.0001$, $F_{1,392} = 9.86$) and ($P <0.0001$, $F_{1,232} = 9.89$) respectively in these two years (Table 2-12). Similar observations were obtained at both locations with regard to the larvae. Mean densities of *F. occidentalis* were significantly ($P < 0.0001$) more in the upper than the lower flowers in 2006 but not in 2007 in both locations. Sex aggregation pattern of the individual species in the various plant parts are shown in Tables 2-13 and 2-14, and the sex distributions for all four species combined are presented in Figs. 2-13, 2-14, 2-15 and 2-16. The ratio of male to female per leaf ranged from about 1:1 to 1:10 in Quincy, and was 1:1 in Marianna, while ratios of about 1:1 to 1:2 were obtained for the flowers in the former location and 1:1 in the latter (Figs. 2-15 and 2-16). Thus significantly more adult females aggregated in the flowers in Quincy but that was not the case in Marianna.

Population Dynamics of Thrips and Hardlock

There appears to be no association between thrips population dynamics and hardlock disease. In Quincy, no association was observed between thrips densities over time and the disease with very low R^2 value of 0.09 obtained in both 2006 and 2007 (Fig. 2-17). Both were not significant with P-values of 0.62 and 0.63. There was also no association between them in

both years in Marianna. The R^2 values in the respective years were 0.04 and 0.18 with P-values of 0.53 and 0.47, respectively (Fig. 2-18). The R^2 values improved slightly when a multiple linear regression was performed on the dates of sampling, thrips densities and hardlock but these were still not significant. Across the years and locations, removing one outlier in each case increased the R^2 values but still tested not significant. When a linear regression was performed on the yearly hardlock incidence and yearly mean thrips densities, again, no association was obtained. Years with higher thrips densities did not translate into higher hardlock incidence.

Discussion

Similar trends in the population dynamics of thrips in both Quincy and Marianna suggest the similarities of the conditions prevailing in both locations. *F. tritici* appears to be the most abundant *Frankliniella* species on cotton during the summer/fall season. This is consistent with Reitz et al. (2002) that *F. occidentalis* is displaced by *F. tritici* and *F. bispinosa* as the spring season approaches. Our results showing that >90% of the adult population are found in the cotton flowers are consistent with the findings of Tavella et al. (1996), who reported that about 96% of adult *Frankliniella* spp. was found in pepper flowers. However, our results showed a consistently lower percentage of larval thrips inhabiting the leaves of cotton in contradiction to their report that about 96% of the larvae were found on the leaves. Funderburk et al. (2000) and Ramachandran et al. (2001) reported findings similar to Tavella et al. (2000). The low densities of *F. bispinosa* observed in our study could be attributed to migration to other crop or wild plants, or to other areas. Certain changes in local conditions might also be contributing to the declining population of this species.

Low densities of both adults and larvae in the squares and bolls could be due to greater risks of exposure to predation that they face in these structures; additionally, the availability of the more nutritious food source (pollen) in the flowers serves to attract most of them. Thrips may

also prefer the leaves to the squares and bolls because the leaves serve as a more stable plant part for survival in terms of food. Generally more thrips were recorded in Marianna than in Quincy and the presence of very large cotton and peanut fields adjacent to our field in Marianna may account for this. That may have offered opportunity for constant migration of thrips between the two fields. The fact that significantly more adult and larval thrips were mostly found in the upper than the lower canopies appears to support the idea plant host phenology may be an important factor in thrips abundance. The availability of more succulent leaves in the upper canopy could be supporting more thrips than older ones in the lower canopies. Similarly, significantly more densities of thrips inhabiting the upper flowers appear to show the nature of flight in the insects, that flight just above the top canopy could be more common than that around the lower canopies.

It is unclear why there were significantly more females than males of *F. tritici* in the flowers in Quincy but not in Marianna, contributing to the 1:2 and 1:1 male:female ratios observed respectively in the two locations. But the presumed constant migration of thrips between our field and the neighboring large cotton and peanut fields in Marianna may have contributed to this. That observation in Quincy is consistent with the explanation by Terry (1997) on sex aggregation in thrips. It appears that, in addition to the fact that *Frankliniella* thrips normally tend to produce more females than males, we agree with (Terry 1997) that males generally tend to spread out to other parts of the plants after mating while females tend to remain in the flowers to feed on the more nutritious pollen for the development of the eggs. The ratio of adult male to female thrips per leaf in our study in Quincy appears consistent with Pearsall (2002). Migration may have also contributed to the 1:1 male to female ratio observed for the leaves in Marianna, thus most of the adults recorded were immigrants.

Thrips may be playing some role in the epidemiology of hardlock. The debate has actually been the extent to which thrips influence the disease incidence and spread. The very low R2 values and the fact that statistical tests prove not significant (very low P-values) show little or no contribution of the insects to the disease incidence in cotton in this study. It appears some factors make more important contributions to the disease incidence and severity. The dates of sampling for thrips appeared important in the epidemiology of the disease. Environmental factors seem to influence the disease more, as explained by Mailhot (2007) in his model that night temperatures could be a reliable factor in predicting the disease severity. Thrips may create entry points for the causal agent of the disease but infection may not occur for subsequent development of the disease if environmental factors are not favorable. Thus, no matter the thrips density in the flowers at any given time the most important driving factor for the development of the disease may be environmental. We therefore suggest that the epidemiology of the disease hinges on the activities of all cotton flower inhabiting insects and environmental factors. It may explain why hardlock severity does not really depend on the seasonal mean densities of thrips per flower. Thus high thrips densities per season do not directly mean severe hardlock and vice versa.

Table 2-1. Mean density of thrips on cotton leaf, square, flower, and boll in the experiment conducted at two locations in Quincy, FL in 2005.

	Mean densities of thrips per plant part							
	FOB				Walshfield			
Date/insect	Leaves	Squares	Flowers	Bolls	Leaves	Squares	Flowers	Bolls
12-Jul								
F. tritici	0.03b	0.08b	5.48a	-	0b	0.05b	7.5a	-
F. bispinosa	0a	0a	0a	-	0b	0b	0.5a	-
Larval thrips	0.01a	0.01a	0.03a	-	0b	0b	0.03a	-
19-Jul								
F. tritici	0.01b	0.05b	10.3a	-	0.05b	0.05b	19.03a	-
F. bispinosa	0a	0a	0a	-	0b	0b	0.13a	-
Larval thrips	0.08b	0.15b	0.53a	-	0b	0b	0.48a	-
26-Jul								
F. tritici	0.03b	0.05b	16.13a	-	0b	0.08b	26.8a	-
F. bispinosa	0a	0.05a	0.05a	-	0b	0b	0.3a	-
Larval thrips	0.13a	0.1a	0.25a	-	0b	0.3b	1.28a	-
1-Aug								
F. tritici	0.03b	0.03b	3.73a	-	0b	0b	7.75a	-
F. bispinosa	0a	0a	0.15a	-	0a	0a	0a	-
Larval thrips	0.05a	0.03a	0.15a	-	0.08b	0.18ab	0.4a	-
8-Aug								
F. tritici	0.03b	0.03b	5.17a	0.05b	0.03b	0b	3.83a	0.05b
F. bispinosa	0a	0a	0a	0a	0b	0b	0.03a	0a
Larval thrips	0.03a	0a	0.03a	0.05a	0.08a	0.75a	0.18a	0.05a
15-Aug								
F. tritici	0.03b	0.03b	1.15a	0.03b	0b	0.05b	5.33a	0.03b
F. bispinosa	0a	0a	0a	0a	0a	0a	0.03a	0a
Larval thrips	0.25a	0b	0.05b	0.03b	0.05b	0b	0.3a	0.03b
22-Aug								
F. tritici	0.05b	0.03b	4.03a	0.05b	0.05b	0.03b	2.4a	0.05b
Larval thrips	0.03b	0.03b	0.2a	0.03b	0.03b	0.03b	0.13a	0.03b

Means followed by the same letter(s) in a row within a location are not significantly different at the 5% probability level

Table 2-2. Mean density of thrips on cotton leaf, square, flower, and boll in the experiment conducted at Quincy and Marianna, FL in 2006.

	Mean densities of thrips per plant part					
	Quincy			Marianna		
Date/insect	Leaves	Squares/bolls	Flowers	Leaves	Squares/bolls	Flowers
5-Jul				21-Jul		
F. tritici	0.4b	0.21b	4.1a	0.43b	0.13b	9.3a
F. bispinosa	0a	0a	0.03a	0a	0a	0a
Larval thrips	0b	0.2a	0.18a	0b	0.13a	0b
12-Jul				28-Jul		
F. tritici	0.18b	0.4b	6.7a	0.42b	0.13b	10.3a
F. bispinosa	0a	0a	0a	0a	0a	0a
Larval thrips	0.05a	0a	0.05a	0b	0b	1.15a
19-Jul				4-Aug		
F. tritici	0.15b	0b	16.6a	0.15b	0b	17.3a
F. bispinosa	0a	0a	0a	0a	0a	0a
Larval thrips	0b	0.13a	0.53a	0b	0b	1.75a
26-Jul				11-Aug		
F. tritici	0.12b	0.13b	14.7a	0.22b	0.05b	33.7a
F. bispinosa	0a	0a	0a	0a	0a	0a
Larval thrips	0.15b	0.12b	3.53a	0.78a	0.05b	0b
1-Aug				18-Aug		
F. tritici	0.15b	0.01b	15.1a	0.12b	0b	11.4a
F. bispinosa	0a	0a	0a	0.03a	0a	0a
Larval thrips	0.03b	0b	1.63a	0.75a	0b	0b
8-Aug				25-Aug		
F. tritici	0.28b	0.03b	4.1a	0.2b	0.05b	11.4a
F. bispinosa	0a	0a	0a	0a	0a	0a
Larval thrips	0.25a	0b	0.13b	0b	0.13a	0.08b
15-Aug				1-Sep		
F. tritici	0.24b	0.02c	4.03a	0.28b	0.13b	18.5a
Larval thrips	0b	0b	0.13a	0.03b	0.18a	0.02b

Means followed by the same letter(s) in a row within a location are not significantly different at the 5% probability level.

Table 2-3. Mean density of thrips on cotton leaf, square, flower, and boll in the experiment conducted at Quincy and Marianna, FL in 2007.

	Mean densities of thrips per plant part					
	Quincy			Marianna		
Date/insect	Leaves	Squares/bolls	Flowers	Leaves	Squares/bolls	Flowers
12-Jul				9-Jul		
F. tritici	0.33b	0.07b	3.7a	0.33b	0.4b	4.43a
F. occidentalis	0b	0.13a	0.13a	0a	0a	0a
Larval thrips	0.18a	0.08b	0.08a	0.08a	0.1a	0.1a
19-Jul				16-Jul		
F. tritici	0.03b	0.1b	3.75a	0.23b	0b	22.48a
F. occidentalis	0a	0a	0a	0a	0a	0a
Larval thrips	0.05a	0a	0a	2.23a	0.06b	2.4a
26-Jul				23-Jul		
F. tritici	0.05a	0.06b	9.45a	0.13b	0b	4.65a
F. occidentalis	0a	0a	0.03a	0.03a	0a	0a
Larval thrips	0.73a	0.02b	0.08b	0.9a	0.1b	0.5ab
1-Aug				30-Jul		
F. tritici	0b	0.03b	5.6a	0.2b	0.06b	24.18a
F. occidentalis	0.03a	0a	0a	0a	0a	0a
Larval thrips	0.28b	0.63a	0.1b	0.58a	0.3b	0.43a
8-Aug				6-Aug		
F. tritici	0b	0b	7.43a	0b	0.08b	8.35a
F. occidentalis	0a	0a	0a	0a	0a	0a
Larval thrips	0.2b	0.13b	0.4a	0.8b	0.26a	0.1c
15-Aug				13-Aug		
F. tritici	0b	0.08b	18.28a	0.03b	0b	6.51a
F. occidentalis	0a	0a	0a	0a	0a	0a
Larval thrips	0.08b	0.08b	0.23a	0.03c	0.21b	0.46a
22-Aug				20-Sep		
F. tritici	0.02b	0.05b	6.88a	0b	0.08b	1.58a
Larval thrips	0b	0b	0.08a	0b	0.05a	0.2a

Mean followed by the same letter(s) in a row within a location are not significantly different at the 5% probability level.

Table 2-4. Percentage of total thrips found on cotton leaves, fruiting structures, and flowers in the experiment conducted at Quincy, FL in 2005.

	% of total thrips					
	Adult			Larval thrips		
Date	Leaves	Fruiting structures (Squares/bolls)	Flowers	Leaves	Fruiting structures (Squares/bolls)	Flowers
Jun 28	59.1	40.9	---	---	---	---
Jul 5	66.7	33.3	---	---	---	---
Jul 12	0.6	0.4	98.4	75.1	0.3	24.6
Jul 19	0.5	0.4	99.1	11.6	12.4	76
Jul 26	0.2	0.3	99.5	12.8	22.3	64.9
Aug 1	0.7	0.2	99.1	14.3	22.9	62.8
Aug 8	0.6	0.3	99.1	14.3	25.1	60.6
Aug 15	0.7	1	98.3	39.2	7.7	53.1

Table 2-5. Percentage of total thrips found on cotton leaves, fruiting structures, and flowers in the experiment conducted at Quincy, FL in 2006.

	% of total thrips					
	Adult			Larval thrips		
Date	Leaves	Fruiting structures (Squares/bolls)	Flowers	Leaves	Fruiting structures (Squares/bolls)	Flowers
Jun 21	15.8	84.2	---	71.4	28.6	---
Jun 28	34.8	65.2	---	65.2	34.8	---
Jul 5	9.5	5	85.5	91.5	0.1	8.4
Jul 12	2.1	1.8	96.1	85.1	0.2	14.7
Jul 19	6.3	0.1	93.6	8.3	0.1	91.7
Jul 26	1.1	0	98.9	3.9	3.2	92.9
Aug 1	1.1	0.7	98.2	7.2	14.5	78.3
Aug 8	3.8	2	94.2	29.4	41.2	29.4

Table 2-6. Percentage of total thrips found on cotton leaves, fruiting structures, and flowers in the experiment conducted at Marianna, FL in 2006.

	% of total thrips					
	Adult			Larval thrips		
Date	Leaves	Fruiting structures (Squares/bolls)	Flowers	Leaves	Fruiting structures (Squares/bolls)	Flowers
Jul 7	32	68	---	37.5	62.5	---
Jul 14	75.9	24.1	---	68	32	---
Jul 21	1.6	1.6	96.8	99.1	0.4	0.5
Jul 28	8.7	6.5	84.8	12.1	3.4	84.5
Aug 4	2.6	0.1	97.2	18.6	42.5	38.9
Aug 11	3.8	0.4	95.8	12	63.9	24.2
Aug 18	1.7	38.4	98.1	11.8	33.3	44.1
Aug 25	1	0.1	97.3	27	8.2	27.8

Table 2-7. Percentage of total thrips found on cotton leaves, fruiting structures, and flowers in the experiment conducted at Quincy, FL in 2007.

	% of total thrips					
	Adult			Larval thrips		
Date	Leaves	Fruiting structures (Squares/bolls)	Flowers	Leaves	Fruiting structures (Squares/bolls)	Flowers
Jul 2	43.7	56.3	---	32.7	67.3	---
Jul 9	7.7	1.8	90.5	43.7	37.5	18.8
Jul 16	0.6	2.5	96.9	66.7	0	33.3
Jul 23	0.5	8.8	90.7	87.8	3	9.2
Jul 30	0.4	0.4	99.2	27.5	62.5	10
Aug 6	0.1	0.1	99.8	28.6	17.8	53.6
Aug 13	0	23.3	99.7	28.5	42.8	28.7
Aug 20	0.1	4.5	99.9	20.0	0	80

Table 2-8. Percentage of total thrips found on cotton leaves, fruiting structures, and flowers in the experiment conducted at Marianna, FL in 2007.

	% of total thrips					
	Adult			Larval thrips		
Date	Leaves	Fruiting structures (Squares/bolls)	Flowers	Leaves	Fruiting structures (Squares/bolls)	Flowers
Jul 9	38.7	61.3	---	41.3	58.7	---
Jul 16	6.3	7.7	84	27.3	36.4	36.3
Jul 23	1.6	0	99	42.6	11.5	45.9
Jul 30	3.1	0	96.9	0.6	6.7	92.7
Aug 6	0.8	0.2	90	44.2	23.1	62.7
Aug 13	0.3	0.9	98.8	6.7	66.7	26.6
Aug 22	0.2	0	99.8	2.6	21.1	76.3
Aug 27	1.4	4.5	94.1	16.7	16.7	66.6

Table 2-9. The mean number of adult and larval *Frankliniella* species thrips inhabiting the upper, mid-, and lower canopies in experiment conducted at Quincy, FL in 2006 and 2007.

	Mean number of thrips per leaf					
	2006			2007		
Leaf position	tritici	occidentalis	larvae	tritici	occidentalis	larvae
Upper canopy	0.23a	0.03a	0.22a	0.03a	0a	0.1a
Mid-canopy	0.04b	0.01a	0.12ab	0.01a	0a	0.09a
Lower canopy	0b	0.06a	0.06b	0.01a	0a	0.04a

Means followed by the same letter(s) in a column within a year are not significantly different at the 5% probability level.

Table 2-10. The mean number of adult and larval *Frankliniella* species thrips inhabiting the upper, mid-, and lower canopies in experiment conducted at Marianna, FL in 2006 and 2007.

	Mean number of thrips per leaf					
	2006			2007		
Leaf position	tritici	occidentalis	larvae	tritici	occidentalis	larvae
Upper canopy	0.69a	0.04a	0.53a	0.06a	0a	0.33a
Mid-canopy	0.09b	0a	0.12b	0.03ab	0a	0.16b
Lower canopy	0.04b	0a	0.07b	0.01b	0a	0.18b

Means followed by the same letter(s) in a column within a year are not significantly different at the 5% probability level.

Table 2-11. The mean number of adult and larval thrips *Frankliniella* species thrips inhabiting the upper and lower flowers in experiments conducted at Quincy, FL in 2006 and 2007.

	Mean number of thrips per flower					
	2006			2007		
Flower position	tritici	occidentalis	larval thrips	tritici	occidentalis	larval thrips
Upper	13.35a	0.02a	1.45a	7.56a	0.01a	0.19a
Lower	5.25b	0.01b	0.15b	2.71b	0a	0.11b

Means followed by the same letter(s) in a column within a year are not significantly different at the 5% probability level.

Table 2-12. The mean number of adult and larval thrips *Frankliniella* species thrips inhabiting the upper and lower flowers in experiments conducted at Marianna, FL in 2006 and 2007.

	Mean number of thrips per flower					
	2006			2007		
Flower position	tritici	occidentalis	larval thrips	tritici	occidentalis	larval thrips
Upper	20.49a	0.73a	0.87a	12.37a	0.01a	0.34a
Lower	6.62b	0.05b	0.23b	2.23b	0a	0.15b

Means followed by the same letter(s) in a column within a year are not significantly different at the 5% probability level.

Table 2-13. Mean densities of adult and larval *Frankliniella* thrips per plant part across 2005, 2006, and 2007 inhabiting the leaf, square, flower, and boll in experiments conducted at Quincy, FL.

	Leaf	Square	Flower	Boll
tritici female	0.09±0.01a	0.06±0.01a	5.49±0.19a	0.02±0.01a
tritici male	0.02±0a	0.03±0.01a	3.19±0.17b	0.01±0.01a
occidentalis female	0.01±0a	0a	0a	0a
occidentalis male	0a	0a	0a	0a
fusca female	0.03±0a	0a	0a	0a
fusca male	0.01±0a	0a	0a	0a
bispinosa female	0a	0a	0.03±0.01a	0a
bispinosa male	0a	0a	0a	0a
Larval thrips	0.43±0.03	0.06±0.01	0.47±0.04	0.02±0.01

Mean density (±SEM).
Means followed by same letter between sexes of a species within a column are not significant different at the 5% probability level.

Table 2-14. Mean densities of adult and larval *Frankliniella* thrips per plant part across 2006 and 2007 inhabiting the leaf, square, flower, and boll in experiments conducted at Marianna, FL.

	Leaf	Square	Flower	Boll
tritici female	0.07±0.01a	0.06±0.01a	6.51±0.26a	0.01±0.01a
tritici male	0.08±0.01a	0.02±0.01a	6.29±0.29a	0.01±0.01a
occidentalis female	0.02±0a	0a	0.15±0.04a	0a
occidentalis male	0.01±0a	0a	0.09±0.04a	0a
fusca female	0.07±0a	0a	0.01±0a	0a
fusca male	0.01±0a	0a	0a	0a
bispinosa female	0a	0a	0a	0a
bispinosa male	0a	0a	0a	0a
Larval thrips	0.27±0.01	0.11±0.01	0.59±0.06	0.11±0.03

Mean density (±SEM).

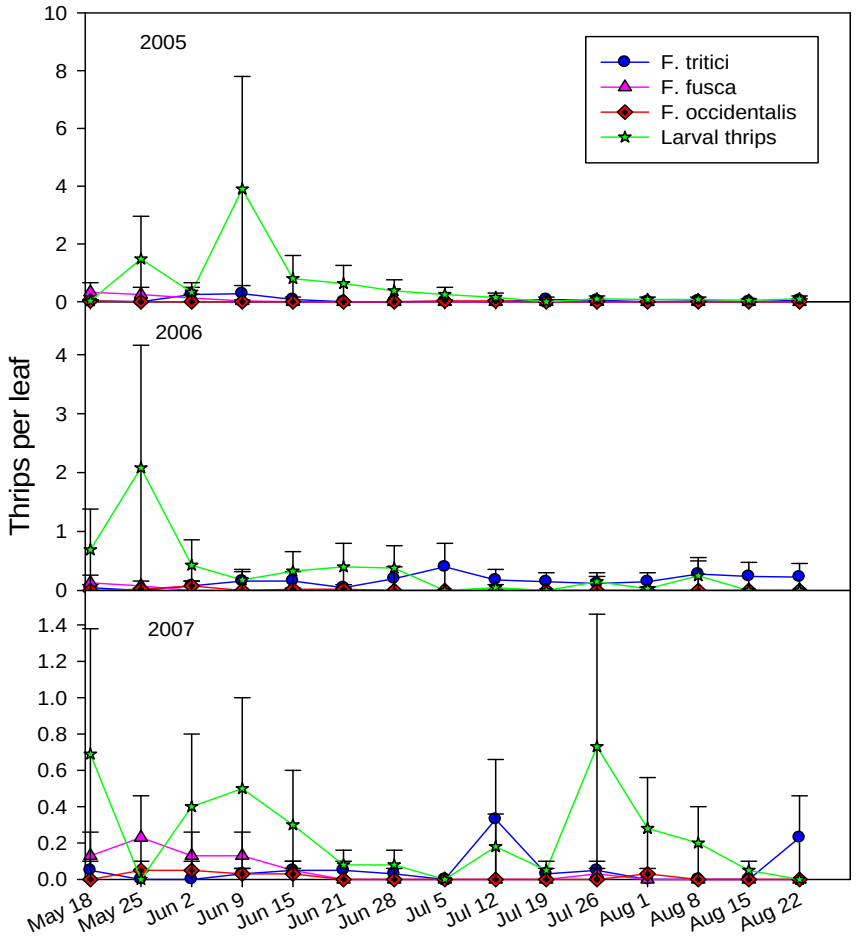

Figure 2-1. Mean densities (±SEM) of *Frankliniella* thrips on cotton leaves from 18 May through 22 August of 2005, 2006 and 2007 in Quincy, FL.

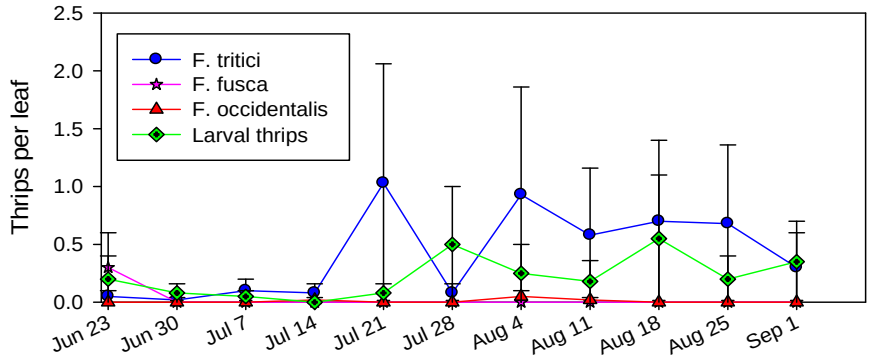

Figure 2-2. Mean densities (±SEM) of *Frankliniella* thrips on cotton leaves from 23 June through September 1, 2006 in Marianna, FL.

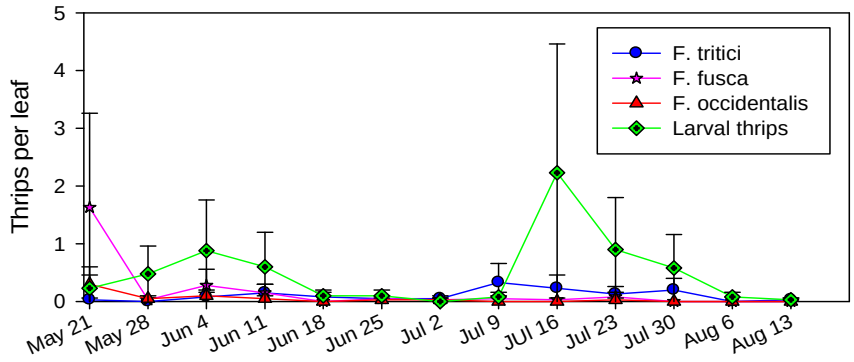

Figure. 2-3. Mean densities (±SEM) of *Frankliniella* thrips on cotton leaves from 21 May through August 13, 2007 in Marianna, FL.

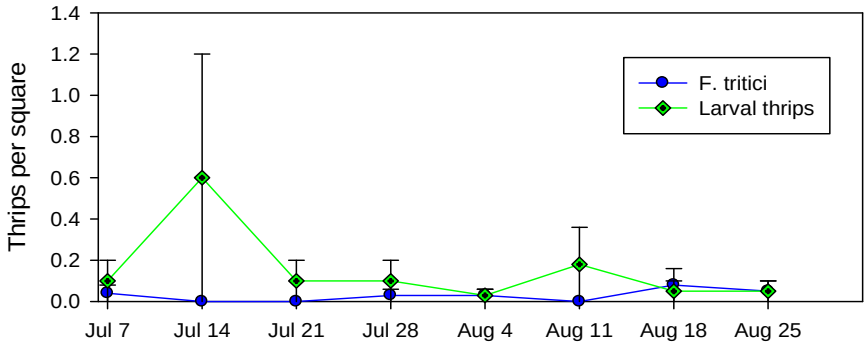

Figure 2-4. Mean densities (±SEM) of *Frankliniella* thrips in cotton squares from 7 July through 25 August, 2006 in Marianna, FL.

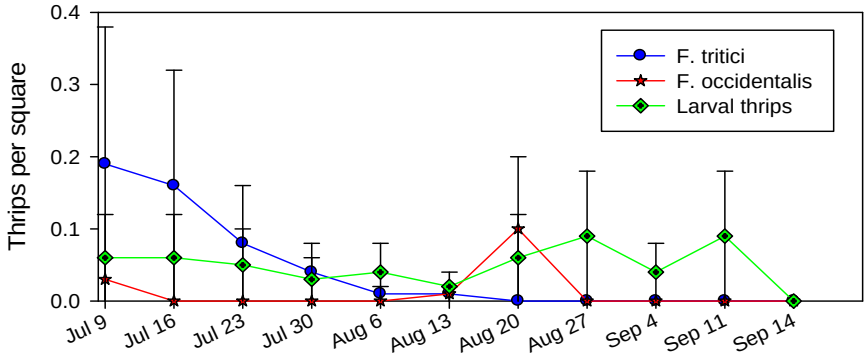

Figure 2-5. Mean densities (±SEM) of Frankliniella thrips in cotton squares from 9 July through 14 September, 2007 in Marianna, FL.

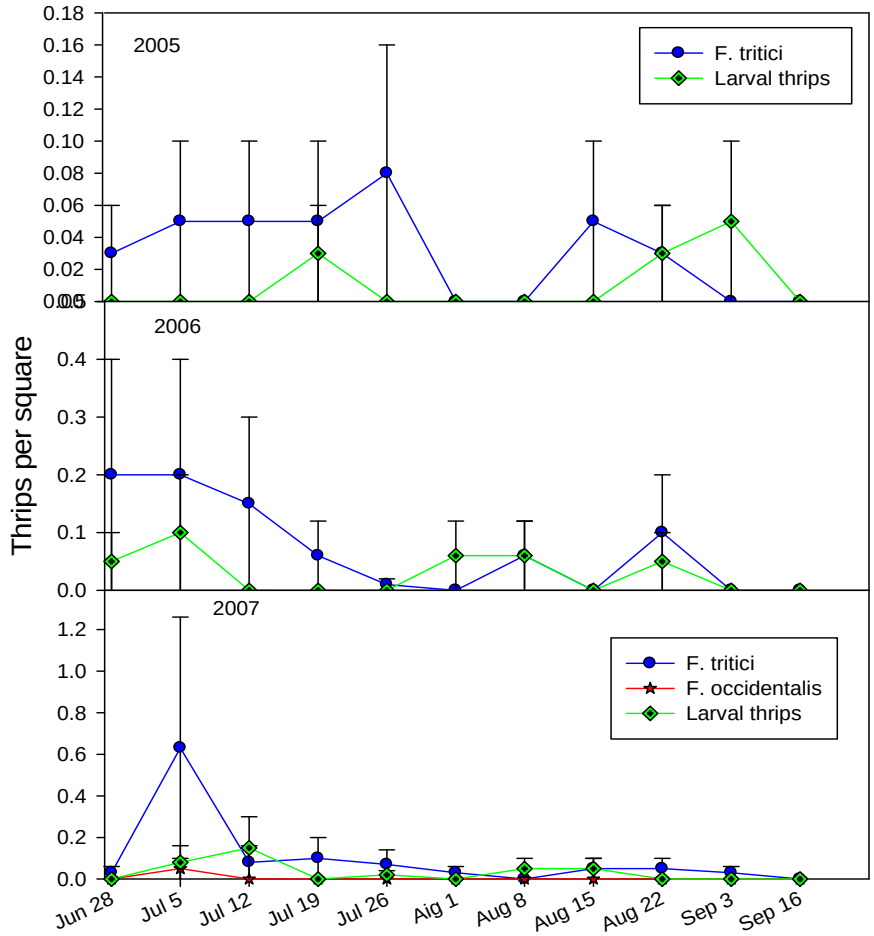

Figure 2-6. Mean densities (±SEM) of *Frankliniella* thrips in cotton squares from 28 June through 16 September of 2005, 2006 and 2007 in Quincy, FL.

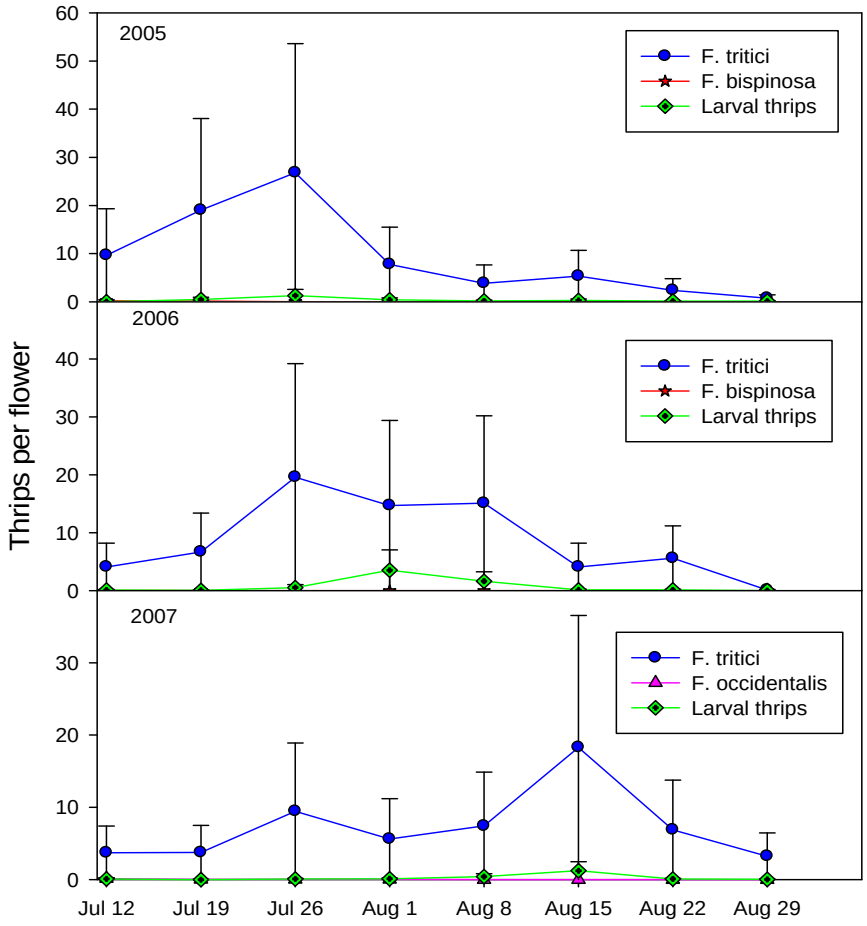

Figure 2-7. Mean densities (±SEM) of *Frankliniella* thrips in cotton flowers from 12 July through 29 August of 2005, 2006 and 2007 in Quincy, FL.

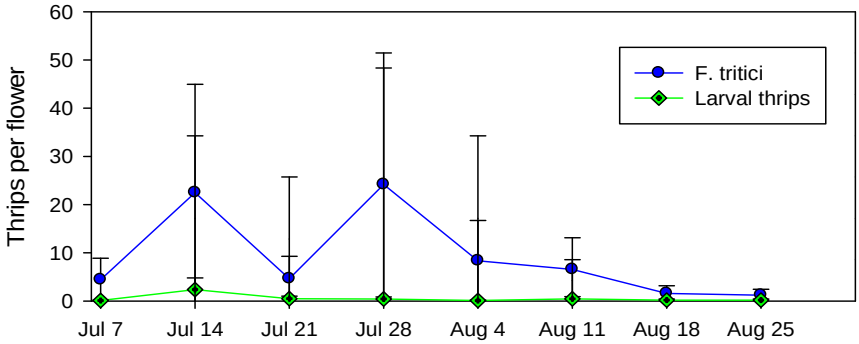

Figure 2-8. Mean densities (±SEM) of *Frankliniella* thrips in cotton flowers from 7 July through 25 August in 2006 in Marianna, FL.

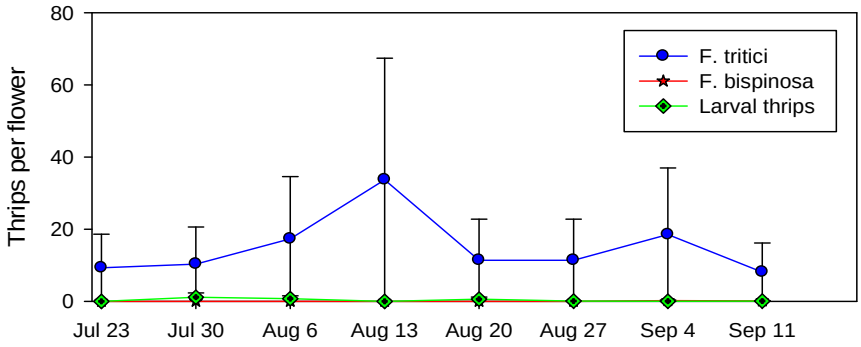

Figure 2-9. Mean densities (±SEM) of *Frankliniella* thrips in cotton flowers from 23 July through 11 September in 2007 in Marianna, FL.

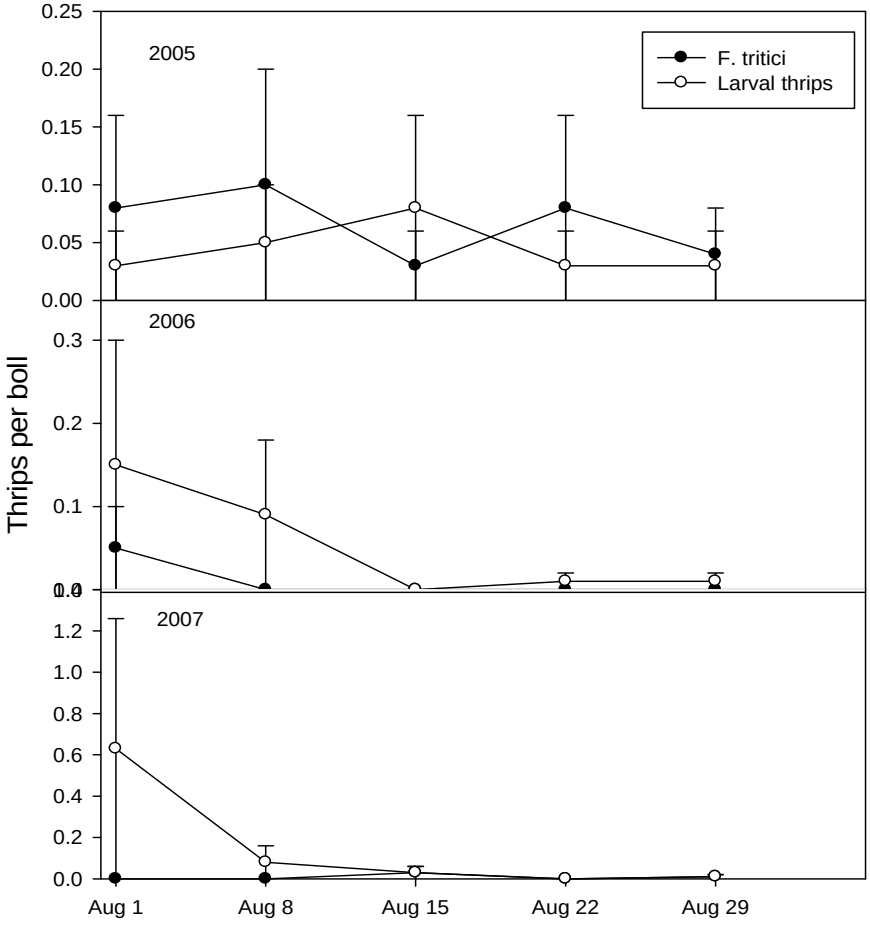

Figure 2-10. Mean densities (±SEM) of *Frankliniella* thrips on cotton bolls from 1 August through 29 August in 2005, 2006 and 2007 in Quincy, FL.

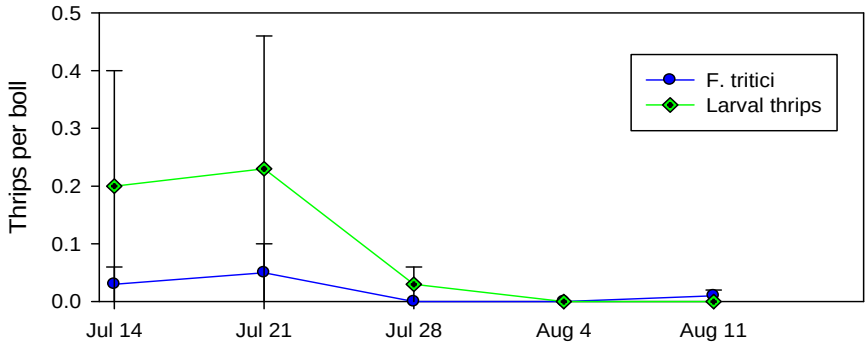

Figure 2-11. Mean densities (±SEM) of *Frankliniella* thrips on cotton bolls from 14 July through 11 August in Marianna, FL.

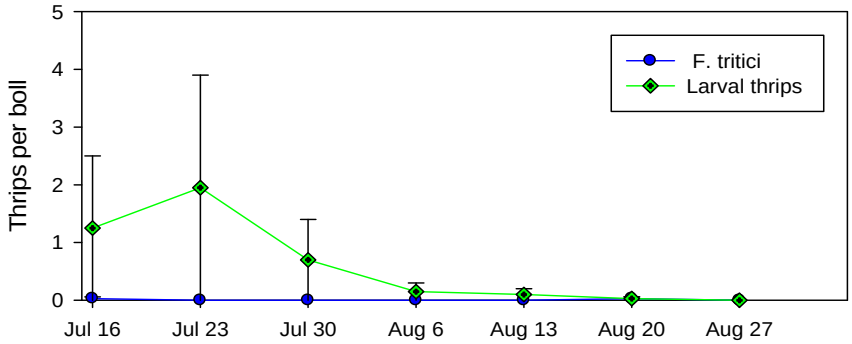

Figure 2-12. Mean densities (±SEM) of *Frankliniella* thrips on cotton bolls from 16 July through 27 August in Marianna, FL.

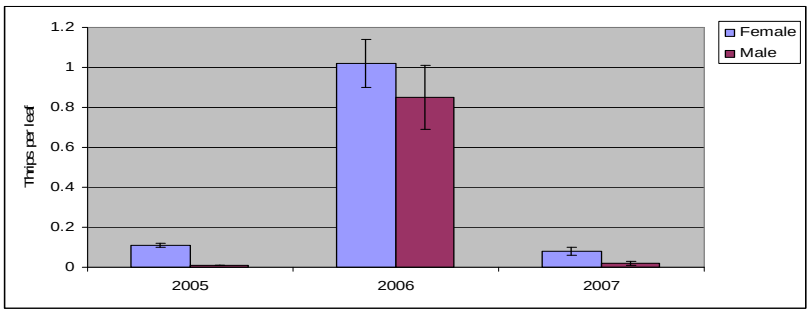

Figure 2-13. Mean densities (±SEM) of *Frankliniella* thrips relating female and male occurrence in 2005, 2006 and 2007 in Quincy, FL.

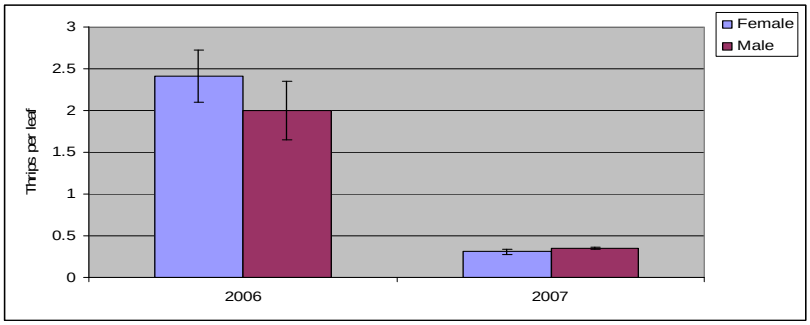

Figure 2-14. Mean densities (±SEM) of *Frankliniella* thrips relating female and male occurrence in 2006 and 2007 in Marianna, FL.

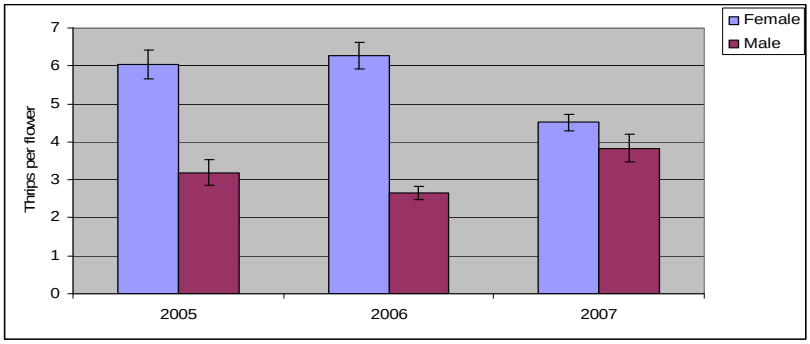

Figure 2-15. Mean densities (±SEM) of *Frankliniella* thrips relating female and male occurrence in 2005, 2006 and 2007 in Quincy, FL.

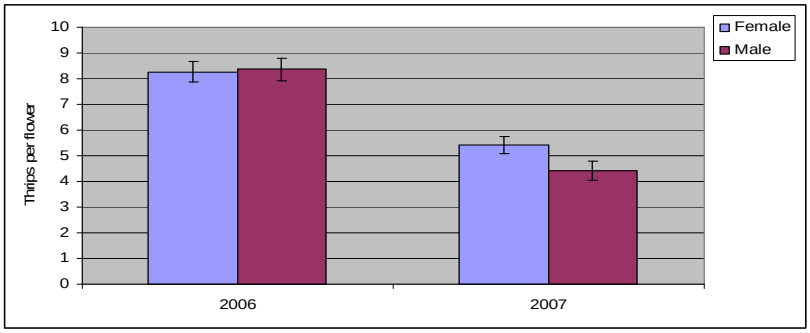

Figure 2-16. Mean densities (±SEM) of *Frankliniella* thrips relating female and male occurrence in 2006 and 2007 in Marianna, FL.

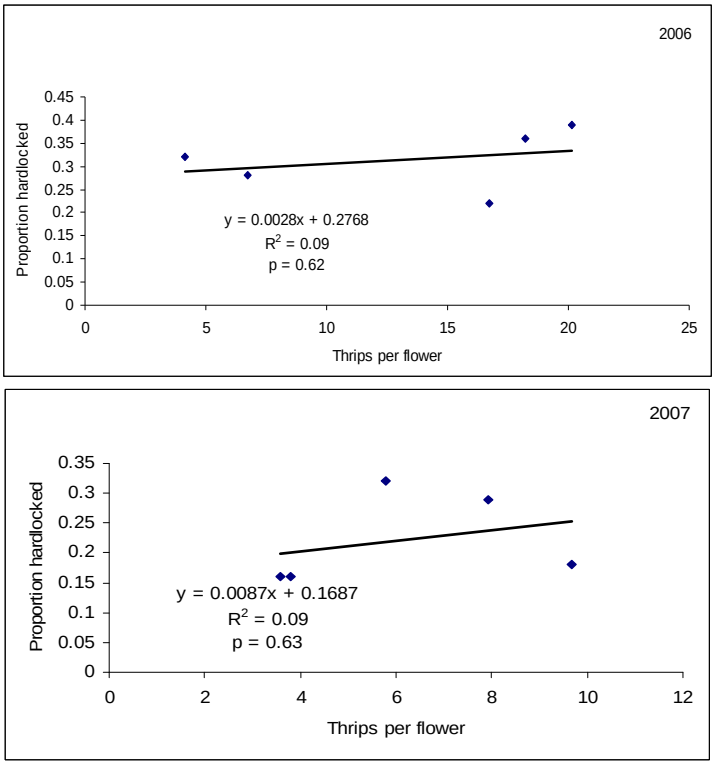

Figure 2-17. Regression of thrips with hardlock in Quincy, FL.

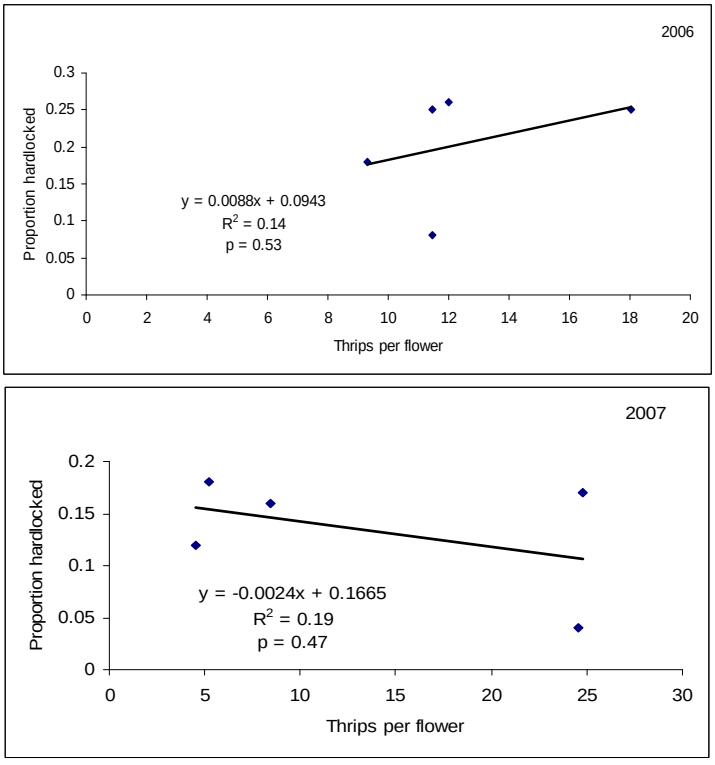

Figure 2-18. Regression of thrips with hardlock in Marianna, FL.

CHAPTER 3
PREDATION OF *FRANKLINIELLA TRITICI* BY *ORIUS INSIDIOSUS* IN COTTON

Introduction

Controlling thrips using insecticides is quite difficult and expensive. Researchers have been considering other strategies that could complement chemical control. Several workers have undertaken studies on the viability of the use of natural enemies to control thrips. A considerable number of studies have also looked at the spatial distribution of thrips and some of their natural enemies on various crops. In emphasizing the importance of spatial distribution, Atakan et al. (1996) stated that the degree of spatial distribution between pests and their natural enemies on plants is likely to influence the ability of these natural enemies to suppress pest populations. Predation is one of the most difficult interspecific interactions to estimate (Stuart and Greenstone 1990). Generalist predators like *O. insidiosus* may prefer a prey based on the prey's occurrence in the preferred habitat of the predator (Cloutier and Johnson 1993), and the vulnerability of the prey (Lang and Gsodl 2001).

It appears more studies are needed on the predatory role of anthocorids against thrips. This is against the backdrop of reported variations in the success of this biological control agent in many of these studies. Mound and Teulon (1995) argued that there is little quantifiable information to indicate density-dependent regulation of thrips under natural conditions, and population attributes of rapid colonization and growth are still thought to possibly outstrip the capacity of natural enemies to regulate thrips population.

O. insidiosus as an Effective Predator of *Frankliniella* Thrips

Extensive research has documented the capacity of natural enemies such as species of *Orius* to suppress population of *F. occidentalis* (Higgins 1992, Chambers et al. 1993, Nicoli 1997, Funderburk et al. 2000, Ramachandran et al. 2001). In supporting the idea of the ability of

anthocorid predators to suppress thrips population, Tavella et al. (1996) noted that anthocorid predators can be effective biological control agents of thrips in greenhouses. Similar observation was made by Sabelis and van Rijn (1997) that the anthocorid *O. insidiosus* has the intrinsic ability to suppress a coherent population of *F. occidentalis* at a predator to prey ratio of 1:217 on plant species.

Experiments in greenhouses suggested that successful biological control of *F. occidentalis* with *O. insidiosus* is possible on chrysanthemum (Beekman et al. 1991). In fact, *Orius* spp. are known as specialized thrips predators (Riudavets 1995). *O. insidiosus* is a generalist predator, and its population dynamics in soybean fields have been linked to both thrips population levels and soybean flowering (Isenhour and Marston 1981). Both nymphs and adults have been observed eating soybean aphids in the field (Rutledge et al. 2004). Reitz et al. (2001) found that larvae of *F. occidentalis* are significantly more vulnerable to predation by *O. insidiosus* than the adults. Funderburk et al. (2000) reported that *O insidiosus* was an effective predator of *F. occidentalis*, *F. tritici*, and *F. bispinosa* in the flowers of field grown pepper. They explained that predation by *O. insidiosus* not only resulted in suppression of adult and larvae of *F. occidentalis* in pepper flowers, but also in a decline of the population towards extinction. The suppression occurred during the period of greatest annual population abundance of *F. occidentalis*, *F. tritici*, and *F. bispinosa*, when adults of these thrips were rapidly colonizing the flowers. Populations of *F. occidentalis* increased in the absence of predation, and densities were very great in the plots treated with synthetic insecticides.

Van den Meiracker and Ramakers (1991) also reported an almost complete elimination of *F. occidentalis* by *O. insidiosus*, and that the predator persisted on sweet pepper for almost 6 months in the absence of the prey. *F. occidentalis* was reported to have been successfully

controlled in Canadian pepper and cucumber in glasshouse using *O. tristicolor* (Gilkeson et al. 1990, Tellier and Steiner 1990). Jindra et al. (1991) noted that *Orius* sp. can reliably control several pests, including spider mites, white-flies, aphids and thrips. Ramachandran et al. (2001) reported a slightly different observation when he noted that while the adults of *F. occidentalis* and larval thrips were significantly suppressed by *O. insidiosus*, there was no significant suppression of the adults of *F. tritici* and *F. bispinosa*. Biological control agents, such as predatory anthocorids *Orius* spp. can provide effective control of *F. occidentalis* but are not successful on all crops or under all situations (Dissevelt et al. 1995, Jacobson 1997, Jarosi et al. 1997). Biossot et al. (1998) found that declines in population abundance of *F. occidentalis* were not related to unfavorable temperature or other environmental factors and that an increase in abundance of a native *Orius* sp. may have been responsible. *Orius* spp. have been identified as the dominant predator in cotton in the Southern Blacklands (Sansone and Smith 2001).

It seems that in spite of their seemingly effective suppression of thrips species, *Orius* spp. are usually not able to completely eliminate them. In pepper, Funderburk et al. (2000) observed that the thrips never went into extinction by the predation of *O. insidiosus*, no matter the population size of the predator. Kawai (1995) also found that populations of *T. palmi* never went extinct despite suppression by *O. insidiosus*. For sustainable biological control, this aspect of the relationship between thrips and the predator is desirable in helping to maintain the population of the predator. Coll and Ridgway (1995) studies indicated that *O. insidiosus* searches less effectively for *F. occidentalis* on tomato than on bean and pepper plants.

O. insidiosus as an Ineffective Predator of *Frankliniella* Thrips

It is worth noting that these reports about the success of *O. insidiosus* to suppress the population of *Frankliniella* spp. were on crops other than cotton. Contrary to the above reported successes of anthocorid predators as agents for the control of the population of *Frankliniella*

spp., Parrella and Lewis (1997) concluded in their findings that natural enemies play a rather insignificant role in regulating thrips in field crops. Hulshof et al. (2003) argued that biological control of thrips is not easily achieved, and its success depends on the crop. They noted, with reference to other studies that, in cucumber, predator populations of *Neoseiulus cucumeris* (Oudemans) [Acari: Phytoseiidae] and *O. laevigatus* (Fieber) [Hemiptera: Anthocoridae] invariably declined after predator release, necessitating repeated releases to achieve sufficient control, whereas on sweet pepper *O. insidiosus* population remained constant even in the absence of thrips prey (van den Meiracker and Ramakers 1991, Chambers et al. 1993, van de Veire and Degheele 1992).

Other authors including Loomans et al. (1997) and Parrela and Lewis (1997) concluded that natural enemies must not be important. Mound (1997) argued that the population attributes of thrips outstripped the capacity of natural enemies to suppress them. That is, the attributes of rapid colonization and growth were believed to outstrip the capacities of natural enemies to regulate opportunistic species of thrips. Relatively few natural enemies of thrips have been identified. Loomans et al. (1997) proposed that the large size of potential natural enemies restrict their entry into the preferred microhabitats of thrips.

It is therefore worthwhile to study how *O. insidiosus* relates to *Frankliniella* thrips and to determine whether they are effective predators of the latter in field cotton. This information, if obtained, may form a basis in deciding on appropriate strategies for thrips and hardlock management. The hypotheses tested under this study were that:

a) there is a positive association between *Frankliniella* thrips and *O. insidiosus*

b) *O. insidiosus* is an effective predator of *Frankliniella* thrips in field cotton

Materials and Methods

Field Plots

The experimental fields described in chapter 2 were also used for this study.

Thrips and *Orius* Sampling

During the first four weeks after the seedlings had emerged, above-ground parts of 40 plants (10 plants from each block) from each field were randomly collected weekly into separate 1-L plastic containers containing 70% ethyl alcohol and sent to the laboratory for processing. Thrips were extracted and adult species and their sexes were determined and counted under a stereomicroscope at 40x based on their taxonomic features. The number of *O. insidiosus* was also noted. Larval thrips were counted as a group. From the fifth week onwards, two leaves from the upper, middle, and lower canopies of 40 plants (10 plants from each block) from each field were sampled and subjected to the same laboratory procedure described above. One each of cotton square, white flower and boll from 40 randomly sampled plants from each field were also collected and put into separate 60 ml wide-mouth high density polyethylene (HDPE) sample bottles containing 70% ethyl alcohol. The flowers were inverted when being placed in the sample bottles such that insects inhabiting them get dislodged and drop to the bottom of the bottle. These were taken to the laboratory for processing. Extracted insects in each bottle were also treated as described above, with respect to identification, sexing and counting. Flowers were checked under stereomicroscope to make sure all thrips and *O. insidiosus* were extracted.

Data Analysis

The data were subjected to analysis using SAS (8.1) GLM procedure and analysis of variance performed at the 5% probability level. Correlation was used to determine the association between thrips and the predator. Orthogonal contrast was used to compare the degree of population suppression between adult and larvae by the predator.

Results

Findings of our study showed that cotton flowers serve as host to the bulk of *Frankliniella* thrips recorded on the plant. Other arthropods that we found inhabiting the flowers were mites, aphids, bugs and ants. *Frankliniella* thrips that were found in the flowers in Quincy and Marianna were same as previously reported in chapter 2. It would therefore be reasonable to suggest that the most abundant sp., *F. tritici*, probably constituted the bulk of the larvae too. In most of the weeks during the study, the mean densities of the predator, *O. insidiosus* inhabiting the flowers were significantly more than those found in other plant parts. Generally, initial (first week of sampling) mean densities of *O. insidiosus* in the flowers were very low (<0.1 per flower) and continued to remain low until about the third or fourth week before increasing to >0.1 per flower and then began to decline again. This was in direct contrast to that of *F. tritici,* for which densities increased rapidly in the flowers after the first week.

The population fluctuations of the thrips species and the predator in the flowers are shown in Figs. 3-1, 3-2 and 3-3. It appears the population fluctuations of the predator and prey are linked. The highest weekly mean density of *F. tritici* recorded in 2005 in Quincy was 26.8 per flower, recorded a week after the peak density of 0.23 per flower for *O. insidiosus*. The population of *O. insidiosus* declined thereafter to almost extinction by the sixth week before rebounding to 0.05 per flower by the seventh week. In both 2005 and 2006, *F. tritici* reached its peak density per flower a week or two after peak population of the predator, but in 2007 both *F. tritici* and *O. insidiosus* attained peak densities of 18.28 and 0.08 per flower, respectively in the sixth week, and declined to 3.23 and 0.01, respectively by the eighth week. In Marianna, *F. tritici* reached its highest mean density per flower of 33.7 a week before that of *O. insidiosus* (0.13 per flower) in 2006. However, there were simultaneous peak densities of 24.18 and 0.06

per flower of *F. tritici* and the predator respectively in the fourth week in 2007. The mean densities of the adult of the other *Frankliniella* species were <1 per flower throughout the study.

The mean densities of the predator and *F. tritici* across years are shown in Table 3-1. The ratio of the nymphal *O. insidiosus* to adult range from 1:2.5 to 1:4 in Quincy and 1: 3 to 1:5 in Marianna. The ratio of male to female *F. tritici* ranged from 1:1 to 1:2 in Quincy but was about 1:1 in Marianna. Sex aggregation of the thrips spp. and the predator in the flowers is presented in Table 3-1.

The predator/prey ratio over time is shown in Tables 3-2 and 3-3. The predator/prey ratio did not show any consistent improvement over time in both locations. In 2005, the lowest predator/prey ratio was 1:200 (first week) and the highest 1:17 (eighth week) in Quincy. In 2006, the lowest was 1:1700 (fifth week) and highest 1:5 (eight week) in Quincy, and lowest of 1:1900 (seventh week) and highest of 1:92 (fifth week) in Marianna. In 2007, the lowest ratio was 1:700 (seventh week) and 1:49 (fifth week) in Quincy, and lowest of 1:700 (sixth week) and highest of 1:170 (third week) in Marianna (Tables 3-2 and 3-3). The high predator/prey ratios obtained towards the end of the sampling period (seventh and eighth weeks) in 2005 and 2006 was possibly due to very low number of thrips in the flowers during that period as there were very few flowers available on the plants. We believe this situation caused migration of thrips to neighboring peanuts and cotton fields which were in their peak bloom, so the low thrips numbers were not as a direct result of predation by *O. insidiosus*.

Generally, thrips numbers were comparatively lower in 2005 and that may have also explained the relatively higher predator/prey ratios in that year in Quincy. A positive correlation was obtained between *O. insidiosus* and thrips with R^2 value of 0.38 in 2005; but no relationship was obtained between them in 2006 and 2007 with R^2 values of 0.01 and 0.08, respectively in

Quincy (Table 3-4). Even though the correlation was significant in 2005 (P = 0.019), it was not so in 2006 and 2007 (P-values of 0.43 and 0.17, respectively). R^2 values of 0.01 and 0.5 were obtained in 2006 and 2007, respectively in Marianna. While this was significant in 2007 (P = 0.008), it was not so in 2006 (P = 0.561). Contrast comparison of the predation of *F. tritici* and the larval thrips by the predator, *O. insidiosus* was not significant even though it appeared the larvae populations were comparably more suppressed than adult *F. tritici,* considering the relatively low numbers of the larvae recorded throughout the study period.

Discussion

Cotton flowers appear to be a good host for *F. tritici* and the gradual decline in the population of the other *Frankliniella* species as summer approaches adds to its success during this period in this part of the Southeast. Predator-prey relationships are often very difficult to estimate in the field. The ability of a predator to effectively regulate the population of the prey depends on several factors including the initial populations of the predator and prey, their fecundity and the host plant architecture. Several researchers ((Higgins 1992, Chambers et al. 1993, Nicoli 1997, Funderburk et al. 2000, Ramachandran et al. 2001) have reported of the ability of *O. insidiosus* to effectively suppress *Frankliniella* spp. in some crops.

In most of the reports about these successes, the predator consistently reduced the thrips population over time. The effectiveness of *O. insidiosus* to suppress *Frankliniella* thrips has been variable and depended on the species involved. Predatory insects like *O. insidiosus* seem to do better as insect population regulators in greenhouses as compared to field as was suggested by Tavella et al. (1996) and demonstrated by Beekman et al. (1991). Environmental factors and microhabitat conditions within plants in the greenhouse are different than field conditions and these also impact on the behavior of both predators and prey. Tommasi and Nacoli (1993) reported that the predator had the capacity to consume 12.5 of *F. occidentalis* per day and in

most cases the population of the prey was less than this predation rate, allowing effective control of this species of *Frankliniella* thrips. Most successes were reported on *F. occidentalis* than *F. tritici* and *F. bispinosa,* and among these three species, *F. occidentalis* is the least active.

In our study with cotton, the most abundant species was *F. tritici,* for which the predator has not been very successful due to the evasive nature of this adult thrips species. The predator seems to be more successful in consuming larvae than the adults of any of the *Frankliniella* species, as was demonstrated by Funderburk et al. (2000), and the less mobility of the larvae may account for this. We did not observe consistent suppression of *F. tritici* populations over time, with a characteristic "dip and rise" pattern in the predator/prey ratio in most cases. Predator/prey ratios in many of the sampling weeks were far lower than 1:217 for which Sabelis and van Rijn (1997) cited as intrinsical capacity ratio for *O. insidiosus* to effectively suppress populations of *F. occidentalis*. Our study agrees with the report by Ramachandran et al. (2001) about the significant suppression of adult *F. occidentalis* and larval thrips but not *F. tritici* and *F. bispinosa*. The rapid build-up of the population or colonization of *F. tritici* in the flowers and the low densities of *O. insidiosus* in the flowers in the first and the subsequent two or three weeks may account for their unsuccessful suppression of population of adult *F. tritici* in our study. We agree with Mound and Teulon (1995) that rapid population attributes of rapid colonization and growth of thrips as was shown in our study possibly outstrip the capacity of *O. insidiosus* to effectively control thrips populations.

The seeming preference and consumption of the larvae to the adult by the predator as was shown by the low numbers of larvae recorded in our study is consistent with Ramachandran et al. (2001) and Reitz et al. (2006). The adults are more active and therefore could more likely evade predation than the larvae. If predator/prey ratio can serve as a reliable predictor of predators like

O. insidiosus to suppress prey like *Frankliniella* thrips in the field, then the ratios obtained in our study suggest that *O. insidiosus* may not be effective in suppressing populations of *F. tritici* in cotton even though we observed *O. insidiosus* consuming thrips in the flowers in the field. This is especially so when thrips numbers are quite high to overwhelm the ability of *O. insidiosus* to suppress them.

> It appears at low thrips numbers, the predator is somehow effective but at high thrips densities, it loses that ability. Coll and Ridgway (1995) noted that *O. insidiosus* searches less effectively for *F. occidentalis* on tomato than on bean and pepper plants. This supports the idea that *O. insidiosus* may not be effective in suppressing populations of all thrips species on all crops and in all instances. It appears the association between *O. insidiosus* and *Frankliniella* thrips is weak. In conclusion, the ability of *O. insidiosus* to suppress populations of *Frankliniella* thrips depends on the host crop and the *Frankliniella* species involved and that it was not effective in suppressing the population of *F. tritici* in cotton in our study.

Table 3-1. Mean densities of *Frankliniella* thrips and *O. insidiosus* per flower across 2005, 2006 and 2007 at Quincy and Marianna, FL.

	Quincy			Marianna	
	2005	2006	2007	2006	2007
Tritici female	5.95±0.38	6.26±0.36	4.11±0.22	7.97±0.38	5.42±0.34
Tritici male	3.19±0.33	2.64±0.17	3.83±0.36	8.18±0.43	4.39±0.37
occidentalis female	0	0.01±0.01	0.03±0.01	0.29±0.07	0
occidentalis male	0	0.01±0.01	0	0.18±0.07	0
Fusca female	0	0.01±0.01	0	0.01±0.01	0
Fusca male	0	0	0	0	0
bispinosa female	0.08±0.02	0	0.01±0.01	0	0
bispinosa male	0	0	0	0	0
Larval thrips	0.36±0.05	0.76±0.10	0.28±0.05	0.06±0.08	0.58±0.09
orius nymph	0.13±0.02	0.05±0.01	0.05±0.01	0.05±0.01	0.03±0.01
orius adult	0.03±0.01	0.02±0.01	0.03±0.01	0.01±0.01	0.01±0.00

Table 3-2. Weekly ratios of *O. insidiosus* to *Frankliniella* thrips inhabiting flowers in Quincy, FL.

Week	2005	2006	2007
1	1:200	1:23	1:49
2	1:85	1:140	-
3	1:200	1:130	1:190
4	1:100	1:140	1:110
5	1:130	1:1700	1:160
6	-	1:420	1:240
7	1:50	1:71	1:700
8	1:17	1:5	1:330

Table 3-3. Weekly ratios of *O. insidiosus* to *Frankliniella* thrips inhabiting flowers in Marianna, FL.

Week	2006	2007
1	1:190	-
2	1:380	1:620
3	1:180	1:170
4	1:420	1:410
5	1:92	1:210
6	1:230	1:700
7	1:1900	-
8	1:830	-

Table 3-4. Covariation of *Frankliniella tritici* and *O. insidiosus* in Quincy and Marianna, FL

		Association	Correlation (r)	p-value
Quincy	2005	Positive	0.62	0.019
Quincy	2006	None	0.11	0.430
Quincy	2007	None	0.28	0.170
Marianna	2006	None	0.06	0.561
Marianna	2007	Positive	0.71	0.008

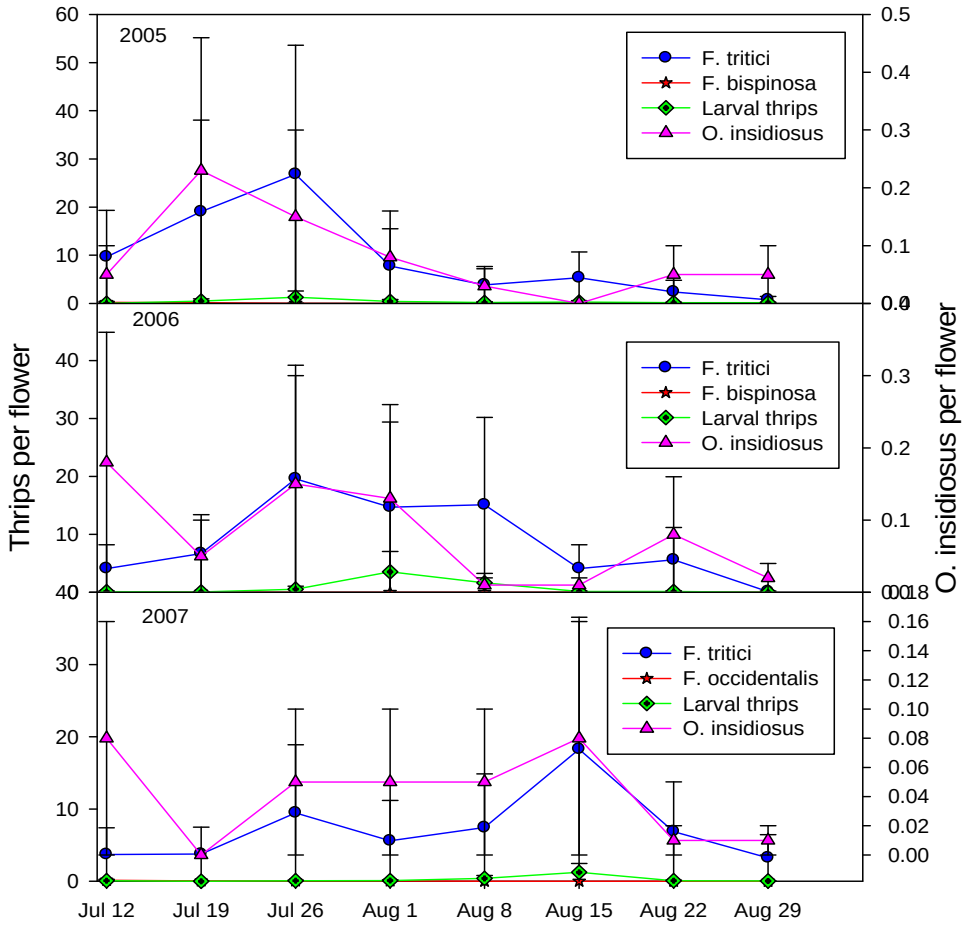

Figure 3-1. Mean densities ((±SEM) of *Frankliniella* thrips and *O. insidiosus* in cotton flowers from 12 July Through 29 August, in 2005, 2006 and 2007 in Quincy, FL.

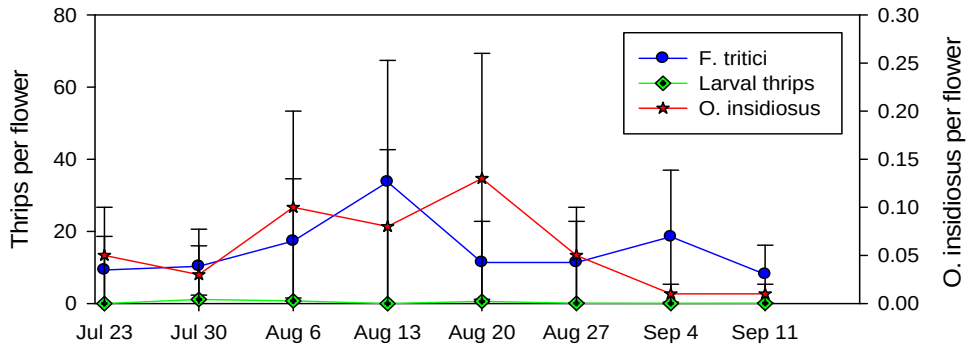

Figure 3-2. Mean densities ((±SEM) of *Frankliniella* thrips and *O. insidiosus* in cotton flowers from 23 July through 11 September, 2006 in Marianna, FL.

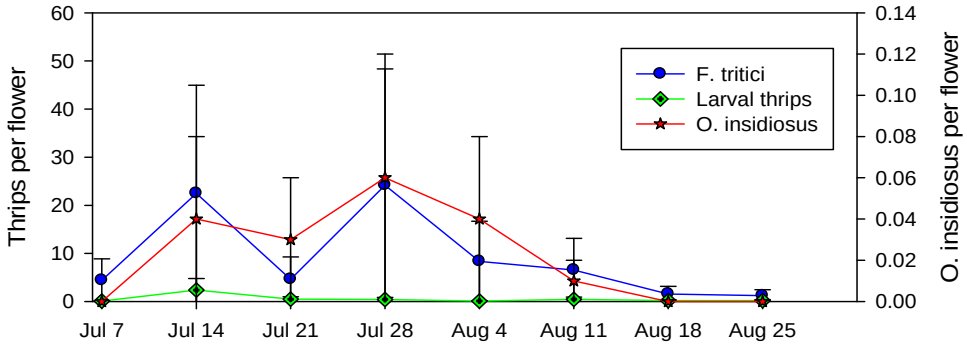

Figure 3-3. Mean densities ((±SEM) of *Frankliniella* thrips and *O. insidiosus* in cotton flowers from 7 July through 25 August, 2007 in Marianna, FL.

CHAPTER 4
FRANKLINIELLA THRIPS, COTTON HARDLOCK, COTTON SQUARES AND THEIR MANAGEMENT USING PESTICIDES

Introduction

Frankliniella Thrips, Hardlock and Their Management

Cotton suffers from many seedling diseases. Kirkpatrick and Rothrock (2001) noted that boll rots ranks second to the seedling disease complex as the most important disease of cotton in the US. They noted that plant disease epidemics from boll (fruit) – rotting pathogens - contribute to reduced yield and quality in cotton, *G. hirsutum*, in most years. Cotton hardlock is classified as a subset of boll rots (Hillocks and Brettell 1993); or that the two are linked. Jones et al. (2000) observed a positive correlation between bolls with seed rot symptoms and the occurrence of hardlock bolls at boll opening, for which case the reduction in yield because of boll rots is loss of entire bolls. Roncandori et al. (1975) and Padgett et al. (2003) emphasized that epidemics occur when excess moisture and humidity are present just before and during boll opening (August to September). Although the symptoms associated with hardlock and rotten bolls may differ, both conditions reduce seed-cotton yield.

Fusarium is associated with hardlock. The disease is believed to result from infection by *F. verticillioides* at the time of bloom (Marois et al. 2002, Wright et al. 2004). Wright et al. (2003) reported that the disease significantly reduced cotton yield in the Panhandle of Florida in 2002. Recent reports indicate that this has been the situation year after year. Some insect species have been associated with the disease; notable among these are thrips and stink bugs. Pinckard et al. (1981) suggested that insects can play a role in predisposing bolls to invasion by pathogens, and that feeding may damage carpel walls and locules of bolls to the extent that boll opening is slowed and often imperfect. For instance, Barbour et al. (1990) determined that the proportion of harvestable locules per boll decreased as the duration of infestation and the number of punctures

per boll by green stink bug, *Acrosternum hilare* (Say), increased. The identification of hardlock disease as a contributing factor of yield reduction in cotton, especially in Florida and other parts of the southeastern US, has contributed to the intensification of research efforts for its control.

Even though some reports (Roncandori et al. 1975, Bell 1999) have played down the effectiveness of fungicides to control boll rots, some of these chemicals appear promising for the management of cotton hardlock, especially if they are combined with insecticides. Seebold et al. (2004) argued that the application of fungicides during bloom may provide a reduction of hardlock severity. It may be possible to focus on the earlier flowers or first 4 weeks of bloom since these contribute the most to yield in some production system (Jenkins et al. 1990). Interestingly, insecticides rather than fungicides appear to have the potential to offer a better management of the disease. The target in this case is the insects, possibly thrips or other flower visitors that supposedly help vector the disease. Thrips control using insecticides has been quite difficult due to factors such as resistance and rapid recolonization of the plant.

Some insecticide trials to control the disease have been conducted with varying successes and implications. Farrar and Davis (1991) reported that controlling thrips with insecticides was an effective way to manage corn ear rot also caused by *F. verticillioides*. In one toxicity effect study of selected insecticides on thrips and their predators, Studebaker and Kring (2000) noted that spinosad and methoxyfenozide had no lethal or sublethal effects on insidious flower bug. Cyhalothrin also did not produce sublethal effects but did cause significant mortality in the flower bug. It may be important to consider the above factors when applying insecticides so that natural enemies can complement insecticidal control. Applying pesticides which have minimal or no adverse effect on predatory insects can allow plants host a number of naturally occurring predatory species, including anthocorid bugs. It is needless to indicate that all these factors may

have to be factored in the overall strategy for the management of hardlock. There is therefore the need to investigate the efficacy and toxicity of different pesticides to verify whether they can be incorporated into an integrated program for the management of cotton hardlock disease.

Pesticides and Abortion of Cotton Squares

Cotton initiates its reproductive stage with the formation of flowers buds commonly referred to as squares. The number of squares initiated and carried to the end determines the yield of the crop. Smith and Cothren (1999) noted that about 60% of squares are normally aborted as a result of the inability of the crop to maintain all into mature bolls. In addition to this natural cause of the abortion of the squares, various environmental, insect pests and diseases problems contribute to square abortion. Since yield of cotton is determined by the final number of bolls at the end of the season, various attempts are usually made to reduce the number of squares that are aborted. Primarily, these attempts are targeted at the biotic factors by the application of pesticides since genetic and environmental ones are not easy to control. There is very little information on the effect of pesticides on the abortion of squares and it is against this background that this aspect was also addressed in this study.

The hypotheses tested in this study were that: (a) cyhalothrin (Karate) was effective against *Frankliniella* thrips and therefore can help manage hardlock, and (b) Karate and Topsin (Thiophanate methyl) have effect on square abortion.

Materials and Methods

Field Plots

Two separate field experiments were conducted to investigate the above hypotheses.

Cotton (DPL-445 BG/RR) was sown on two fields at the Quincy and Marianna branches of North Florida Research and Education Center (NFREC), during the summer/fall of 2006 and 2007. Cotton plants were grown according to normal production practices recommended by the

University of Florida Extension Services unless otherwise stated. The field in each site consisted of four blocks in a randomized complete block design. Each field measured 121 m x 30.5 m with block size of 55.4 m x 5.5 m, and 6.4 m maintained between blocks. A treatment plot measured 7.6 m x 5.5 m, consisting of 6 rows of plants, with a row spacing of 0.9 m. Sowing was done after the application of 5-10-15 (N-P-K) fertilizer at 225 kg/ha three days prior to planting. Weekly applications of either:

1) Lambda-cyhalothrin (Karate) (insecticide) in 17 ml of Karate/3 gal of water, or

2) Thiophanate-methyl (Topsin-M) (fungicide) in 52 ml/3 gal of water, or

3) A combination of the two (fungicide + insecticide).

There was a control treatment where there was no pesticide application. Application of the pesticides started at early bloom, when 50% of plants had one open bloom. The pesticides were applied using a CO_2, backpack sprayer delivering 24 gal/A with one 8002 nozzle/row at 25 psi.

Thrips and *Orius* Sampling, Hardlock and Yield Assessment

Weekly sampling of five white flowers from each treatment plot started for thrips and *O. insidiosus* a week following the first application of the pesticides. The sampling and processing techniques were same as described in chapter 2. Hardlock and yield were also assessed and determined, respectively, as previously described in chapter 2.

Effect of Pesticides on Square Abortion

Two field experiments maintained at Quincy and Marianna and described previously in this Chapter were used. A distance of 3 m was demarcated with flags in each treatment plot from which aborted squares were collected into labeled plastic Ziploc bags every three days at the Quincy plot and twice per week from the Marianna plot.

Data Analysis

The data were subjected to analysis using SAS (8.1) GLM procedure and analysis of variance performed at the 5% probability level.

Results

Thrips and *O. insidiosus* Population Dynamics and Pesticide Treatments

Thrips species identified in the flowers in all the treated plots in Quincy and Marianna in both 2006 and 2007 were *F. occidentalis, and F. tritici. F. fusca* was rarely identified and no *F. bispinosa* were identified. The predator, *O. insidiosus* was also identified in all the treatments in both years. The population fluctuations of these insects are shown in Figs. 4-1, 4-2, 4-3 and 4-4. *F. tritici*, as usual, constituted the bulk (>98%) of the adult population across treatments across years. Averaging thrips population across the two years, *F. occidentalis* constituted <1%, 19%, 45% and <1% of the adult population respectively in the fungicide alone, insecticide alone, insecticide plus fungicide and the control treatments in Quincy. In Marianna, <1%, 7%, 7% and 1% respectively were obtained in those treatments. In Quincy the highest weekly mean density per flower of adult *F. tritici* in all the treatments were recorded on a single day (August 1) (mid-season); population densities of 18.1, 5.3, 8.5 and 18.1 per flower were recorded in the fungicide alone, insecticide alone, fungicide plus insecticide and control treatments, respectively on that date. A similar trend was observed in 2007 with the peak mean densities occurring on August 15; with densities of 16, 3.5, 1.35 and 12.3 per flower in the respective treatments. However, peak weekly mean densities in the respective treatments were recorded on different dates in Marianna.

Peak populations per flower in the insecticide alone and the fungicide plus insecticide treatments occurred on August 6 (16 and 21.5 respectively) in 2006. Peak populations per flower in the fungicide alone and the control treatments were 38.2 (August 13) and 56.4 (August 20). In 2007, population peaks recorded in the fungicide alone, insecticide alone and control treatments

respectively were 25.9, 4.7 and 2.5 per flower on July 21 and 18.9 in the fungicide plus insecticide treatment on July 28. With a few exceptions, the mean population per flower of *F. occidentalis* were <1 in both locations in the fungicide alone and insecticide alone treatments. Similar trends were observed for the larval thrips and *O. insidiosus*. Generally, more thrips and *O. insidiosus* were recorded in Marianna than in Quincy.

Thrips and Pesticide Treatments and Hardlock

Thrips populations were greatly suppressed by insecticide treatments in both 2006 and 2007 in both locations. There were significant (P<0.0001) differences in the effect of the pesticides on thrips population (Tables 4-1, 4-2, 4-3 and 4-4). Insecticide treatments reduced thrips population in the flowers by 77 to 82% in Quincy and 75 to 80% in Marianna. These reductions in thrips numbers possibly resulted from avoidance of those treated plants (flowers) by thrips. There were no significant differences between the insecticide alone and the fungicide plus insecticide treatments on the population of adult *F. tritici* and the larvae in both locations and years. There was also no significant difference between the fungicide alone and the control treatments. In 2007 significantly (P = 0.01) more *F. occidentalis* were recorded in the insecticide alone and the fungicide plus insecticide treatments in both locations. A similar observation was made in 2006 in Marianna but it was mixed in Quincy. There were no significant differences in the effect of the treatments on the population of *O. insidiosus* in both locations in both years.

Thrips densities per flower based on sex are shown in Table 4-5. The ratios of male to female *F. tritici* across years and treatments were 1:1.3 and 1:1.2 in Quincy and Marianna, respectively and that of *O. insidiosus* nymph to adult were 1:4.5 and 1:5, respectively. Suppression of thrips population reflected in reduction of hardlock. Significant (P <0.001) differences in hardlock incidence among treatments were obtained in both locations and years (Tables 4-6 and 4-7). However, while there were significant differences (P < 0.001) in the yield

in both years in Quincy, there were no significant differences in 2007 in Marianna. In assessing the relationship between thrips and hardlock across treatments, strong relationships were obtained in Quincy (R^2 =0.42, P = 0.0065 and R^2 = 0.8124, P = 0.001) in 2006 and 2007 (Fig. 4-5). No relationship was obtained in Marianna (R^2 = 0.3123, P = 0.024 and R^2 = 0.1915, P =0.09) (Fig. 4-6). Pesticides treatments did not affect the abortion of cotton square (Table 4-8).

Discussion

Hardlock disease still remains an important disease of cotton and the role of thrips in its spread has been controversial. However, results from our studies and Mailhot (2007) involving pesticide treatments targeting insects and particularly thrips have shown that reducing populations of these insects usually results in reduction in the disease severity. Insecticide applications have proven more effective in reducing the disease severity than fungicides and this may be due to the sharp drop in thrips population as a result of the treatments. Weekly applications of insecticides keep the thrips population low throughout the season. Hardlock incidence in the fungicide alone and control treatments was similar because it appears fungicide applications are not able to significantly reduce the amount of inoculum present (Roncandori et al. 1975, Bell 1999). Combining a fungicide and an insecticide has been suggested by some researchers (Seebold et al. 2004) as one way that could provide a better management of the disease even though our results showed that application of insecticide alone was equally effective.

Controlling thrips is quite difficult due to resistance and recolonization but combining insecticides application with predation by natural enemies may be helpful, especially if the insecticide used has no lethal or sublethal effects on the natural enemy (Studebaker and Kring 2000). In our study, we observed no significant differences in the population of the predator, *O. insidiosus* in the treatments, which indicates that its population may not have been significantly

affected by the insecticide treatments. The relatively low numbers of the predator in our study could have also contributed to this. Combining this observation of low densities of the predator in the flower and the fact that there were no significant differences in the treatment effect on its population densities, we think the marked suppression of the thrips population was largely due to the application of insecticides and not directly from predation by *O. insidiosus*. Nevertheless, it may be useful to explore combining chemical control and use of natural enemies in managing such diseases.

One interesting observation in our study was the significantly high numbers of *F. occidentalis* recorded in the insecticide treated plots, which was also reported by Funderburk et al. (2000), as this has implications for chemical control of this species. *F. occidentalis* appears to be resistant to Lambda cyhalothrin. This observation may be a strategy by the species to avoid predation in the insecticide plots. However, it remains unclear whether such a trait in this species is inheritable. Reduction in hardlock resulting from insecticide application sometimes did not translate into yield and the reason is not clear. The fact that insecticide application does not always reflect in significant reduction in hardlock and the fact that it does not always translate into yield increase, opens the debate as to when and how much of pesticides should be applied since farmers would want to maximize profits by reducing cost of pesticides.

Based on our results, we suggest pesticide application to control the disease should be considered in line with thrips abundance during the cotton growing season. Pesticides (especially insecticides) could be applied when conditions have been projected to favor the disease development and applications may also target the first four weeks of bloom (Jenkins et al. 1990) since bolls set during this period contribute most to the yield. Mailhot (2007) showed that cool,

moist conditions may favor hardlock and his model may help schedule fungicide and insecticide applications.

The relatively high R^2 values and the significant regression values obtained in the relationship between thrips numbers and hardlock in our studies in Quincy but not Marianna tend to suggest that thrips may be playing some role in the disease spread. Even though more studies are needed to establish the strength of this relationship, thrips seem to play some role in the epidemiology of the hardlock. Since, without doubt, environmental factors appear to play a key role in hardlock development (Mailhot 2007), we suggest that for seasons where favorable weather conditions for the disease are forecast, and there is the possibility of having high thrips population, hardlock incidence may be high and would therefore warrant immediate plans for its management.

The fact that no significant differences were observed in the number of squares aborted among treatments show that pesticides do not significantly protect squares from abortion. Thus square abortion is influenced basically by normal physiological and environmental factors.

Table 4-1. Mean densities of *Frankliniella* species thrips and *O. insidiosus* per flower as affected by pesticide treatment at Quincy, FL in 2006.

Treatment	*F. tritici*	*F. occidentalis*	Larval thrips	*O. insidiosus*	Adult thrips
Fungicide	9.41a	0.03b	1.11a	0.08a	9.43a
Insecticide	2.04b	0.05b	0.05b	0.07a	2.1b
Both	2.94b	0.13a	0.08b	0.05a	3.07b
Control	8.87a	0.01b	1.03a	0.08a	8.89a

Means followed by the same letter(s) in a column are not significantly different at the 5% level.

Table 4-2. Mean densities of *Frankliniella* thrips species and *O. insidiosus* per flower as affected by pesticide treatment at Quincy, FL in 2007.

Treatment	*F. tritici*	*F. occidentalis*	Larval thrips	*O. insidiosus*	Adult thrips
Fungicide	9.75a	0.0c	0.44a	0.15a	10.28a
Insecticide	1.85b	0.46b	0.1b	0.11a	2.41b
Both	0.94b	0.95a	0.08b	0.18a	2.0b
Control	10.16a	0.03c	0.45a	0.21a	10.61a

Means followed by the same letter(s) in a column are not significantly different at the 5% level.

Table 4-3. Mean densities of *Frankliniella* thrips species and *O. insidiosus* per flower as affected by pesticide treatment at Marianna, FL in 2006.

Treatment	*F. tritici*	*F. occidentalis*	Larval thrips	*O. insidiosus*	Adult thrips
Fungicide	27.87a	0.65b	0.73a	0.07a	28.25a
Insecticide	6.19c	2.56a	0.32b	0.04a	8.81c
Both	10.18b	2.85a	0.41b	0.06a	13.09b
Control	24.77a	0.41b	0.53ab	0.07a	25.32a

Means followed by the same letter(s) in a column are not significantly different at the 5% level.

Table 4-4. Mean densities of *Frankliniella* thrips species and *O. insidiosus* per flower as affected by pesticide treatment at Marianna, FL in 2007.

Treatment	*F. tritici*	*F. occidentalis*	Larval thrips	*O. insidiosus*	Adult thrips
Fungicide	13.53a	0.03b	0.84a	0.08a	14.4a
Insecticide	2.28b	0.1a	0.04b	0.06a	2.3b
Both	1.83b	0.14a	0.11b	0.03a	2.09b
Control	11.37a	0.02b	0.57a	0.08a	11.78a

Means followed by the same letter(s) in a column are not significantly different at the 5% level.

Table 4-5. Mean densities of *Frankliniella* species thrips and *O. insidiosus* per flower across 2006 and 2007 in Quincy and Marianna, FL.

	Quincy	Marianna
tritici female	3.24±0.16	7.93±0.32
tritici male	2.52±0.16	6.67±0.32
occidentalis female	0.12±0.02	0.53±0.06
occidentalis male	0.06±0.01	0.32±0.04
fusca female	0	0.01±0.01
fusca male	0	0
bispinosa female	0	0
bispinosa male	0	0
larval thrips	0.45±0.05	0.54±0.04
orius adult	0.09±0.01	0.05±0.01
orius nymph	0.02±0.01	0.01±0

Mean density (±SEM)

Table 4-6. Effect of pesticides on hardlock and yield in Quincy, FL.

	% Hardlock		Yield (kg/ha)	
Treatment	2006	2007	2006	2007
Fungicide	29.1b	40.4a	1245a	1264b
Insecticide	20.8c	17.1b	1362a	1721a
Both	19.9c	12.3b	1158ab	1966a
Control	47.8a	39.1a	953b	1240b

Columns followed by same letter(s) are not significantly different at 5% probability level.
Weight (kg/ha) include lint + seed.

Table 4-7. Effect of pesticides on hardlock and yield in Marianna, FL.

	% Hardlock		Yield (kg/ha)	
Treatment	2006	2007	2006	2007
Fungicide	6.0a	14.4a	1189ab	2083a
Insecticide	1.0b	11.6bc	1363a	2007a
Both	1.8b	8.6c	1213ab	1961a
Control	7.8a	17.4a	1169b	1937a

Columns followed by same letter(s) are not significantly different at 5% probability level.
Weight (kg/ha) include lint + seed.

Table 4-8. Effect of pesticides on abortion of cotton squares per day with aborted cotton squares collected from 3 m of two rows of cotton plants in Quincy and Marianna, FL.

	Number of squares aborted per day			
	Quincy		Marianna	
Treatment	2005	2006	2006	2007
Fungicide	43.5a	56.5a	19.3a	64.6a
Insecticide	44.3a	58.8a	20.3a	61.8a
Both	42.3a	61.3a	18.7a	58.2a
Control	45.9a	69.2a	22.0a	57.8a

Columns followed by same letter(s) are not significantly different at 5% probability level.

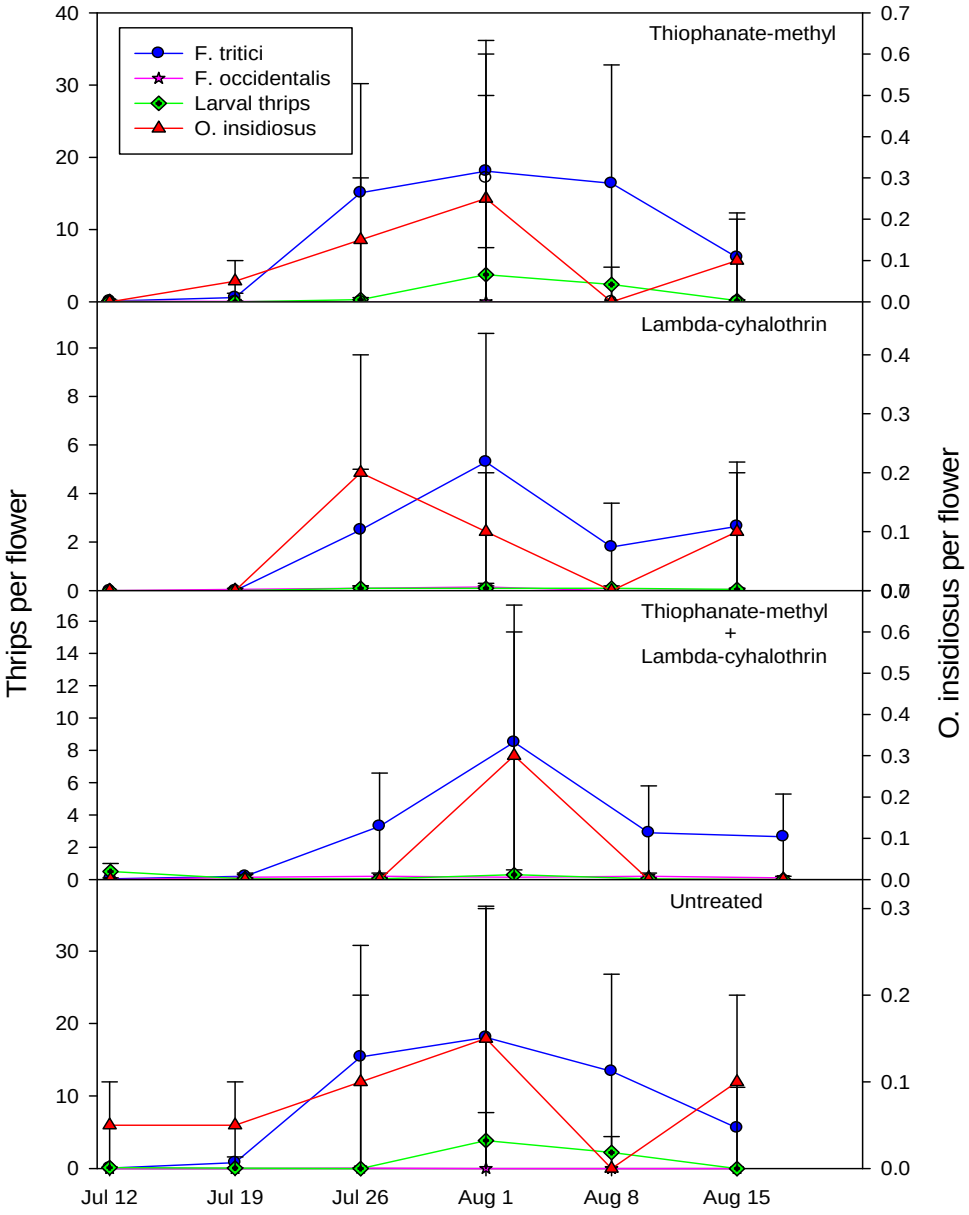

Figure 4-1. Mean densities (±SEM) of *Frankliniella* thrips and *O. insidiosus* in cotton flowers as affected by pesticides from 12 July through 15 August 2006 in Quincy, FL.

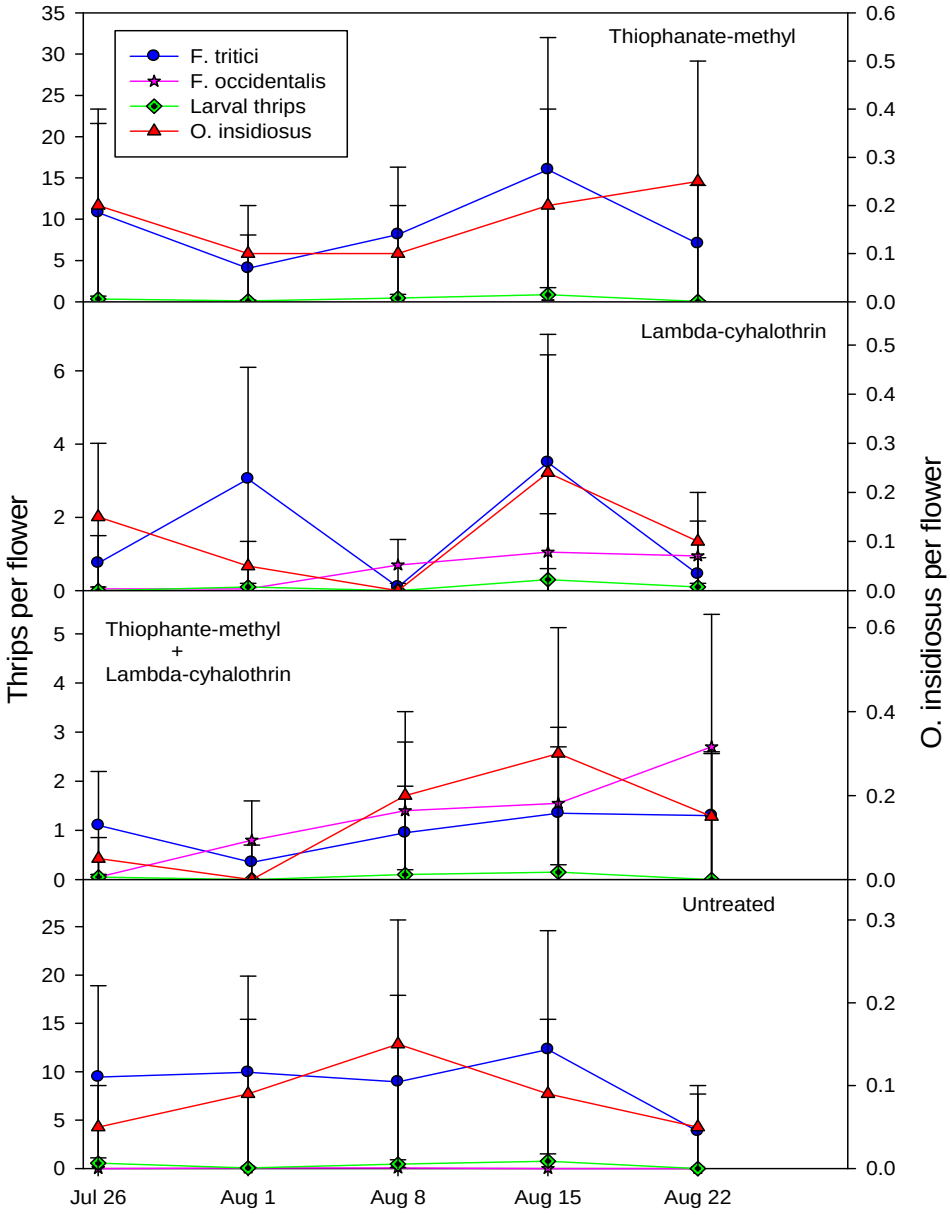

Figure 4-2. Mean densities (±SEM) of *Frankliniella* thrips and *O. insidiosus* in cotton flowers as affected by pesticides from 26 July through 22 August 2007 in Quincy, FL.

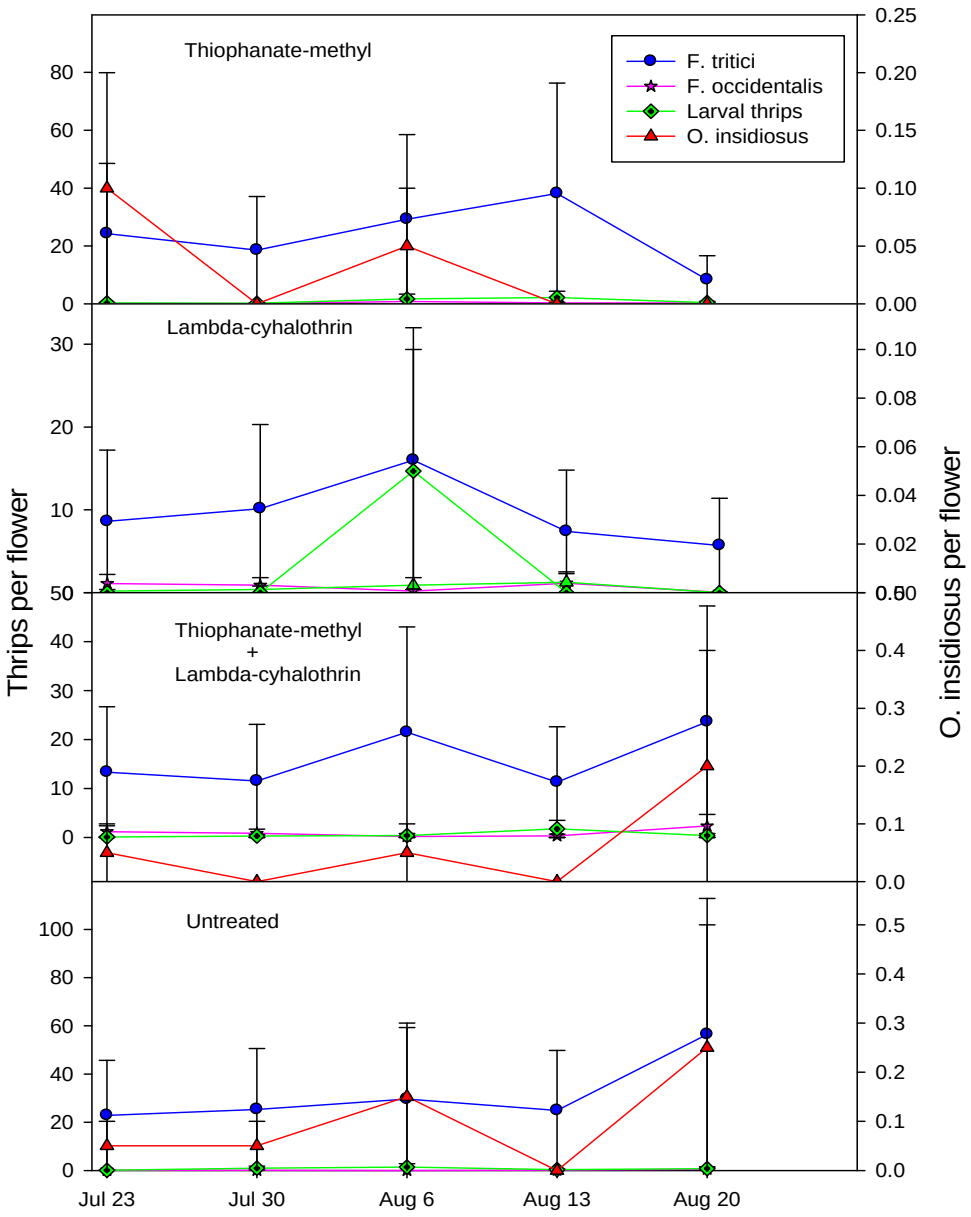

Figure 4-3. Mean densities (±SEM) of *Frankliniella* thrips and *O. insidiosus* in cotton flowers as affected by pesticides from 23 July through 20 August 2006 in Marianna, FL.

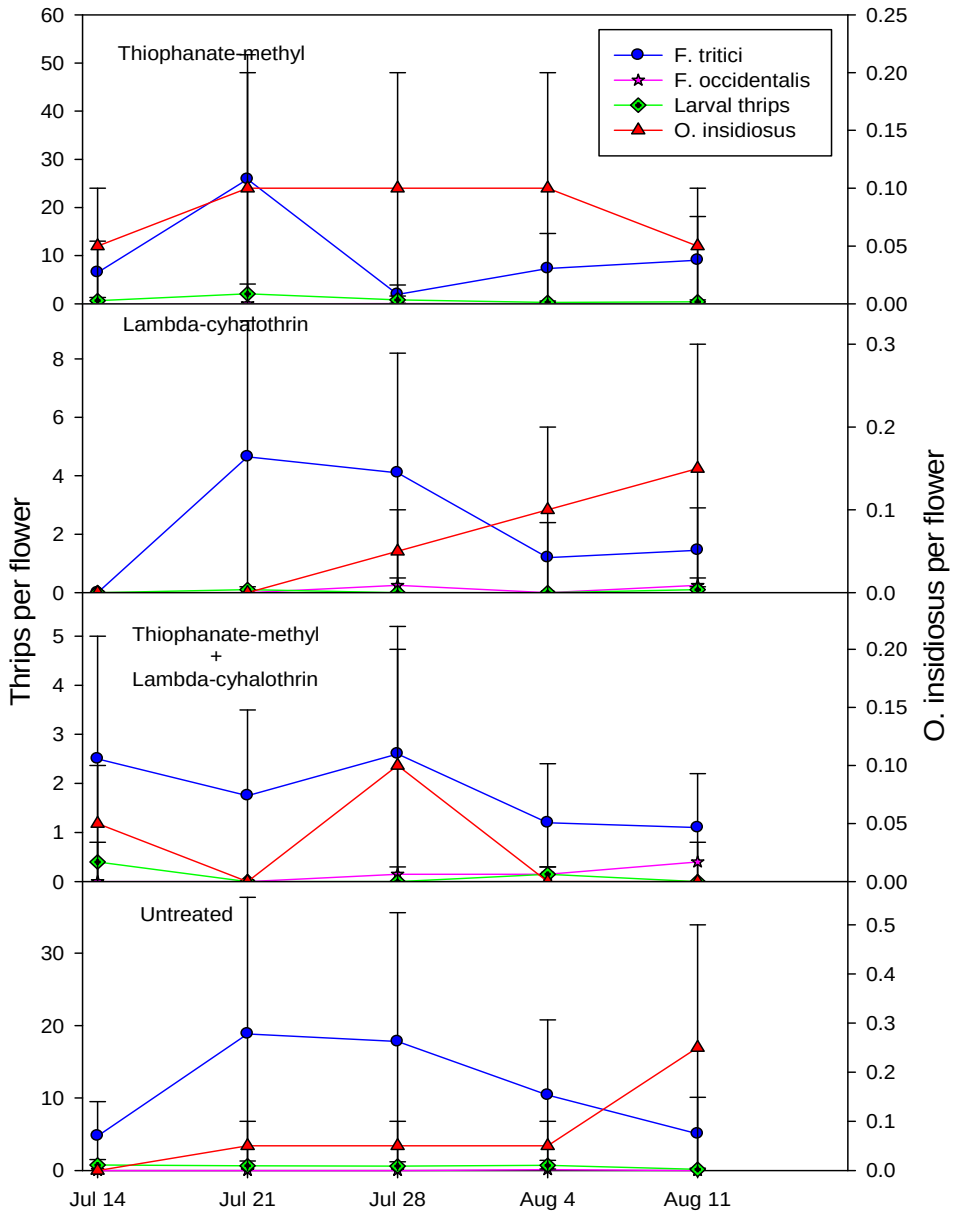

Figure 4-4. Mean densities (±SEM) of *Frankliniella* thrips and *O. insidiosus* in cotton flowers as affected by pesticides from 14 July through 11 August 2007 in Marianna, FL.

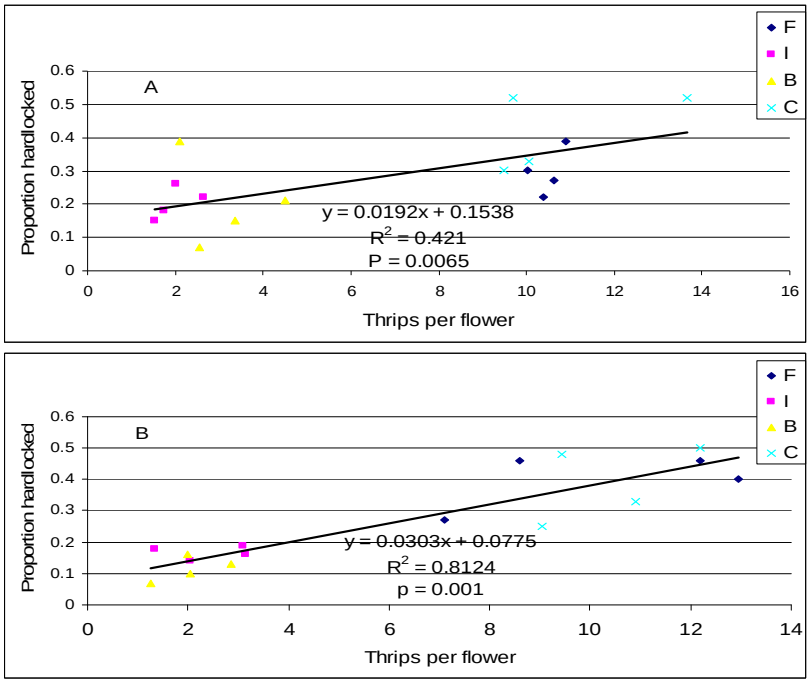

Figure 4-5. Relationship between thrips and hardlock on per plot basis in Quincy, FL. A) In 2006. B) In 2007. F = fungicide (Thiophanate-methyl), I = insecticide (Lambda-cyhalothrin), B = (fungicide + insecticide) and C = untreated control.

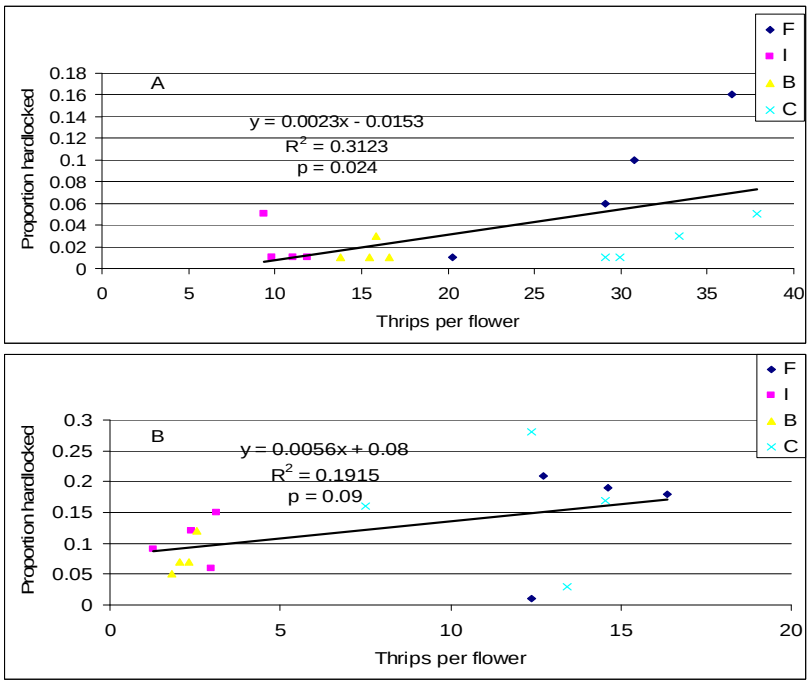

Figure 4-6. Relationship between thrips and hardlock on per plot basis in Marianna, FL. A) In 2006. B) In 2007. F = fungicide (Thiophanate-methyl), I = insecticide (Lambda-cyhalothrin), B = (fungicide + insecticide) and C = untreated control.

Figure 4-7. Cotton boll with symptoms of hardlock.

CHAPTER 5
SUMMARY AND CONCLUSIONS

Flower thrips, *Frankliniella bispinosa* (Morgan); tobacco thrips, *Frankliniella fusca* (Hinds); western flower thrips, *Frankliniella occidentalis* (Pergande) and eastern flower thrips *Frankliniella tritici* (Fitch) were identified in both Marianna and Quincy on cotton. However, *F. tritici* accounted >98% of the adult population. *F. fusca* was identified on the leaves usually in the seedling stage of the cotton plant, and rarely after the fourth week of sampling. Mean densities of *F. occidentalis*, *F. bispinosa* and the larval thrips per leaf were <1 during the sampling period. Thrips population increased rapidly with the onset of bloom, peaking around mid-season which also coincided with the peak of bloom. Adult thrips (about 90%) prefer flowers to other plant parts. Only adult *F. tritici* and the larvae were found in all the parts of the plant.

There was significantly more adult and larval thrips in the upper canopy than the mid- and lower canopies in Marianna but was mixed in Quincy. There was also significantly ($P < 0.0001$, $F_{1,312} = 9.35$) more adult *F. tritici* in the upper than the lower flowers in both locations. Mean densities of *F. occidentalis* was significantly ($P < 0.0001$) more in the upper than the lower flowers in 2006 but not in 2007 in both locations. The ratios of male to female per leaf ranged from about 1:1 to 1:10 in Quincy, and about 1:1 in Marianna, while ratios of about 1:1 to 1:12 and about 1:1 in the flowers were obtained in the former and latter locations, respectively. In Quincy, no association was observed between thrips densities over time and cotton hardlock, with very low R^2 value of 0.09 obtained in both 2006 and 2007, and these were not significant. No association was obtained in Marianna either in both years and the respective R^2 values were 0.04 and 0.18 (not significant).

The very low R^2 values and the fact that statistical tests proved not significant (demonstrating no association) seem to show little or no contribution of the insects to the disease spread. It appears other factors other than thrips make more contributions to the epidemiology of the disease.

A series of field studies were also conducted to estimate the predation of *F. tritici* by the predator, *O. insidiosus*. In most of the sampling weeks, the mean densities of *O. insidiosus* inhabiting the flowers were significantly more than those found in the other plant parts. However, generally, mean densities of *O. insidiosus* per flower were very low (<0.3 predator per flower) in all the sampling weeks. In Quincy, the highest weekly mean densities per flower of *F. tritici* recorded were 26.8, 19.6 and 18.28 in 2005, 2006 and 2007 and that of *O. insidiosus* were 0.23, 0.18 and 0.08. Similarly, densities of 33.7 and 24.18 per flower were obtained in 2006 and 2007 and that of *O. insidiosus* were 0.13 and 0.06.

The ratio of the nymphal *O. insidiosus* to adult ranged from 1:2.5 to 1:4 in Quincy and 1:3 to 1:5 in Marianna. The ratios obtained for male to female *F. tritici* ranged from1:1 to 1:2 in Quincy and about 1:1 in Marianna. The lowest predator/prey ratio obtained in Quincy was 1:1700 and the highest 1:5. In Marianna, the lowest was 1:1900 and highest 1:92. No correlation was obtained between the predator and the thrips with R^2 values of 0.38, 0.01, and 0.08 in 2005, 2006 and 2007, respectively in Quincy. R^2 values of 0.01 and 0.5 were obtained in 2006 and 2007, respectively in Marianna. There was not a consistent suppression of the population of *F. tritici* over time. It appears no association exists between *O. insidiosus* and *Frankliniella* thrips. The predator, *O. insidiosus* was not effective in suppressing the population of *F. tritici* in cotton in our study.

In the studies on the effect of pesticides on thrips population and hardlock, *Frankliniella* thrips identified in all the pesticide treatments were *F. tritici*, and *F. occidentalis*; and the larvae. *F. tritici* constituted >98% of the adult population. *O. insidiosus* was also identified in all the treatments. *F. occidentalis* constituted about 1% of the adult population in the fungicide alone and control treatments and 19 and 45% in the insecticide alone and the fungicide plus insecticide treatments in Quincy. In Marianna, they constituted about 1% in the fungicide alone and control treatments and about 7% in the insecticide alone and fungicide plus insecticide treatments. Generally, more thrips and *O. insidiosus* were recorded in Marianna than in Quincy.

Insecticide treatments reduced thrips populations by about 77 to 82% in Quincy and 75 to 80% in Marianna. The insecticide alone and the fungicide plus insecticide treatments were significantly more effective than the fungicide alone and the control treatments in reducing thrips population and hardlock. The ratios of male to female *F. tritici* across years and treatments were 1:1.3 and 1:1.2 in Quincy and Marianna, respectively and that of *O. insidiosus* nymphs to adult were 1:4.5 and 1:5, respectively. In assessing the relationship between thrips and hardlock across years, a strong one was obtained in Quincy ($R^2 = 0.42$, P =0.0065 and $R^2 = 0.81$, P = 0.001) in 2006 and 2007. A relatively weaker relationship was obtained in Marianna ($R^2 = 0.31$, P = 0.024 and $R^2 = 0.19$, P = 0.09).

Weekly applications of insecticides which usually resulted in suppression of thrips population proved more effective in reducing the disease than fungicides application. Insecticide applications did not significantly suppress the population of *O. insidiosus*. Based on our results, we suggest pesticide application to control hardlock should be considered in line with weather forecast during the planting season. Pesticide applications could be done when conditions have been forecast to favor the disease, and may also target the first four weeks of bloom since bolls

set during this period contribute most to the yield. Since, without doubt, environmental factors especially night temperatures play a key role in hardlock development, we suggest that for seasons where good weather conditions for the disease are forecast, and there is the possibility of having high thrips population, hardlock incidence may be high and would therefore warrant immediate plans for its management.

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BIOGRAPHICAL SKETCH

Enoch Adjei Osekre was born in 1965 in Teshie-Accra, Ghana. He earned both his B.Sc. in Crop Science and his MPhil. in Insect Science from the University of Ghana, in 1990 and 1998, respectively. After earning his first degree, he worked with the Ghana Education Service as a Tutor at Teshie Presbyterian Senior High School until 1996, when he left to pursue the second degree.

Enoch also worked as a Research Scientist with the Plant Genetic Resources Research Institute at Bunso, Ghana, from 1998 to 2004. In summer 2004, he entered the University of Florida in the Department of Agronomy on an assistantship to pursue a PhD degree. He worked on the impact of the population dynamics of thrips on cotton hardlock disease. After graduation, he plans to remain in Agricultural Research. Enoch is married to Lawrenda Osekre, and they have two daughters: Portia, age 11; and Benedicta, age 8.