A STUDY OF THE BEHAVIOR, ECOLOGY, AND CONTROL OF FLOWER THRIPS IN BLUEBERRIES TOWARDS THE DEVELOPMENT OF AN INTEGRATED PEST MANAGEMENT (IPM) PROGRAM IN FLORIDA AND SOUTHERN GEORGIA

By

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To my family Hector, Olga and Pedro for standing with me all the way.

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Abstract of Dissertation Presented to the Graduate School
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A STUDY OF THE BEHAVIOR, ECOLOGY, AND CONTROL OF FLOWER THRIPS IN BLUEBERRIES TOWARDS THE DEVELOPMENT OF AN INTEGRATED PEST MANAGEMENT (IPM) PROGRAM IN FLORIDA AND SOUTHERN GEORGIA

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Flower thrips are considered by growers as one of the key insect pests for early-season blueberries in Florida and southern Georgia. The objective of this study was to understand interactions between thrips and early-season blueberries and to develop strategies that can be used in an Integrated Pest Management (IPM) program to control flower thrips in blueberries. This study included the two blueberry species cultivated in Florida and southern Georgia, rabbiteye and southern highbush. The investigation began with the refinement of thrips sampling techniques and a study of dispersion of thrips in blueberry plantings. From these observations, I concluded that the distribution of flower thrips was highly aggregated in blueberry fields, which is an important factor when considering management strategies. I also developed a new system to collect thrips from inside blueberry flowers, which is more efficient than flower dissection. This work continued with the analysis of population dynamics and descriptions of thrips species

assemblage in blueberries. The results obtained showed a high correlation between thrips populations and the latitude at which blueberry plantings are located as well as with the phenology of the flowers in blueberry bushes. I developed a dichotomous key for the six most common species of thrips found in blueberry fields during flowering. The damage inflicted by flower thrips on blueberries was also described. An 'economic injury level' analysis for two of the most popular cultivars of rabbiteye blueberries was completed. A correlation between the number of thrips captured in sticky traps and the number of thrips found inside the flowers was developed to improve monitoring efficiency. For the chemical control of thrips, I screened nine commercial and three experimental insecticides. From these trials, I concluded that acetamiprid is the most effective insecticide for thrips control. The reduced-risk insecticide spinosad is as effective as any of the other insecticides (except for acetamiprid) and it is compatible with *Orius insidiosus* Say, one of the main natural enemies of thrips. Biocontrol trials did not show any advantages of mass releasing natural enemies as preventive or curative methods to control flower thrips in blueberries.

CHAPTER 1
INTRODUCTION

Blueberries belong to the genus *Vaccinium* in the family Ericaceae. This family also includes azaleas, cranberries, and huckleberries as their most economically important species. There are more than 400 species of *Vaccinium* in the world, 26 of them are found in North America (Pritts and Strik 1992). Cultivated blueberries are native to North America, and have been dispersed around the world, principally to Europe and South and Central America.

The United States (US) blueberry industry started in 1908 when breeding programs were developed to improve wild species present in New Hampshire and New Jersey. By 1916 the first harvest of the new crosses were released to the market, but it was not until the 1930s when several new blueberry cultivars were released and commercial production of blueberries became popular. Despite the new and more productive cultivars today, only 70% of the fruits come from commercial blueberry cultivars, the remaining 30% are wild blueberries (Pollack and Perez 2004).

Worldwide production of blueberries started around 1990. The world production of blueberries for 2003 was estimated at 238,358 metric tons (t), with the U.S. producing approximately 51.3% of the total production, followed by Canada (32.9%), and Poland (7%). Other countries that produce blueberries are Netherlands, Ukraine, and Chile, Argentina (Food and Agriculture Organization of the United Nations (FAO) 2004).

In the United States, blueberry production was estimated at 113,800 t for 2004 (NASS-USDA 2006a). Michigan leads the national production with one third of the

highbush blueberries in the country. Maine produces 80% of the total low-bush blueberries in the United States. In general, most of the states are increasing their overall production with exception of New Jersey, which had a small reduction in the production since 2003 (NASS-USDA 2006a). For the 2004 and 2005 season, there was an increase in the production of fresh market blueberries, apparently due to a general increase in production in low producing states. USDA anticipates a reduction on the price of blueberries despite the increase in production over the next couple of years. The consumption of fresh blueberries per-capita is expected to remain close to 0.17 Kg / year in the United States. During the off-season (December to March) the U.S. imports fruit principally from Chile, which is the principal provider of "winter" blueberries (NASS-USDA 2006a).

There are only two cultivated blueberry species with low chill requirement, southern highbush (*Vaccinium corymbosum* L.) and rabbiteye blueberries (*Vaccinium ashei* Reade). Due to the environmental conditions these two species are the only species cultivated in Florida and southern Georgia. These states along with California, are the only producers of early-season blueberries (April to May) in the U.S. Early-season blueberries have prices that can be five to six times higher than mid-season blueberries. Although Florida represented only 1.18% of the national production of fresh blueberries for 2003, it collected 8.24% of the money produced from blueberries in the nation. In Florida, the total acreage has increased 25% since 2001 and overall revenue has increased to more than $50,000,000 /year (NASS-USDA 2006a).

There are 26 insect pests reported in blueberries for Florida (Mizell 2003). However, only four of them are considered as key pests for early-season blueberries.

These species include blueberry gall midge, cranberry fruitworm, flower thrips, and blueberry maggot (Liburd and Arévalo 2006)

The blueberry gall midge [cranberry tipworm], *Dasineura oxycoccana* (Johnson) is the primary early-season pest in blueberry plantings affecting up to 80% of the floral buds in susceptible cultivars (Lyrene and Payne 1996). Damage resulting from *D. oxycoccana* in blueberry plantings has increased significantly in the last 10 years. Floral and leaf bud injuries caused by *D. oxycoccana* were previously misdiagnosed as frost damage (Lyrene and Payne 1996). Many growers in Florida are replacing the susceptible rabbiteye blueberries with southern highbush, which is more tolerant to this pest (Williamson et al. 2000). In a recent study, Sarzynski and Liburd (2003) found that allowing adults to emerge from buds kept in storage bags at room temperature was the most effective technique for monitoring populations in highly infested blueberry fields. Blueberry gall midge can damage developing vegetative buds after the harvest, which may affect the yield in the following year (Liburd and Arévalo 2006).

Flower thrips of the genus *Frankliniella* are another important pest of early-season blueberries. In (1999), the USDA reported that 40% of the losses in blueberries in Georgia were attributed to flower thrips. Three species of flower thrips have been reported repeatedly in blueberries throughout Florida and southern Georgia, and are *F. bispinosa, F. occidentalis* and *F. tritici* (Finn 2003, Liburd and Arévalo 2005). Thrips populations are known to move rapidly into blueberry fields with the help of wind currents and farm workers (Lewis 1997a). Their life cycles are extremely short, taking only 15 days if environmental conditions are conducive for their growth and development. The short life cycles, as well as overlapping generations during the

blueberry flowering cycle, make this insect a dangerous pest that can reach economic damaging levels in a very short period (Finn 2003). Generally, information on the types of damage and behavior of flower thrips in early-season blueberries is limited. Sarzynsky and Liburd (2003) were only able to obtain initial but limited information on monitoring techniques for thrips.

Cranberry fruitworm, *Acrobasis vaccinii* Riley, is found from Nova Scotia in Canada to Florida in the U.S. In the northern states and Canada it has only one generation per year but a second generation is possible in the southern states. The larva feeds on the fruits and each one can damage as many as 10 fruits by feeding on them and secreting a web around the fruits, which make them unmarketable (Liburd et al. 2005).

A very important late-season pest that has the potential to be a problem is the blueberry maggot, *Rhagoletis mendax* Curran. The females oviposit under the fruit's exocarp. Seven to ten days later the larvae emerge and feed on the pulp of the blueberry for two to three weeks and then drop to the ground to pupate. After overwintering, 80% of the pupae emerge the next season, 19% emerge in the second season after pupation, and the remaining 1% emerges four to five seasons later. Its damage is so severe that berries produced on farms in eastern and midwestern states must be certified "maggot free" to be able to be transported. There is zero tolerance to blueberry maggot in most fresh markets and a very low tolerance in processing markets. Some of the practices to reduce blueberry maggot infestations include sanitation, collection of fruits after harvest and weed control (Maund et al. 2003, Liburd et al. 2005).

To control these pests, farmers have relied on the intensive use of insecticides. However, as a response to the excessive use of highly toxic pesticides and the public

concern for a cleaner environment and healthier products, the Environmental Protection Agency (EPA) created the Reduced-Risk Pesticide Program in 1993, but not until 1996 was it formalized by the Food Quality Protection Act (FQPA) (1996). Some of the characteristics of reduced-risk insecticides include.

- Low effect on human health
- Lower toxicity for non-target organisms
- Low potential for groundwater contamination
- Low use rates
- Low pest resistance potential
- Compatibility with IPM practices as defined by EPA (2003)

The main objective of this work was to study the biology, movement and the effects of flower thrips in commercial plantings of early-season blueberries. It is my goal to develop the fundation for an IPM program to control thrips in commercial early-season blueberry plantings in the southeastern United States. The knowledge gained will be used to establish a management program involving monitoring, use of reduced-risk insecticides and their effect on specific natural enemies, use of biological control, and the calculation of an Economic Injury Level to help farmers to make the decisions in controlling this pest.

CHAPTER 2
LITERATURE REVIEW

Blueberry History and Production Practices

Blueberries and cranberries are some of the few fruit crops native to North America, along with blackberries, grapes, pawpaw, and mulberry. Blueberries belong to the genus *Vaccinium* in the family Ericaceae and have been part of the North American tradition for centuries (Pritts and Strik 1992). Native Americans used almost every part of the plant for their consumption. Roots and leaves were used to make teas, the fruits were used for fresh consumption, and dried as seasoning for meats, including beef jerky, and the juice was used as dye for various items including covers and clothing items. During the seventeenth century, English settlers learned to cultivate blueberries from the Wampanoag Indians and to preserve the fruit (sun-dried) for the winter as a nutritional supplement. However, it was not until the 1880s that the canned-blueberry industry started in the northeast United States (U.S. Highbush Blueberry Council 2002).

In the early 1900s, Elizabeth White and Dr. Frederic Coville started the efforts to domesticate wild highbush blueberries in New Hampshire and New Jersey. By the 1930s the first group of domesticated blueberry cultivars was released. Today, there are 3 principal sources of germplasm for the blueberry cultivars: *Vaccinium corymbosusm* L. (northern highbush), *V. ashei* Reade (southern rabbiteye), and *V. angustifolium* Ait (lowbush blueberry). Despite the development of many new cultivars and the effort put into improvement of blueberry quality, only 70% of the total production of blueberries in

the U.S. is the product of commercial cultivars. The other 30% are the product of wild blueberries (U.S. Highbush Blueberry Council 2002, Pollack and Perez 2004).

Interest in blueberries as a minor crop influenced horticultural departments to develop breeding programs at several land grant universities and colleges including Rutgers and Michigan State Universities. The breeding program at the University of Florida started in 1949. The objective of this program was initially to develop blueberry cultivars that could be produced commercially in Florida where the winter temperatures on average are above 13°C. Two main types of blueberries are produced by this program: the tetraploid highbush also known as southern highbush, based on crosses between *V. corymbosum*, *V. darrowi*, *V. ashei.* Several native blueberries have been used as gene sources for adaptation to the particular conditions in the region (i.e., a low number of chill hours, warm conditions most of the year, soils with low organic matter and high bicarbonates). The most important species used in this program as gene sources are *V. darrowi, V. arboreum, V. corymbosum,* among others (Lyrene 1997). The program has been very successful, allowing the Florida blueberry industry to develop as the principal producer of early-season blueberries between April and May. This window of opportunity gave producers of early-season blueberries a price advantage of 3 - 5 USD more per pound than producers of mid-season blueberries (NASS-USDA 2006a).

Plant Selection and Common Varieties

Blueberries are a perennial crop and with proper care can be productive for many years. The development of a successful crop starts with varietal selection. According to Lyrene (2005), there are four main obstacles that producers encounter when selecting the adequate variety for their farms. 1) The newer varieties have the best potential to be highly productive but a lot of information is still unknown. On the other hand, the older

varieties are obsolete, but most of the information about their productive capabilities and needs in the field are well known. 2) The chosen plants might not be available when needed and in the quantities needed. In some cases the order for new plants needs to be placed a year or more in advance to ensure the availability of the varieties selected. 3) Blueberries in Florida need cross-pollination. It is necessary to select two or more varieties that are highly compatible to ensure maximum fruit-set. At the same time, it is necessary to have alternating rows of the varieties in the field, which complicates the management and harvest. 4) Finally, there are difficulties in using Dormex (Dormex Co. USA. LLC Parsippany, NJ) in the varieties. The use of Dormex is variety-specific, some varieties respond positively to the use of this plant growth regulator, while some present phytotoxicity, and the buds can be destroyed.

Principal blueberry varieties used in Florida are

Star: This variety is planted from Ocala, FL to North Carolina. It is in the late-flowering group of blueberries in Florida. The fruit quality is high, with desirable size, firmness and flavor. In north-central Florida it is harvested in three pickings. This variety is usually considered as low-yield. However, it is very responsive to care during the previous fall, and requires applications of fungicides and fertilizers from the beginning of the crop.

Emerald: It is considered as a high-yield variety. However, it ripens 7 to 10 days later than Star. Due to its productivity, a careful winter pruning is needed to ensure that the fruits left on the bush will set properly. This variety responds well to Dormex in productive areas south of Orlando, FL (Lyrene 2005).

Jewel: This variety is especially popular in north and central Florida. Jewel fruits start ripening about five days after Star, approximately at the same time as Emerald. In north and central Florida, Jewel may produce too many flower buds; therefore, it needs winter-pruning to remove weak branches that may fail to carry the fruits during harvest. Jewel responds well to applications of Dormex ^{TM}. When harvesting, it is necessary to leave the fruits on the bush for extended periods of time because the fruit has a tart flavor. Leaving the fruits on the bush allows them to accumulate sugars, which eventually decreases their tartness.

Millennia and Windsor: These two varieties used to be popular in Florida. However, their popularity was reduced due to several factors. Millenia and Windsor are early-ripening varieties with good yields. The problem with Windsor is that, if the weather is too hot or the fruits are not picked on time, fruit scars develop, which could be a problem. Ideally, fruits should have a small and dry scar between the pedicle and the fruit, which will prolong their shelf life. Millennia has excellent fruit characteristics, but has problems with fruit-setting and is highly susceptible to botrytis, a key fungal disease, during flowering.

The recommendations for varieties in Florida depend on the tests and knowledge gathered year after year. However, varieties have been divided into three groups: Obsolete, Core, and New. The actual recommendation is to plant 75% of the area with core varieties (Star, Emerald, and Jewel for Florida) and 25% with new varieties that show good potential. Among these new varieties: Springhigh, Springwide, Abundance, Sapphire, and Southern Belle are the ones with the highest potential. All of them are low-

chill varieties with desirable characteristics of fruit quality, ripening and fruit set (Lyrene 2005).

Soil Management and Preparation

Blueberries prefer porous, well-drained soils (sandy-loam or loamy-sand) with high organic matter and a low pH. It appears that there is a positive correlation between good growth of southern highbush and the amount of sand in the soil and a negative correlation with the amount of clay and silt (Korkac 1986). In heavy soils, such as southern Georgia, blueberries might take longer to reach maturity but once they are mature the production will be similar to that of other soil types (Williamson et al. 2006). For blueberry bushes to achieve their life expectancy, 50 years, it is necessary to select a good place to plant this crop. This place must have low risk of freeze injury, adequate soil conditions, and easy access to water. The soil management practices described by Williamson et al. (2006) and the actual recommendation for soil preparation of blueberries in the southeastern U.S. region are as follows:

1. Collect and analyze soil samples, determine drainage and options to improve it
2. Clear and drain the land
3. Incorporate sulfur, phosphorus, and organic matter as recommended by the soil analysis
4. Construct beds so that plants will have at least 18 inches of well-drained soil

Plants should be spaced 0.6 to 1.2 m appart in the row with 2.7 to 3.3 m between rows; this density will average 2,400 plants per ha. In the southern U.S. the use of pine bark has become a common practice. The high cost of using pine bark mulch makes it exclusive for early-season blueberry` producers in Florida and southern Georgia. The pine needs to be replaced every 3 to 4 years. In most cases the roots of the plants concentrate in the pine bark and usually do not penetrate the soil. This method makes it

possible to produce blueberry in soils that are otherwise not adequate for its production (Williamson et al. 2006).

Blueberry Pollination

Due to structure and genetics, early-season blueberries need to be cross-pollinated to achieve an adequate fruit set. Blueberry plants are known to be entomophilous and depend mostly on hymenopterans for their pollination. Adequate pollination must occur between three and six days after the stigma is receptive, otherwise the fruit set will be poor.

In North America, some hymenopterans have co-evolved with blueberries. This is the case of bees from the genera *Osmia* and *Habropoda*, which pollinate only blueberries and their entire life cycle is coordinated with blueberry bloom (Yarborough 2006). However, the commonest bee used by commercial growers is the honey bee, *Apis mellifera* L. Because *A. mellifera* is commercially available, it reduces the growers' dependency on fragile natural populations of bees for their blueberry pollination, ensuring a high fruit setting. The recommendation for the number of beehives in blueberries is between 50,000 and 150,00 bees per ha for northern highbush (Yarborough 2006). In the case of rabbiteye blueberries, three main pollinators can be used successfully in the field: *Osmia ribifloris* Cockerell, *Habropoda laboriosa* (F.), the southeastern blueberry bee, and the honey bee, *A. mellifera.* Sampson and Cane (2000), compared the pollination efficiency of *O. ribifloris*, *H. laboriosa*, and *A. mellifera* in three of the core cultivars for rabbiteye, Tifblue, Premier, and Climax. They found no significant difference in fruit set among the varieties. However, when all the varieties were averaged, there were significant differences in terms of which species prefers which variety. Tifblue was reported to have a good response to *O. ribifloris* and *H. laboriosa*,

but not to *A. mellifera.* Premier has a high percentage of fruit set when *H. laboriosa* and *A. mellifera* are used but not when *O. ribifloris* is the pollinator. Finally, Climax seems to have a good response to all the bee species used in the trial (Sampson and Cane 2000). Experiments conducted by Sampson (unpublished data) found that the optimal number of bees needed for maximum fruit set is between 5 and 6 bees per 1,000 opened flowers, this means 5 to 6 bees per bush during peak pollination. However, the number of bees needed should be studied on a farm-to-farm basis. Pollinators tend to get distracted by other nectar sources around the blueberry crops, therefore the distribution of the hives and the number of hives needed depend on the conditions of the farm and the natural population of bees in the surrounding areas.

Unlike honey bees, indigenous genera of bees including *Andrena*, *Halictus*, *Bombus*, *Lasioglossum* use sonication to harvest the pollen from certain plant species including plants of the genus *Vaccinium*. This sonication or buzz-pollination significantly increases the amount of pollen collected and thus the amount of pollen transported to other flowers (Cane and Payne 1988, Javorek et al. 2002). Javorek et al. (2002), compared various bee genera to determine which ones were the most efficient in collecting and pollinating lowbush blueberry flowers. They found that, for example, a honey bee, which does not use sonication, will need to visit a flower 4 times to harvest the same amount of pollen than a bumble bee, which uses sonication; at the same time, bumble bees (97%) pollinate close to 4 times more flowers than honey bees (24%).

Pest Complex in Blueberries

Arthropod Pests

Seven arthropod species are considered as major pests in blueberries. However, only four of them are considered as key pests for early-season blueberries in Florida and

southern Georgia. These insects are blueberry maggot, *Rhagoletis mendax* Curran, blueberry gall midge, *Dasineura oxycoccana* Johnson, cranberry fruitworm, *Acrobasis vaccinii* Riley, and flower thrips *Frankliniella* spp. (Liburd and Arévalo 2006), which are discussed below.

Blueberry maggot: *Rhagoletis mendax* Curran (Diptera: Tephritidae). This insect is the principal pest in blueberries in the eastern U.S. (Liburd et al. 1999). It is found in all blueberry regions east of the Rocky Mountains. This species belongs to the same genus as the apple maggot, *Rhagoletis pomonella* (Walsh). Both of them are host-specific and concentrate their damage on the fruits, making these unmarketable (Liburd et al. 1999). Their damage is so devastating that USDA has imposed restrictions on the transport of blueberries, and some states, such as Florida, that do not have *R. mendax* reported, have a zero-tolerance policy for this insect (Liburd et al. 1998, Liburd and Arévalo 2006). Monitoring for this particular species is based on the use of yellow sticky boards, green sticky spheres and red sticky spheres. There must be a minimum of one trap per ha and one of the traps should be placed within 18 m from the border of the crop. The economic threshold for *R. mendax* has been defined as 2 flies per trap per week (Liburd et al. 2000, Liburd et al. 2006). Management strategies for this tephritid include reduced-risk insecticides, insecticide-treated spheres, and natural enemies such as *Diachasma alloeum* Muesebeck (Hymenoptera: Braconidae) which is being researched in order to improve its efficiency controlling this pest (Liburd and Arévalo 2006)

Blueberry gall midge: *Dasineura oxycoccana* (Diptera: Cecidomyiidae). This species, formerly known as cranberry tipworm, was recently reported a pest of blueberries in southeastern crops (Lyrene and Payne 1992, Sarzynski and Liburd 2003).

After their discovery, it was established that, if left unmanaged, blueberry gall midge can destroy up to 80% of the crop production (Lyrene and Payne 1996). Eggs hatch between 2 and 3 days after oviposition, then larvae feed on the young buds, killing them and preventing the formation of new flowers and leaves. Post-harvest damage could potentially affect the yield for subsequent years (Liburd and Arévalo 2006). To monitor blueberry gall midge, Sarzynski and Liburd (2003) established that collecting buds from the field, 20 buds per ha, and placing them in zip-lock bags for 14 days is the most accurate way to determine the presence of this species. The recommendations to control this insect rely on the use of reduced-risk insecticides for fields with a history of blueberry gall midge or, even if the presence of this species has been confirmed (Liburd and Arévalo 2006). However, six natural enemies of *D. oxycoccana* have been identified, but none of them has been made commercial, and studies about their efficacy managing the pest are still under way (Sampson et al. 2006).

Cranberry fruitworm: *Acrobasis vaccinii* (Lepidoptera: Pyralidae) is present in all the places where its host plants are present in North America. Its host plants include huckleberries, dangle-berries, beach plumbs, apples, cranberries, and blueberries (Beckwith 1941). It is considered a key pest for blueberries. Each larva can damage between 5 and 10 fruits during its development, and the affected blueberry clusters will present webbing and berry deformation. The use of pheromones in sticky traps is recommended to monitor the activity of this insect, and based on the observations on these traps insecticide applications might be necessary at the beginning of the flying season (Liburd and Arévalo 2006).

Blueberry Diseases

Blueberries are susceptible to many diseases. Most of them can be prevented with optimal management of the crop and with good decisions at the moment of selecting varieties and plots to be used for blueberry production. Blueberries are susceptible to diseases caused by fungus, viruses, phytoplasmas, bacteria, nematodes, dodder, and some physiological disorders. Some diseases have been attributed to abiotic factors such as deficient nutrition, freeze, and poor water management, among others. A summary of the diseases reported for blueberries is found in Table 2- 1

Thrips: Diversity and Ecology

Thrips belong to the order Thysanoptera, which literally means "fringed wings." However, the English name for thrips is derived from the Greek word for "woodworm," because early naturalists found various species in dead branches (Mound 2005). Thysanoptera are characterized by fringed wings in the adult stage, and asymmetric mouthparts (Triplehorn and Johnson 2005). The left mandible is the only one that develops because the right one is resorbed by the embryo (Heming 1993). The mouthparts of this order have been described as "punch and suck". The mandible is used to break the external layer of plant cells or pollen grains and the contents are sucked through the maxillary stylets, which are joined to form a tube (Triplehorn and Johnson 2005).

The order Thysanoptera is divided into two suborders, Tubulifera, one family, and Terebrantia, eight families worldwide. The females in Tubulifera do not have an ovipositor and the distal abdominal segment is similar to the males. This segment is tubular in shape and ends in a series of setae. The forewings in Tubulifera have neither venation nor setae except for the base. Terebrantia are the most common suborder and the

one that has the greatest effect on agriculture. Close to 94% of the total pest species are in this suborder, all of them in the family Thripidae (Moritz et al. 2004b).

The metamorphosis of thrips is intermediate. There have been some discussions as to whether thrips should be classified as holometabolous or hemimetabolous. The first two instars do not have external wings, because they are being developed internally. Usually these two instars are called larvae and resemble holometabolous metamorphosis. Thrips display two more distinct immature stages, which show vestigial wings but they do not feed. The first of these stages is called propupa, which shows vestigial wings (except in Tubulifera). Following the propupa stage, a real pupa is formed, similar to the adults. The main differences between pupa and adult are that the pupa are not mobile, has two pairs of vestigial wings, and the antenna has fewer segments, while the adults are mobile, macropterous have well formed wings and have between 6 and 9 antennal segments. The pupa is also inactive but has external development of the wings and morphological resemblance to the adult stage, which refers to a hemimetabolous metamorphosis (Triplehorn and Johnson 2005). Propupa and pupa differ from the adult stage in the size, morphology and functionality of the wings, and the segments in the antennae and legs are reduced. Pupa and propupa are immobile (Moritz 1997).

Behavior and Ecology

Based on thrips' alimentary preferences, they can be divided into fungivorous, phytophagous, predacious, and omnivorous species. The damage caused by thrips in agricultural crops is primarily due to feeding on leaves, flowers or fruits, and secondarily to oviposition in these same structures (Kirk 1995). However, little is known about the feeding behavior of these insects in the field including diets, host-switching behavior, etc. (Kirk 1997a). In the case of Terebrantia, more than 95% of the species are associated

with green plants. However, in most of the cases the host report is based on the places where thrips are found and not on the places where they breed, making most of the records confusing and the definition of host plant very subjective (Mound 2005).

Dispersal behavior of thrips

Thrips in general have two means of dispersal, artificial and natural dispersal. Artificial dispersal is usually human-assisted and is facilitated by the increasing international transportation of agricultural products. Thrips are easily transported in various products including potted and cut flowers and several fruits and vegetables that are imported and exported. Accidentally transporting thrips across borders is relatively easy. They are difficult to spot in a port inspection due to their small size. Furthermore, the eggs of these insects are found inside plant tissues and the signs left by the ovipositing female are minimal.

The second method, natural dispersal, is accomplished by thrips using natural means and the most common method is flying. Just before to flying, thrips have a very complicated preparation for takeoff. During this period macropterous forms bend their abdomen and use setae located on abdominal tergites V to VIII to comb those located on the wings. The objective of this movement is to increase the surface-area of the wings, facilitating take-off (Ellington 1980). Thrips have been reported to fly at 6 to 30 ms^{-1} depending on the species. However, it is known that thrips disperse to distances further than that which they would be able to independently fly. One of the explanations for this phenomenon is the use of wind currents (Lewis 1997a). Thrips, like many small insects, potentially use wind currents to move long distances. This phenomenon is summarized by Gatehouse (1997). Small insects might take advantage of the convective upper currents developed by warm air-pockets, which have speeds of ascension measured up to

3m s^{-1} (Drake and Farrow 1988). These currents help the insects to reach the Flight Boundary Level (FBL) for each insect species, which might run into the Planetary Boundary Level (PBL), which is the layer between the ground and the free atmosphere. This PBL is located between 100 and 3000m above the ground and once the insects break it, it facilitates their dispersal. Radar data show that most of the massive flights are short-lived; but some of the populations can travel overnight (Gatehouse 1997). One of the main disadvantages of this mode of transportation is that insects have little to no control of the direction that they are being transported. However, despite the small size of thrips and their apparent lack of control of their flight patterns due to wind interaction, there is good evidence indicating that thrips have a certain amount of control in the landing. Field observations indicate that thrips land on their feet on individual plants, showing some amount of control (Lewis 1997a). Kirk (1984) demonstrated that thrips have control of their landing selection. The author used various colored traps on the ground separated by 5 m from each other to show that there was a 20-fold difference between flower thrips and grass-dwelling thrips in their color selection for landing. Flower thrips were attracted to bright colors such as white while grass-dwelling thrips were attracted to colors that were closer to green (Kirk 1984, Teulon and Penman 1992). There is evidence that thrips are attracted to various odors, the use of anisaldehyde (for flower thrips), or ethyl nicotinate (for *Thrips obscuratus*) increased the trapping of the respective thrips compared with the controls (Kirk 1985, Teulon 1988).

Population dynamics of thrips

To understand the population dynamics of thrips, it is necessary to understand their relation with their host plants. There are two types of plants where thrips have been reported. The first type is a provisional or alternate host, which might offer temporary

shelter or food, but in the vast majority of cases thrips do not reproduce in these plants. The second group of hosts might be called proper hosts; these plants offer food, shelter, a reproductive substrate and alimentation for the immature thrips. Unfortunately, there is a controversy about whether the plants reported as hosts in the literature are proper hosts or alternate hosts, and if these alternate hosts should be defined as hosts or if they are just accidental relationships (Mound 2005). There are approximately 50 economically important pest species among 5,300 known species of thrips. Some thrips species are considered to be very host-specific. Those thrips species that are considered as crop pests are usually very prolific and non-host-specific. For example *Frankliniella occidentalis* (Pergande), the western flower thrips, is reported on more than 500 plant species within 50 families. However, it is necessary to remember there is controversy about reports of host plants (Moritz et al. 2004b).

Thrips are ideal for population dynamics studies. Their populations are large and are generally easy to sample. However, thrips sampling presents some challenges, such as the difficulty of finding dead thrips and the fact that big migrations go unnoticed most of the time, sometimes for unknown reasons. Some species are very common in one year and very rare in the next. To study their population dynamics, it is necessary to consider feeding and reproductive behavior, migration, short and long term effects of the environment, and the effect of management techniques in the field populations (Kirk 1997b).

Feeding behavior: The mouthparts of Thysanoptera are one of the identifying characters of this order. The mouthparts are located on the underside of the head and form a mouthcone. This structure is formed by a single mandible (characteristic of

Thysanoptera) and two maxillary stylets. In order to feed, thrips use their mandible to "punch" a hole in the external walls of the tissue that they are going to feed upon and then use the stylets to suck the liquids from inside these tissues (Kirk 1997a). In the past, feeding behavior of thrips was considered to be "rasping" or "gashing" and sucking. However, this observation has been re-evaluated and the feeding is considered to be the "piercing and sucking" type (Hunter and Ullman 1992).

Thrips in general, can feed on diverse plant tissues (leaves, flowers, fruits, pollen) and some fungal tissues such as spores and hyphae. Most of the attention has been focused on the feeding behavior of phytophagous species, thus this is the group of which we have broader knowledge of their preferences (Kirk 1995). The feeding behavior displayed by thrips is similar for all plant tissues. Once the thrips have landed on what seems to be an appropriate substrate on which to feed on they start the process of probing the tissue. They start using the legs and antennae, walking in circles or forming figure eights on the tissue. Once they find a spot that seems to be adequate, thrips use their mandible to probe and open a small hole in the cell wall. A small amount of liquid comes from this small puncture. Using their palps, thrips test the liquid for the correct nutrient compositions. If the tissues and nutrient composition are adequate, they use their mandible and head to punch a bigger hole in the tissue and start feeding. This causes nearby cells to collapse. If the damage occurs in the ovary in the flower these marks will become magnified during the fruit development and the scars will be very noticeable, reducing fruit quality (Kirk 1997a, Liburd and Arévalo 2006).

Pollen-feeding is another behavior that is common, principally among flower thrips. These thrips feed on individual pollen grains one by one. The time spent on each

pollen grain varies between 3 to 120 s depending on thrips species and instar, grain volume, and temperature (Kirk 1987). Thrips can ingest pollen from the anthers or the grains found around the flowers and leaves. The potential damage that flower thrips can have on pollen quantity depends upon the plant production of pollen and thrips populations present in the field as observed in Table 2- 2.

As observed in Table 2- 2 there is the potential that thrips may affect the availability of pollen for fertilization. However, thrips populations will need to be extremely high and the pollen production by the plant very low for this to occur. Based on calculations presented by Kirk (1987), one thrips could potentially destroy between 0.2-0.7% of the pollen in a flower per day, assuming that it fed exclusively on pollen. Furthermore, thrips might be responsible for the destruction of anthers or the destruction of pollen on stigmas, which would affect pollination. The damage caused by thrips on plant fertilization depends on many factors such as timing, amount of pollen produced by the plant, amount of pollen destroyed by thrips, effectiveness of pollinators, temperature, etc. (Kirk 1987). In addition to interfering with pollen availability and fertilization, thrips balance their diet by consuming other plant tissues (Kirk 1997a).

Because thrips are usually associated with plant pests, they have been overlooked as pollinators, and there are no studies about their efficiency. However, to determine the correlation between pollinators and flowers, a chart of "pollination syndromes" describes the characteristics of flowers that may attract certain types of pollinators (Kirk 1997a). Thrips pollination syndrome is called thripophily (Kirk 1988). Thrips flowers are described by Kirk (1997a) and Mondal et al. (1993) as "medium size, white to yellow, sweetly scented, with or without nectar, with compact floral structures or globose or

urceolate blossoms providing shelter, and with small to medium-sized pollen grains, possibly with nocturnal pollen presentation". This description is very close to blueberry plants, which have medium-sized white flowers with nectar, globose blossoms that provide good shelter for thrips. So blueberry flowers meet the criteria to be pollinated by thrips; however, more research is needed to determine the role thrips play in pollination.

It is difficult to determine the net effect of thrips on the flowers taking into consideration the benefits of pollination and the damage to floral structures. Several species of plants have been reported to be pollinated by thrips. *Peltophorum inerme* (Roxb.) Llanos, is pollinated by two species of thrips, *Thrips hawaiiensis* (Morgan) and *Haplothrips ceylonicus* Schmutz, in addition to various hymenopteran species (Mondal et al. 1993). *Erica tetralix* L. is not only pollinated by *Taeniothrips ericae* (Haliday), but they have a close mutualistic relationship. Flowers of *E. tetralix* offer protection to thrips from the environment and a place to reproduce, the insect offers the plant self and cross pollination (Hagerup and Hagerup 1953).

Another feeding behavior shown by thrips is predation. There are a few specialist predators among thrips that have some behavioral adaptations such as speed or color among others. Among the specialists the most common prey are mite motiles and eggs. Some of the most common species of predatory thrips are *Haplothrips kurdjumovi* Karny, which feed on moth and mite eggs (Putnam 1942), *Scolothrips sexamaculatus* (Pergande), which feed on mites that form webs (Trichilo and Leigh 1986), and *Trichinothrips breviceps* Bagnall, which feed exclusively on psocids (Kirk 1997a). Some species of thrips feed upon other thrips larvae. Including *Aeolothrips intermedius* Bagnall, which feeds on thrips immatures through their abdomen (Kirk 1997a). Some of

the polyphagous thrips are well known as pests but they can switch their preferences and become predatory. For instance, *Frankliniella occidentalis* (Pergande) feed on mites in cotton (Trichilo and Leigh 1986) and prey on twospotted spider mites. *Thrips tabaci* (Lindeman) is considered to be a pest of vegetables susceptible to tospoviruses, but preys on twospotted spider mites in Australia (Wilson et al. 1996).

Reproductive behavior: Thrips in general have short life cycles. Many environmental factors can affect the reproduction rate and the length of their life cycle. One of the most important factors are host plants. Plant species and quality (age, vigor, phenological stage, etc.) affect the net reproductive rate (R_0) of thrips populations (Table 2- 3). Abiotic conditions affect the reproduction of thrips as well. These include light regimen, temperature, and humidity among others. Kirk (1997b) presents a summary of the effects of plant species and conditions that affect thrips reproductive behavior.

The effect of plant quality on thrips populations is very important. As observed in Table 2- 3, plant species influence the life history of some species. Some thrips have particular preferences towards the quality of the tissues used for oviposition. For example, *Taeniothrips inconsequens* (Uzel) will only lay its eggs on convex structures like veins in the leaves or stems (Teulon et al. 1994). Bates and Weiss (1991) showed that *Limothrips denticornis* Haliday only lay their eggs on the intervein space of barley leaves, limiting the oviposition to mature leaves. Furthermore, Chau et al. (2005) showed a close correlation between the populations of *F. occidentalis* and the level of nitrogen fertilization in chrysanthemum. The experiment reported an increase in the number of thrips correlated to the level of nitrogen used up to 100% of the recommended dosage for this crop.

Many intrinsic behaviors help us to understand the relationships among thrips from the same or from different species. The first one is the use of semiochemicals such as alarm pheromones, aggregation pheromones, defensive mechanisms, etc (Terry 1997). Kirk and Hamilton (2004) demonstrated the existence of some type of substance produced by males of *F. occidentalis* that has an attractive effect on females of the same species. Unfortunately, identification of the compounds in the pheromones is still in progress, but the description of the behavior of females, virgin females and males in a Y-tube bioassay indicate that this might be a sex-pheromone. Milne et al. (2002) observed what seems to be some type of attraction pheromone produced by males for females from the same species, *Frankliniella schultzei* (Trybom), and a direct correlation between the number of females per male attracted and the number of males present. There is not yet evidence of sex-pheromones that work at long distances, but there is some indication of short-range attractants that might help thrips to locate their mates (Terry 1997).

Apparently due to the bias in the female: male ratio, males and females have exhibited different behaviors to locate each other. *Frankliniella occidentalis* males tend to aggregate on the external side of floral structures where the females might be attracted, probably by the substances described in Kirk and Hamilton (2004). Some females are attracted while others ignore the signals and move themselves towards the food sources inside the flowers. Because females do not need to mate to lay fertile eggs, mating behavior in this order of insects is complex and not completely understood; their behavior is very inconsistent and species specific, making it difficult to state generalizations about this topic (Terry 1997).

Unlike mating, oviposition behavior is more general and well-described at least for terebrantian species. These females raise the tip of the abdomen, test the tissues using the setae in the last abdominal segment, and insert the ovipositor into selected plant tissues. While in this position the saw-like ovipositor cuts a space for the egg in the tissue, which is pushed out by a contraction of the abdomen. Thrips prefer to lay their eggs in mature non-expanding tissues to avoid having the eggs crushed by the expanding cells (Terry 1997). Oviposition preferences depend on the species. Most species prefer to oviposit on leaves or on floral tissue. In citrus, *F. bispinosa* oviposit in the floral tissues, it has a preference for the pistil- calyx area followed by the petals and finally, filaments and anthers (Childers and Anchor 1991). In apples, *F. occidentalis* prefers to lay its eggs in blossoms of any age, although most adults are found in opened blossoms, the egg concentration is higher in petalless clusters mainly in the 'king bud' (Terry 1991). Other thrips species lay their eggs close to the inner veins of the leaves or in the fruits. The damage caused by these thrips due to oviposition depends on the place and plant stage selected for oviposition. Thrips that lay their eggs and feed in the commercial part of the plant, flower or fruits, are the ones that are considered as major threats to the agricultural industry independent of their role as virus vectors.

Thrips as Crop Pests

Monophagous thrips are rarely considered as pests. Only a few examples of this interaction are known: *Liothrips karnyi* Bagnall, which damages Asian piper, *L. adisi* Strassen, which feeds on Brazilian guarana trees, and *Sciothrips cardamomi* Ramakrishna a common pest of cardamom (Mound 2005). Most of the thrips that are considered as severe pests are polyphagous. Due to their high adaptability, they can feed on various resources and modify their larval stages, adapting to various temperature ranges, etc. Due

to their high plasticity, agricultural systems should not be looked at as if they were isolated islands (Altieri 1988). Thrips are notorious for moving their population to alternate hosts during the season when the main hosts are not very conducive. This is the case of flower thrips, which reproduce and feed in the flowers of our crops and then during the season when flowers are not present, they migrate to nearby crops and wild flowers to continue their cycle (Kirk 1997b).

Thrips as *Tospovirus* vectors

Tospoviruses are one of the most damaging groups of pathogens in agriculture. In recent decades, due to the increase in international trade, the spread of infected plants and vectors has increased worldwide. Thrips and viruses are probably two of the most difficult things to detect in the ports of entry. Thrips eggs inside the plant tissues as well as asymptomatic plants infected with the viruses are virtually impossible to detect (Lathman and Jones 1997). There are 16 species of viruses in the genus *Tospovirus*, family: Bunyaviridae, recognized as plant pests, and they are transmitted by 11 species of thrips, of the family Thripidae. However, the list of viruses and vectors changes due to the complicated genetics of the virus and the discovery of new relationships with various thrips species (Ullman 2005).

Thrips acquire viruses in the first or early second instar when there is a close relationship between mid-gut, visceral muscles and salivary glands. Once the wing muscles start developing and the supra-oesophageal ganglion moves towards the head the connection between the salivary glands, the mid-gut, and the visceral muscles is ended stopping the movement of virus particles into the salivary glands. If the thrips did not acquire the virus during this short period, it will not be able acquire the virus due to the lack of connection between the salivary glands and the mid-gut. In adult thrips the virus

is located in the malpighian tubes, in the lumen, the hemocoel, and in the salivary glands. Until recently, the only proven way thrips transmit the virus is through the salivary glands during feeding. However, there is enough evidence to support the possibility that the virus might be transmitted through excrements and oviposition wounds, but more research is needed (Moritz et al. 2004a).

Thrips in blueberries

To study the relationship between thrips and blueberries we can divide thrips into three groups, which is a very broad division found in the literature: leaf thrips, flower thrips, and flower and leaf thrips (Kirk 1997a, Liburd and Arévalo 2006).

Leaf thrips: *Frankliniella vaccinii* Morgan and *Catinathrips kainos* O'Neill are the two main leaf pests of blueberries in northeastern U.S. They feed on the leaves right after pruning and their larvae are found feeding inside curled leaves, which prevent them from developing properly. In Maine, these thrips are found during the summer from late July to early August after the pruning. After the damage is done, the larvae mature and the adult thrips migrate to other hosts disappearing until next season (Collins et al. 1995).

Flower thrips: Unfortunately, the relationship between flower thrips and blueberries is not well known. In an interview conducted by Finn (2003), growers of early-season blueberries considered flower thrips as one of the most important pests of his crop along with blueberry gall midge and blueberry maggot. The USDA reported in (1999) that 40% of the losses in blueberries in Georgia were attributed to flower thrips. Thrips populations are known to rapidly move into blueberry fields with the help of wind currents and workers. Their life cycles are extremely short, taking between 15 and 20 days if environmental conditions are conducive for their growth and development. The short life cycles as well as overlapping generations during the blueberry flowering cycle,

make this insect a dangerous pest that can reach economically damaging levels in a very short period. The reduced amount of knowledge and the importance of this pest for blueberry growers is the main reason to develop an Integrated Pest Management (IPM) program to control the populations of thrips. The results shown in this dissertation are the beginning of this IPM program answering some of the basic questions about the relationship between blueberries and flower thrips.

Thrips control

Due to their behavior, quick reproduction rate, and potential to inflict great damage even at low populations (in the case of virus vectors), there are 236 products registered to control thrips in the U.S. listed by Crop Data Management Systems Inc. (CDMS) (Marysville, CA). In blueberries there are 24 insecticides labeled to control thrips, but only 8 active ingredients(CDMS 2006). Due to high pressure of these insects, growers have a high dependence on chemical control for fast management of the pest.

Thrips resistance to tartar emeric insecticides was detected as early as 1941. However, the typical example of thrips resistance is described by Morse and Brawner (1986). They described how in four years thrips became resistant to DDT and dieldrin, 18 years to dimethoate, seven years to be resistant to malathion. Other tests in the same species showed how *Scirtothrips citri* (Moulton) increased its resistance by 428-fold to fluvalinate after only 10 selections, at the same time that the resistance to other pyrethroids increased by 10 or more (Morse and Brawner 1986).

Today there is a greater adoption of Integrated Pest Management (IPM) initiatives to control thrips. The IPM approach is based on five techniques: host plant resistance, chemical control, mechanical control, cultural control, and biological control (Parrella and Lewis 1997). The only type of plant resistance that has been achieved is resistance to

certain tospoviruses vectored by thrips, which considerably reduces their damage (Ullman 2005). In the case of direct resistance to the insect most of the work is being conducted in non-preference changes in morphological characteristics such as form of the leaf or even color of the product (Parrella and Lewis 1997). Various forms of mechanical control have being tested to control thrips; the most evaluated ones are mechanical barriers such a screens in greenhouses and filtration systems, and the use of UV reflective mulches. Barriers in the field have proven to be not economically viable. Yudin et al. (1991) used 1.5 m tall plastic barriers around the crop. The results showed that the barriers only reduced the movement of *F. occidentalis* by 10% while they had no effect on the intra-crop movement of the insects. The use of reflective mulch to reduce the population of thrips in field crops has proven to be effective. However, the reduction was only evident when sticky traps were used in the study (Scott et al. 1989, Kring and Schuster 1992). When the number of thrips in the flowers was counted by Kring and Schuster (1992), they found no differences between the treatments.

Biological control of thrips is very successful in closed environments such as greenhouses. However, in field crops the use of biocontrol agents has not been very successful (Parrella and Lewis 1997). Hoy and Glenister (1991) tried to control *T. tabaci* by inoculating and inundating the field with *Amblyseius* spp. but it failed to show positive results. The reason why biological control is not effective in the field might be due to the fact that thrips populations move very fast and in large numbers. Also, thrips might cause significant damage before the beneficial organisms have time to react and achieve the appropriate control (Parrella and Lewis 1997)

Reduced-risk insecticides

The concept of reduced-risk insecticides was introduced by the Environmental Protection Agency (EPA)'s Office of Pesticide Programs (OPP) in July 1992. In this public notice there are incentives for the development and registration of new chemistries that comply with the following characteristics to be registered as reduced-risk insecticides (Environmental Protection Agency (EPA) 1997).

Human health effects

- Very low mammalian toxicity
- Between 10 to 100 times less toxic than alternatives
- Displace chemistries with known lethal effects on human health such as organophosphates
- Reduce exposure to workers

Non-target organisms

- Very low toxicity to birds, fish, honey bees, and other beneficial insects, and non-target organisms in general (calculated as direct toxicity of degree of exposure)
- Highly selective to target pests

Groundwater (GW)

- Low potential for GW contamination
- Low drift and runoff

Lower use rates than the alternatives

Low pest resistance potential

Highly compatible with IPM

Effective to control target pests

Currently there are approximately 60 new chemistries that are considered as reduced-risk insecticides, or biopesticides as described by the Food Quality Protection Act of 1996 (United States Congress (104th) 1996, IR 4 project 2006). Nine of these chemistries are registered or pending registration for use in blueberries, its chemistry and

status is summarized in Table 2- 5 as well as four Organophosphate (OP) alternatives that can be used to reduced the effect of OPs in the enviroment.

Reduced-risk insecticides are considered a fundamental part of IPM programs independent of the commodity in question (Environmental Protection Agency (EPA) 1997, Atanassov et al. 2002, Environmental Protection Agency (EPA) 2003, Finn 2003, Hamill et al. 2003, Liburd and Finn 2003, Liburd et al. 2003, Mizell 2003, Liburd and Arévalo 2005, IR 4 project 2006).

Economic Injury Levels (EIL)

Economic Injury Level (EIL) is one of the most discussed topics in entomology. The reason for this is that the EIL gives us the most basic information needed for a successful IPM program. "How many insects will cause significant damage?" The answer to this question is usually the starting point for decision making in a commercial crop (Pedigo et al. 1986). Stern et al. (1959) developed the first concepts of economic damage, EIL, and the majority of these have not changed since then (Pedigo et al. 1986). In entomology, Stern et al. (1959) defined the EIL as "The lowest population density that will cause economic damage." This concept assumes the possibility of scouting, evaluation and use of control tactics as needed. For this reason, it is very practical in the case of arthropod pests since this is the root of IPM programs. Several authors have criticized the simplicity of the EIL, arguing the lack of a more comprehensive view of the farm as a system. Variation on commodity prices, interaction with other arthropods and climate conditions made some EILs stationary, obsolete, and only valid for one season (Poston et al. 1983, Pedigo et al. 1986). Despite these critiques, EIL is the most used method of decision-making for arthropod pests. That new authors include their ideas and

suggestions to improve it, makes the EIL a dynamic concept (Pedigo et al. 1986, Pedigo 2003).

I would like to define some of the concepts as used in this dissertation. Some authors have determined EIL as a level of injury (Shelton et al. 1982), but in most of the cases standardization of the injury is difficult to determine in such a way that might be practical for growers. Pedigo et al. (1986) uses the term "injury equivalent" to determine the injury level caused by one pest through its life cycle and the term "equivalence" as the total injury equivalents inflicted by a population at a given moment. The term EIL in this dissertation will correspond to the insect density causing economic damage as defined by Pedigo (2003) and described in Equation 2-1. In this case (C) is the cost of management per production unit, (V) is the market value per production unit, (I) defines the injury unit per pest, (D) is the damage per injury unit and (K) is the proportional reduction in pest attack originated by the control.

Another important value complementary to the EIL at the moment of taking decisions is the gain threshold (GT). To define GT it is necessary to understand the concept of economic damage (ED), which refers to the equilibrium point where the cost of controlling the pest is equal to the damage caused by the pest, it is determined as monetary value and it is described in terms of ($C_{(a)}$), the cost of the control, (Y), yield, (P) price per unit of yield, (s) level of pest injury, and (a) control action (Equation 2-1 (a)). Stone and Pedigo (1972) defined GT in function of the same terms that Stern et al. (1959) had defined as ED, but the GT is described in terms of loss of marketable product per cultivated unit (Equation2-1 (b)).

(a) $$C_{(a)} = Y[s_{(a)}] \times P[s_{(a)}] - Y_{(s)} \times P_{(s)}$$

(b) $$GT = \frac{C_a}{P[S_{(a)}]}$$

Equation 2-1:

Some producers might use this number as indicator to make decisions. However, it is too risky to take actions when the pest has reached the EIL or the GT, because by the time that the control practices are in place the pest might have reached the point where the cost of controlling is higher than the value of the crop and it would not be economically wise to take any actions. For this reason the concept of economic threshold (ET) was included. Economic threshold is defined as the practical or operational pest density when control must be taken in order to keep the crop as a profitable business. The ET includes variables such as EIL, pest and host phenology, population growth rates (variable depending on the conditions for each farm), and interaction with other organisms or chemicals applied for other purposes. Due to the practical and mathematical complexity of calculating this ET, most ET are "*relatively crude*" as expressed in Pedigo (2003).

There are some limitations to the concept of EIL expressed by Pedigo (2003). Some of the limitations mentioned are:

1. Lack of mathematical definition for ET
2. Lack of more comprehensive EIL
3. Reduced ability of make cost-effective, accurate population analysis in the field
4. Inability to predict market, population trends and other variables for the ET
5. Difficulty to quantify variables such as weather, environmental cost etc.

However, despite these limitations, this concept it is still the best tool at present for growers to decide pest management strategies. Some of the values used by the growers are empirical due to the lack of research in some of the commodities.

The relationship between blueberries and flower thrips is still unexplored. There is a lot of knowledge about these two species generated throughout years of research. Our objective is to use all this information to guide our research and understand the relationship between flower thrips and blueberries. The following dissertation is an attempt to generate and compile information regarding this relationship. The ultimate goal is to develop an IPM program for early-season blueberries in Florida and Southern Georgia.

Tables and Figures

Table 2- 1: List of diseases reported in blueberries in the United States.

Type	Agent	Distribution	Symptoms	Transmission	Management
Fungi	*Phomopsis vaccinii*	Southeastern U.S.	– Phomosis canker – Dieback of fruit bearing stems – Yield reduction up to 70% – Rotting of fruits	Spores are released from infected case that overwintered in the field	Remove infected and suspicious branches during winter pruning
	Botryosphaeria dothidea	Southeastern U.S. 1-2 year old bushes	– Blueberry stem blight – Blight of individual branches – Brown r red branches "flags"	Spores are released from infected stems (blueberry and alternate hosts) and need an injury in the stem to be able to penetrate	Timely pruning of infected branches far from the start if the symptom. Resistant varieties are available
	Botryosphaeria corticis	Southeastern U.S. (NJ, GA, FL, AL, MS)	– Stem Canker – Swelling at the point of infection – Spore-producing structures emerge through the bark	Spores are released during the wet season and are wind transported. Only young stems are susceptible	Sanitation, avoidance and the use of resistant cultivars
Viruses and Phytoplasmas	*Blueberry scorch carlavirus*	Northern coastal states in the U.S.	– Scorch – Rapid necrosis of leaves and flowers – Small Chlorosis of the leaves and stems	Vectored by aphids	Infected bushes should be removed, burned and replaced with tolerant cultivars

Table 2-1 continued

Type	Agent	Distribution	Symptoms	Transmission	Management
Viruses and Phytoplasmas	*Blueberry shock ilarvirus*	Western U.S.	– Shock – Sudden necrosis of flowers and leafs – A second vegetative flush is present but no flowers produced – In well-managed fields close to normal production is possible 1 to 4 years after infection	It is vectored by pollinators carrying infected pollen	Infected bushes should be destroyed before bloom
	Blueberry shoestring	Northeastern U.S.	– Shoestring – Symptoms appear 4 years after infection – Reddish lines in the stems – Leaves become red and deformed – Ripe fruits are red	It is transmitted by the blueberry aphid, *Illinoia pepperi* MacGillivray	Use of resistant cultivars, use of virus free plantings, control of the vector to reduce spread of the virus
	Tobacco ringspot virus		– Necrotic ringspot – Leaves have 2-3 mm necrotic spots, the center of the injury may fall off	Vectored by the dagger nematode *Xiphinema americanum* Cobb	Avoid the nematode, fumigate in case the vector-nematode is present and use of virus free plantings

Table 2-1 continued

Type	Agent	Distribution	Symptoms	Transmission	Management
Viruses and Phytoplasmas	*Blueberry stunt phytoplasma*	Midwestern and eastern U.S.	– Stunt – Short bushy canes – Leaves with yellowing in the margins – Reduced internodal distance	Vectored by leafhoppers	Eradication and destruction of the infected plants
Bacteria	*Agrobacterium tumefaciens*	Cosmopolitan	– Crown gall – Potted plants and new plantings present galls in the roots up to 2.5 cm in diameter	It is a soil-borne bacterium. Enters through wounds and cuts on the roots	Avoid planting material with obvious galls. If site is infested plant non-host materials for 3 to 4 years before planting blueberries
	Pseudomonas syringae	Pacific northwest U.S.	– Bacterial canker – Die back of young branches	The bacterium penetrates through wounds caused by insects, wind, or manual labor	Cut infected canes in late fall during the dry season and sterilize the equipment used with bleach

* Modified from (2006)

Table 2- 2. Number of pollen grains per flower for four plant species, and the extrapolated percentage of the grains that could be eaten by five or 100 thrips per flower in three days (95% confidence limits).*

Plant species	Grains per flower	Extrapolated consumption	
		5 thrips / 3 days	100 thrips/3 days
Echium plantagineum	156,600	7.6% (4-11)	152% (77-227)
Actinidia deliciosa	2,000,000	0.5% (0.2-0.7)	9% (5-14%)
Brassica napus	140,000	3.2% (2-4)	64% (47-80)
Jacaranda acutifolia	13,400	3.2% (2-5)	64% (35-94)

* From Table 2 in Kirk (1987).

Table 2- 3: Some estimates of population parameters of pest thrips*

Thrips species / Crop	Temperature °C	L:D	R_0	r_m day $^{-1}$	T days	r_c day^{-1}	Tc days
Frankliniella fusca							
Peanut	20	14:10	5.07			0.05	31.2
Peanut	30	14:10	16.0			0.16	17.5
Peanut	35	14:10	1.67			0.04	13.2
F. occidentalis							
Bean	23	04:20	3.7	0.062	21.2		
Bean	23	16:08	12.2	0.140	17.9		
Chrysanthemum	15		42.2	0.056	66.5		
Chrysanthemum	35		2.7	0.056	17.6		
Cotton – pollen	27	14:10	30.1	0.157	21.6		
Cotton + pollen	27	14:10	111.8	0.220	23.4		
Peanut	20	14:10	1.1			0.02	19.7
Peanut	30	14:10	2.3			0.02	15.6

R_0 is the net reproductive rate; r_m is the intrinsic rate of natural increase; T is the mean generation time; r_c is the capacity for increase; and T_c is the cohort generation time; L:D is hours of light and dark per day. Note that r_c and T_c are approximations of r_m and T.
* Modified from table 7.1 in Kirk (1997b)

Table 2- 4: Known tospoviruses and thrips vectors in the world *

Virus	Thrips vector
Tomato Spotted Wilt Virus	*Frankliniella bispinosa* *F. fusca* *F. intosa* *F. occidentalis* *F. schultzei* *Thrips setosus* *T. tabaci*
Impatiens Necrotic Spot	*F. occidentalis* *F. schultzei* *F. intosa*
Zucchini Lethal Chlorosis	*F. zucchini*
Watermelon Bud Necrosis	*T. palmi*
Watermelon Silver Mottle	*T. palmi*
Melon Yellow Spot	*T. palmi*
Capsicum Chlorosis	*Ceratothrips claratis*
Groundnut Ringspot	*F. occidentalis* *F. schultzei* *F. intosa*
Tomato Chlorotic Spot	*F. intosa* *F. occidentalis* *F. schultzei*
Peanut Chlorotic Fan-spot	*Scirtothrips dorsalis*
Groundnut Bud Necrosis	*S. dorsalis*
Peanut Yellow Spot	*S. dorsalis*
Iris Yellow Spot	*T. tabaci*
Chrysanthemum Stem Necrosis	*F. occidentalis* *F. schultzei*
Physalis Severe Mottle	Not described

* Table modified from Naidu et al. (2005) and Ullman (2005).

Table 2- 5: Reduced-risk, biopesticides and OP alternative insecticides registered or pending registration for use in blueberries*.

Chemical name	Trade name	Chemistry	Status	Classification
Acetamiprid	Assail 70 WP Adjust	Chloronicotinyl	Pending	Reduced-risk
Azadirachtin	Neemix Niblecidine	Extract from neem oil	Registered	Biopesticide
Bacillus thuringensis	Dipel	Bacteria	Registered	Biopesticide
Cinnamaldehyde	Cinnacure Cinnamite	Natural product	Registered	Biopesticide
Flonicamid [1]	Carbine 50 WG Beleaf	Nicotinamide	Potential	OP alternative
Imidacloprid	Admire Provado Gaucho I	Chloronicotinyl	Registered	OP alternative
Indoxacarb	Avaunt Steward	Oxadiazine	Pending	Reduced-risk OP alternative
Metaflumizone	BAS 320 I	Semicarbazone	Potential	Reduced-risk
Methoxyfenozide	Intrepid Runner	Diacylhydrazine	Pending	Reduced-risk OP alternative
Novaluron [1]	Diamond Rimon	Benzoylphenyl	Pending	Reduced-risk OP alternative
Spinosad [1]	Success Spintor Entrust	Macrocyclic lactone	Registered	Reduced-risk OP alternative
Thiamethoxam [1]	Actara Platinum Centric Cruiser Helix	Second generation Neonicotinoid	Registered	OP alternative
Zeta-cypermethrin [1]	Mustang Mustang Maxx	Pyrethroid	Pending	OP alternative

* Table Modified from IR 4 Project (2006)

[1] Indicates chemistries registered or that have the potential to control thrips

CHAPTER 3
SAMPLING TECHNIQUES AND DISPERSION OF FLOWER THRIPS IN BLUEBERRY FIELDS

Blueberries are one of the fastest growing crops in Florida. Due to climatic conditions and the early-season varieties produced, Florida and most of southern Georgia blueberries mature during April and May, making these two states the principal producers in the world during this time. This window of production gives the growers a price advantage of 3 to 5 USD per pound compared to regular season blueberries produced between the end of May and August (NASS-USDA 2006a).

Thrips have been identified by blueberry growers as insect pests that require immediate management (Finn 2003). Twenty five percent of blueberry growers from southern Georgia and Florida identified flower thrips as one of their main problems surpassed only by blueberry bud mite, *Acalitus vaccinii* (Keifer). Other major pests of concern for the growers include cranberry fruitworm, *Acrobasis vaccinii* Riley, and blueberry gall midge, *Dasineura oxycoccana* (Johnson) (Finn 2003). For these reasons the Small Fruit and Vegetable IPM Laboratory at the University of Florida started a project to understand the relationship between blueberries and flower-thrips as an initial step to develop an IPM program for thrips in early-season blueberries. Finn (2003) initiated preliminary work in sampling techniques for flower thrips in blueberries. As a common practice, flower thrips have been monitored by using sticky traps of various colors. The two colors most commonly used are yellow and blue (Diraviam and Uthamasamy 1992, Cho et al. 1995, Hoddle et al. 2002, Finn 2003). Finn (2003) found

non significant differences between the numbers of thrips captured in yellow, blue, or white sticky cards in blueberry plantings. Due to the contrast between the thrips and the white background on the sticky cards, I decided to use white sticky cards for monitoring populations in my experiments. Because there is little information about the relationship between flower thrips and blueberries, I must determine some of the basic characteristics of this relationship. One of the basic characteristics I are looking at is dispersion. Ordinarily there are three types of dispersion: random, uniform, and clumped. Distribution depends on the mobility of the insects. Highly mobile insects tend to have a more random distribution than insects with low mobility, which tend to form "hot-spots" in highly clumped populations (Flint and Gouveira 2001).

My objectives were to select an efficient and effective sampling method to monitor flower thrips inside blueberry flowers, and to determine the vertical and horizontal distribution of thrips populations in blueberry plantings. My final goal was to characterize thrips populations depending on their level of aggregation in blueberry fields.

Materials and Methods

To address my objectives, I have conducted a series of experiments on private blueberry farms in Florida and southern Georgia.

Methodology to Determine Thrips Population Inside Blueberry Flowers

Due to the high volume of flower samples, a more efficient system to determine the number of thrips inside the flowers was developed by combining procedures from various researchers (Finn 2003, Funderburk and Stavisky 2004). Flower clusters were collected using Corning 50 ml plastic tubes (Fisher Scientific, Pittsburg, PA). Flowers were collected in the field by cutting the pedicels using the rim of the vial and allowing them

drop inside the plastic tubes containing 70% ethanol. Each vial was manually shaken for approximately one minute. The contents were emptied into a 300 ml white polyethylene jar (B & A Products, Ltd. Co., Bunch, OK) and filtered through a plastic screen with 6.3 x 6.3 mm openings to ensure that thrips pass through, leaving the flowers on the screen. The remains left on the screen were rinsed with water from a polyethylene wash bottle into a white container. The flowers left on the screen were placed in a 300 ml white polyethylene jar while the corollas and the calyxes of the flowers were manually separated. This procedure was repeated three times to ensure the collection of the maximum number of thrips. After each rinsing, the thrips found in the rinsing water were collected inside a white container and counted. This water was then transferred to another container with black background to ensure I collected the maximum number of thrips.

To determine the efficiency of this system, I decided to compare the results obtained with this method with standard flower dissection, which is the method commonly used in the laboratory to determine thrips populations inside flowers (Finn 2003). I selected 20 samples from the weeks that had the highest number of thrips. After following the 'shake and rinse' procedure, samples were dissected and observed under a microscope to determine how many thrips were missed. I then used a *t*-test to compare the total number of thrips collected using the shaking and rinsing procedure with the total number obtained by shaking and rinsing plus the number of thrips found under the microscope by dissecting the samples after this procedure (SAS Institute Inc. 2002).

Vertical Distribution of Flower Thrips in Blueberry Fields

To determine thrips distribution within blueberry bushes, I placed ten sampling stations in each of my two farms. The first was located on farm FL01 in south-central Florida (N 28° 04' W 81° 34'). This farm was planted with Southern highbush. A second

farm, Farm GA01, located in southern Georgia (N 31° 31' W 82° 27'), was planted with rabbiteye blueberries. Samples were taken during the 2004 and 2005 flowering seasons. To collect the samples I randomly established 10 sampling stations around the selected plot in each farm. Each sample station consisted of a blueberry bush where I took four samples: three white sticky traps (23 x 17 cm of effective area) (Great Lakes IPM Vestaburg, MI) and one flower sample. One of the traps was placed on the ground in an inverted V shape with the sticky surface towards the ground, a second trap was located inside the canopy approximately in the middle of the bush, and the third one was approximately 40 cm above the canopy. The number of thrips in the sticky traps was determined by counting the number of thrips in 16 out of the 63 squares (each square is 6.45 cm^2) that the trap is divided into (2003). Flower samples were taken from the same bush containing the sampling station and consisted of five flower clusters collected in Corning 50 ml plastic tubes filled with 70% ethanol. I cut the flowers using the thumb and the rim of the vial, thereby reducing the manipulation of the flowers. The flower samples were processed using the shake and rinse method described above and the total number of thrips was recorded. The sampling stations were randomly placed in the field each week by using random number tables based on the number of rows and the number of plants in each row. The data were collected from bloom to petal-fall 2004 and 2005.

Data were analyzed using the repeated measures analysis (SAS Institute Inc. 2002). I decided not to use the soil traps in Georgia since the results in Florida showed that the number of thrips captured was too low for analysis. On average, 0.66 ± 0.3 thrips per trap per week in 2004 and 0.38 ± 0.1 thrips per trap per week in 2005 were collected in the soil samples. Data were transformed to comply with the assumptions of the analyses.

The data for 2004 and 2005 in Florida and 2005 in Georgia were transformed using the natural logarithm of the original data plus one; for 2004 in Georgia, the transformation used was the square root of the number of thrips captured.

Thrips Dispersion

We selected two fields in north central Florida, Farm FL02 (N 29° 40' W 82° 11') and Farm FL03 (N 29° 43' W 82° 08'). Both farms were planted with southern highbush blueberries during 2005. However, during 2004 FL02 was planted half on rabbiteye and half in southern highbush as indicated in Figure 3-3. Two grids one of 5 x 6 and the second one of 8 x 7 traps were respectively deployed in each one of the selected plots. The traps were spaced 30.48 m from each other, which covered blueberries and adjacent non-cultivated areas. These traps were replaced every other day starting from bloom initiation and finishing at petal fall. The total number of thrips trapped was recorded to monitor the movement of thrips into and out of blueberry fields for two flowering seasons. In 2004 sampling begun on March 3, while in 2005 it begun on February 20 at both locations.

To determine degree of aggregation I selected the standardized Morisita's coefficient of dispersion (Ip) (Smit-Gill 1975) and Green's coefficient of dispersion (Cx) (Green 1966), because they have low or no correlation with the mean (Myers 1978, Taylor 1984, Schexnayder Jr. et al. 2001). The aggregation indices were calculated for each day that the sticky traps were collected. I graphed the number of thrips captured in each trap using Sigma Plot (SYSTAT Software Inc. 2006). Once the "hot-spots" were graphically identified, I conducted a Gaussian regression to describe the population behavior in each one of the "hot-spots".

In this study populations were considered to be clumped if Green's index Cx > 0, random if Cx = 0, or uniform if Cx < 0 (Myers 1978, Schexnayder Jr. et al. 2001). In the case of standardized Morisita's index (Ip) populations were considered to be significantly clumped (α = 0.05) if Ip > 0.5, not significantly clumped if 0.5 > Ip > 0, random if Ip = 0, not-significantly uniform if 0 > Ip > -0.5, and significantly uniform if Ip < - 0.5 (Smit-Gill 1975). Overall comparisons were conducted by averaging all the indices calculated and comparing them to 0 for Cx, and 0.5 for Ip using a *t*-test (SAS Institute Inc. 2002).

$$Ip = \frac{q\sum_i^q [x_i(x_i - 1)]}{X(X-1)} \qquad Cx = \frac{\frac{s^2}{X} - 1}{(q-1)} \qquad \text{Equation 3- 1}$$

Results

Methodology to determine thrips population inside blueberry flowers

I found no significant differences between the dissecting (35.7 ± 4.3) and the shake and rinse (34.7 ± 4.3) methods (t = 0.17; df = 1, 38; P = 0.869), when comparing the number of thrips obtained with each method. These results allow us to use the shake and rinse procedure in the following experiments with confidence in the data collected.

Vertical Distribution of Flower Thrips

The thrips distribution within the bushes follows the same pattern independent of the year and the location. In Florida, there are no significant differences between 2004 and 2005 when the same positions within the bush were compared. For soil (t = 0.531; df = 1, 325; P = 0.595), for flowers (t = 1.474; df = 1, 325; P = 0.142), for the traps in the bushes (t = 0.308; df = 1, 325; P = 0.7582) and for the traps above the canopy (t = 0.438; df = 1, 325; P = 0.662). However, when comparing the treatments within each one of the

years, I found significant differences among the positions with respect to the bush (For 2004, $F = 291.13$; $df = 3, 157$; $P < 0.0001$, and for 2005 $F = 197.51$; $df = 3, 164$; $P < 0.0001$). In both years, the number of thrips captured was significantly higher within the canopy compared with all other positions evaluated. The second highest number of thrips captured was found in the traps deployed above the canopy, followed by the number of thrips inside the flowers, and finally by traps on top of the soil (Figure 3- 1).

Our results on farm GA01 in southern Georgia were different from the situation presented in Florida. As in Florida, I found no significant differences between the number of thrips captured in the flowers between 2004 and 2005 ($t = 0.682$; $df = 1, 144$; $P = 0.496$) in Georgia. However, I found that in 2004 I captured significantly more thrips within the canopy ($t = 7.345$; $df = 1, 144$; $P <0.0001$), and above the canopy ($t = 8.563$; $df = 1, 144$; $P < 0.0001$) than in 2005. When comparing the number of thrips captured at the various positions, I found no significant differences between the number of thrips within the canopy and above the canopy during 2004. However, these values were both significantly higher than the number of thrips captured in the flowers sampled during the same year. In 2005, there was a reduction in the number of thrips captured on farm GA01 compared with 2004 (

Figure 3- 2). However, despite the reduced numbers, I found a significantly higher number of thrips captured in the canopy than above the canopy of the bushes. Both of which were significantly higher than the number of thrips captured in the flowers (

Figure 3- 2).

Thrips Dispersion

2004 farm FL02

Thrips aggregation increased over time and peaked 12 to 14 d after bloom initiation. This peak coincides with the highest population density of thrips 14.7 d after bloom initiation (Table 3- 1 and Figure 3- 5). Table 3- 1 shows that thrips population can be considered clumped from day 4 based on Cx. This observation is reinforced by Ip, which shows a significant level of aggregation from the beginning.

After recording a clumped-type distribution, I plotted thrips population and the coordinates where the traps were located to determine the position and number of "hot-spots" based on the locations presented in Figure 3- 3. During the 2004 field-season I found only one "hot-spot" located at the coordinate (4, 4) in Figure 3- 6. When analyzing this "hot-spot" during 2004, I found that the dynamics of thrips population could be described by a Gaussian non-linear regression (Equation 3-2 a.). The pattern for the "hot-spot" on farm FL02 in 2004 is described by the equation represented in Equation 3-2 b.

Overall Cx (0.467 ± 0.147) is significantly higher than 0 (t = 3.17; df = 8; P = 0.013), and Ip (0.521 ± 0.004) is significantly higher than 0.5 (t = 7.48; df = 8; P <0.0001), which shows a significant level of aggregation of the flower thrips on farm FL02 for 2004.

a.

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\left[-0.5\left(\frac{x-\mu}{\sigma}\right)^2\right]}$$

b.

$$y = 194.17e^{\left[-0.5\left(\frac{x-14.7}{2.6}\right)^2\right]}$$

Equation 3-2:

2004 farm FL03

The distribution of traps on farm FL03 is shown in Figure 3- 4. Thrips population for farm FL03 was considerably lower compared with farm FL02 during 2004. However, it appears that there are two main areas, identified using the graphic method, where thrips tended to aggregate. Two "hot-spots" were (Figure 3- 7). One "hot-spot" was located at coordinate (0, 4) and a second at coordinate (2, 2) of Figure 3- 7. The peak population for these "hot-spots" occurred on different days. For the spot found at (2, 2) the peak occurs at 11.3 d after bloom and for the "hot-spot" located at (0, 4), aggregation occurred 17 d after bloom (Figure 3- 8 and Equation 3-3).

a. b.

$$y = 5.32e^{\left[-0.5\left(\frac{x-11.3}{4.1}\right)\right]} \qquad y = 4.36e^{\left[-0.5\left(\frac{x-17}{2.4}\right)\right]}$$

Equation 3-3:

Green's index (Cx) and the standardized Morisita's index (Ip) showed a tendency towards a random distribution of thrips on farm FL03 in 2004. The overall Cx for farm FL03 (0.046 ± 0.041) was not significantly different from 0 ($t = 1.14$; $df = 6$; $P = 0.298$), and the Ip value (0.020 ± 0.006) was significantly higher than 0 ($t = 3.21$; $df = 6$; $P = 0.0184$) but still in the region $-0.5 < Ip < 0.5$. However, this aggregation appears not to be significant on farm FL03 in 2004. The distribution appears to be more aggregated for days 7 to 15, which again coincides with the peak of the population (Figure 3- 8).

2005 farm FL02

The same set up used in 2004 was used in 2005 to describe the dispersion of flower thrips in the field. During this year the farmer replaced the rabbiteye blueberries with a

new planting of southern highbush. Thrips population on farm FL02 was lower in 2005 than in 2004. During this year I found two "hot-spots" located at coordinates (2, 3) and (5, 2) in Figure 3- 9. The highest aggregation was between days 10 and 14, which again coincides with the days of maximum population (Table 3- 3 and Figure 3- 10). The "hot-spots" reached their maximum population at 13.8 d after bloom initiation for the coordinate (2, 3) and 12.1 d for coordinate (5, 2) (Figure 3- 10 and Equation 3- 4).

The overall indices show a highly significant aggregation for 2005. Green's index, Cx = 0.24 ± 0.06, was significantly greater than 0 (t = 3.87; df = 9; P = 0.0047), and the overall Standardized Morisita's index, Ip = 0.52 ± 0.01, was significantly greater than 0.5 (t = 4.94; df = 9; P = 0.0011).

a. $$y = 63.49e^{\left[-0.5\left(\frac{x-13.78}{3.44}\right)^2\right]}$$

b. $$y = 58e^{\left[-0.5\left(\frac{x-12.05}{2.67}\right)^2\right]}$$

Equation 3-4:

2005 farm FL03

Thrips population for this farm was too low to make a robust analysis. The highest number of insects captured in one trap was three thrips 15 d after bloom initiation. Most of the other traps captured no thrips, and the data were not considered significant.

Discussion

The literature has discussed several types of sampling methods for thrips inside flowers. Finn (2003) mentions the use of alcohol dipping, tapping the floral clusters on a white surface, and flower dissection as methods to determine the number of thrips inside the flowers. Finn's study showed no significant differences in the number of thrips

captured among the various methods for southern highbush blueberries. However, the Finn (2003) found that sampling by tapping the flowers in rabbiteye blueberries resulted in significantly fewer thrips captured than did other treatments. A large variation was observed probably due to the distribution of the thrips in blueberry fields. High aggregation and random sampling usually produces high variance in the results. Palumbo (2003) compared trapping at canopy level, plant beating, direct observations and whole plant washes. Whole plant washes (very similar to the shake and rinse method used in this study) were used as absolute samples. Palumbo (2003) found a significantly higher number of thrips in his absolute method when compared with the other methods used. The fact that I found no significant differences between the shake and rinse method and the dissection method, which is considered to be an absolute count of the thrips in the flowers (Hollingsworth et al. 2002), indicates that the shake and rinse method is appropriate to estimate thrips population inside the flowers. The shake and rinse method might be too time-consuming and not very useful for growers who need to determine the population rapidly and accurately, but it might be useful for research purposes, as it is as accurate and less time-consuming than flower dissections.

The vertical distribution of thrips remained the same independent of location and year. The highest number of thrips was consistently captured in or above the canopy of the blueberry bushes using sticky traps. However, the most damaging population is inside the flowers (Arevalo and Liburd unpublished data).

The average number of thrips captured varies from year to year. In 2005, thrips population was lower on farm FL01 located in Florida than the farm GA01 located in

Georgia. However, only in GA01 were the differences in the number of thrips captured between the years significant, having a lower population in 2005 than in 2004.

The analysis of the distribution based on Morisita's and Green's indices described the distribution of thrips in the field as aggregated. However, the level of aggregation seems to be lower in cases when peak populations are lower. For instance, on farm FL03 in 2004 (peak population = 5.3 thrips per trap) the average Cx (0.046 ± 0.041) and average Ip (0.02 ± 0.006) were lower than for farm FL02 in 2005 (peak population = 63.49 thrips per trap) Cx (0.24 ± 0.06) and Ip (0.52 ± 0.01) and lower than Farm FL02 (Peak population = 194.1 thrips per trap), Cx (0.467 ± 0.147) and Ip (0.521 ± 0.004). In Figures 3-5 and 3-11, I observed that the "hot-spots" start forming between 7 and 10 days after bloom initiation and in both cases the population at these spots grew beyond 20 thrips per trap every two days. After this initial period, thrips population captured in the traps increased exponentially, reaching a maximum population between 12 and 15 days after bloom initiation. The population then declined at the same rate that it increased, virtually disappearing about 22 days after bloom started, after most of the flowers had become fruits.

Apparently, formation of "hot-spots" on blueberry farms is random. I did not find any correlation among the locations where "hot-spots" were formed between the years. However, several variables such as flower concentration, soil type, fertilization methods, and wind direction, might be studied to determine a correlation among these variables and "hot-spot" locations to create a predictive dispersion model of flower thrips on blueberry farms. For now, sampling methods that consider highly aggregated populations should be explored to reduce the variability of the data when sampling flower

thrips in blueberry farms (Southwood 1989, Wang and Shipp 2001). Despite that until now no sex pheromones have been isolated, some behavioral observations show the presence of a mating or an aggregation pheromone in thrips (Milne et al. 2002, Kirk and Hamilton 2004). Kirk and Hamilton (2004) showed how virgin females are attracted to the smell of males and not to the smell of other females. This situation was interpreted as the presence of some type of sex pheromone in *Frankliniella occidentalis* (Pergande). Milne at al. (2002) found a high correlation between the number of males in hibiscus flowers and the number of females landing on these flowers. Salguero-Navas et. al (1994) found indications of aggregation in tomato plants for virus thrips species including *F. occidentalis,* and *F. tritici.* However, differences in the degree of aggregation were also found between years in their experiment as it was also found in my trials. Thrips populations were demonstrated to be variable within the same region. For instance, farms FL02 and FL03 are 7.02 km from each other and the peak populations are significantly different, 194.2 for FL02 and 5.3 for farm FL03. However, there appears to be a correlation between the population dynamics and the year; in my observations, 2005 had a lower number of thrips captured than 2004 in all farms, and studies to determine the reasons for this pattern are needed.

Tables and Figures

Table 3- 1: Distribution indices, Green's index (Cx) and Standardized Morisita's index (Ip), used to describe the level of aggregation of thrips population on farm FL02 in Florida in 2004

Index	Days after blooming								
	2	4	6	8	10	12	14	18	22
Cx	-0.005	0.438	0.223	0.138	0.227	0.967	1.336	0.207	0.670
Ip	0.518	0.549	0.525	0.517	0.524	0.543	0.539	0.520	0.538

Table 3- 2: Distribution indices, Green's index (Cx) and Standardized Morisita's index (Ip), used to describe the level of aggregation of thrips population on farm FL03 in Florida in 2004.

Index	**Days after blooming**						
	2	4	6	8	14	16	19
Cx	-0.011	-0.065	-0.013	0.129	0.062	0.246	-0.021
Ip	0.041	0.042	0.024	0.013	0.006	0.014	-0.0002

Table 3- 3: Distribution indices, Green's index (Cx) and Standardized Morisita's index (Ip), used to describe the level of aggregation of thrips population on farm FL02 in Florida in 2005.

Index	**Days after blooming**								
	2	4	6	8	10	14	16	18	22
Cx	0.124	0.098	0.142	0.185	0.314	0.713	0.320	0.233	0.112
Ip	0.051	0.513	0.518	0.522	0.528	0.556	0.529	0.525	0.511

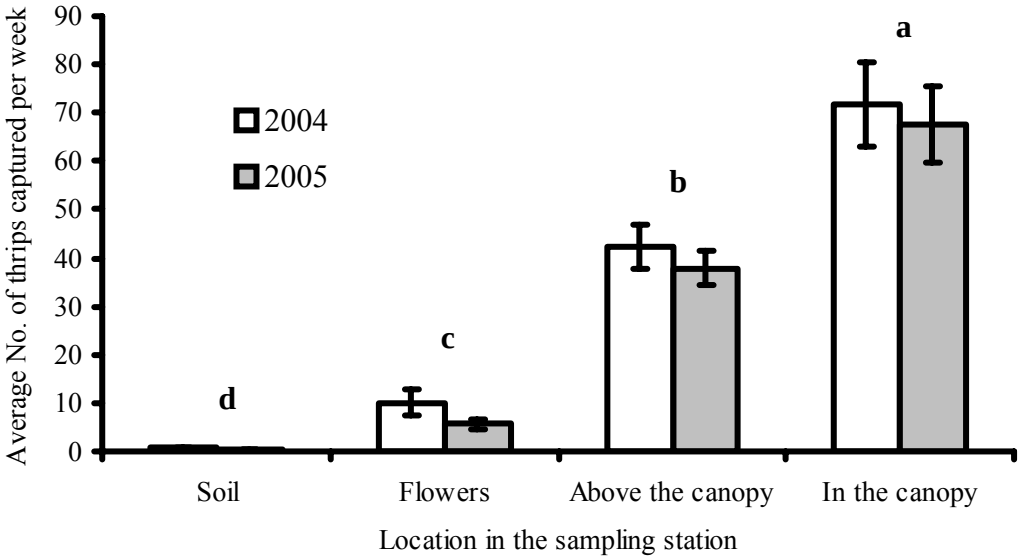


Figure 3- 1: Vertical distribution of thrips captured with respect to southern highbush blueberry bushes in south Florida. Different letters represent significant differences among the groups using LSD mean separation test, $\alpha = 0.05$.

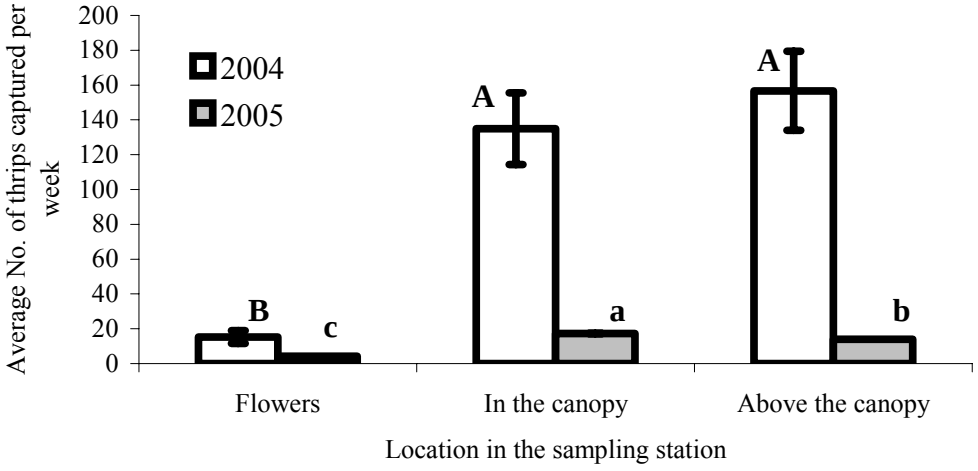


Figure 3- 2: Vertical distribution of thrips captured with respect to rabbiteye blueberry bushes in southern Georgia. Different letters in capitals represent significant differences among the groups in 2004, small letters represent significant differences among groups in 2005 using LSD mean separation test $\alpha = 0.05$.

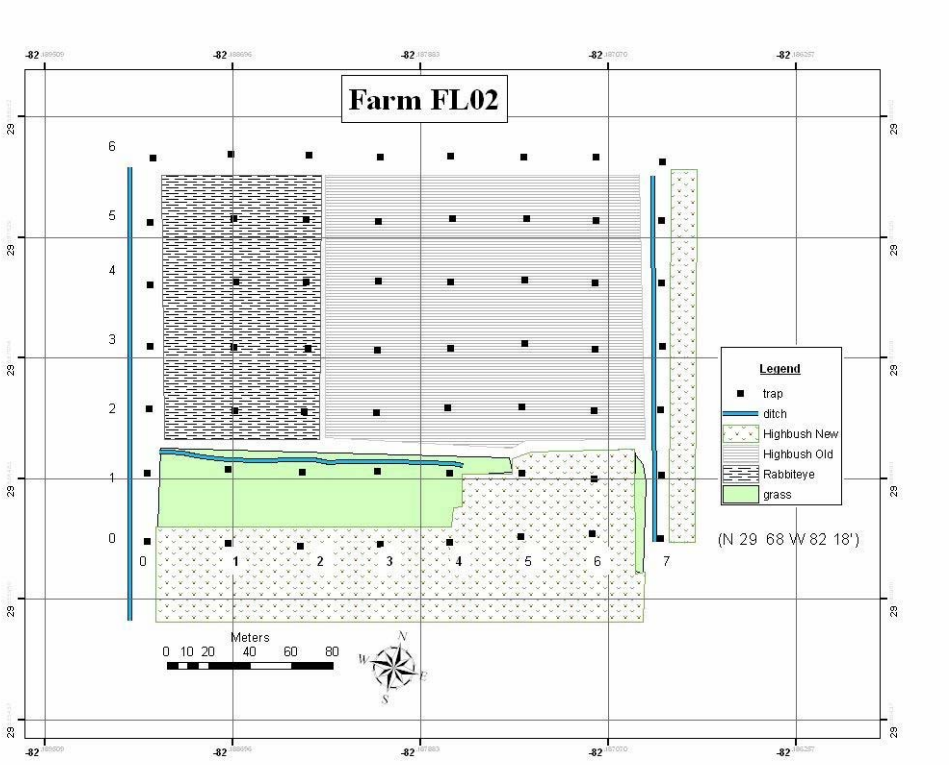


Figure 3- 3: Map of farm FL02 located at N 28º 04’ W 81º 34’ in north central Florida

Figure 3- 4: Map of farm FL03 located at N 28º 04’ W 81º 34’ in north central Florida

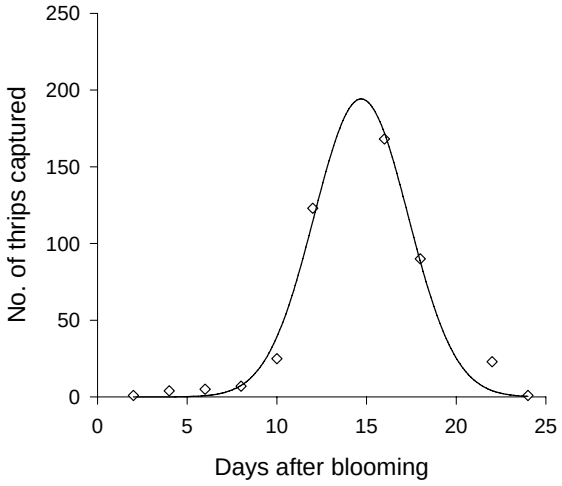


Figure 3- 5: Population dynamics inside the “hot-spot” in coordinates (4, 4) of Figure 3- 6 for 2004 on farm FL02.

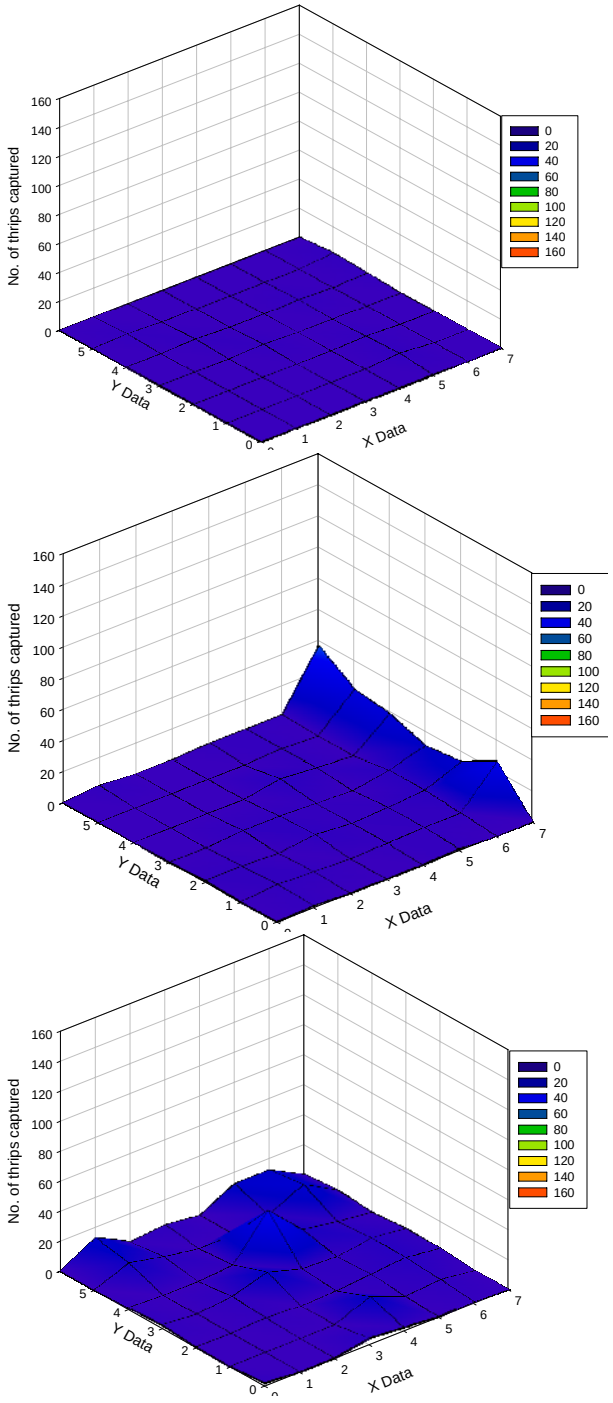
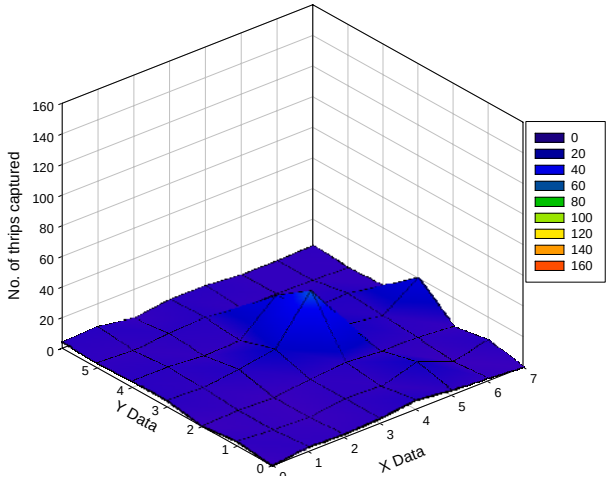
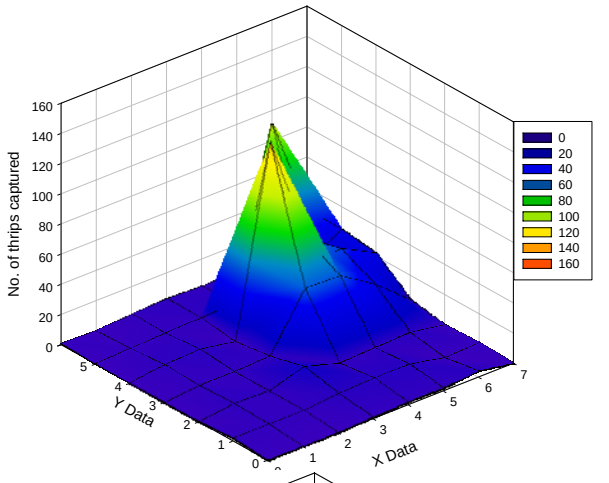


Figure 3- 6: Number of thrips captured at 2 (a), 6 (b), 8 (c), 10 (d), 14 (e), 16 (f), 18 (g), and 22 (h) days after bloom began on farm FL02.

d.



e.



f.

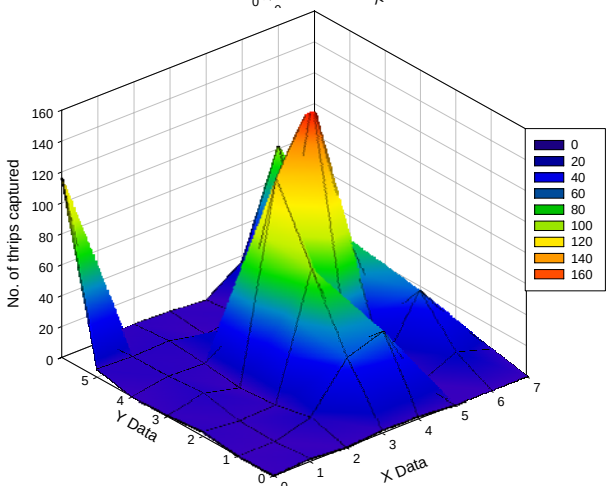
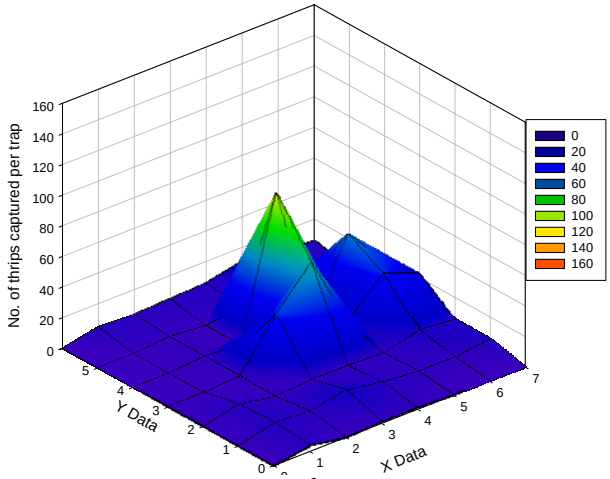


Figure 3-6: Continued

g.



h.

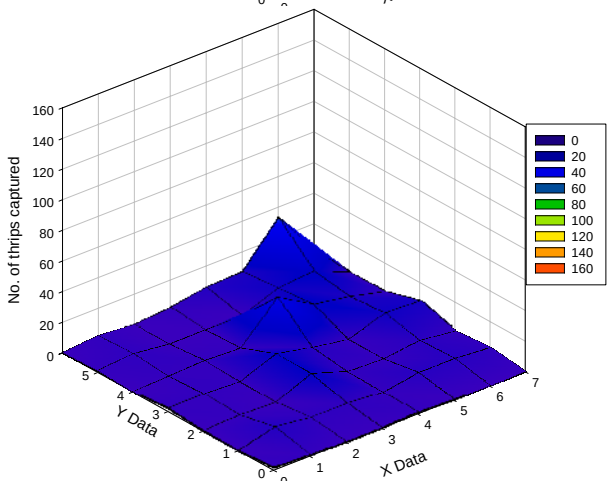
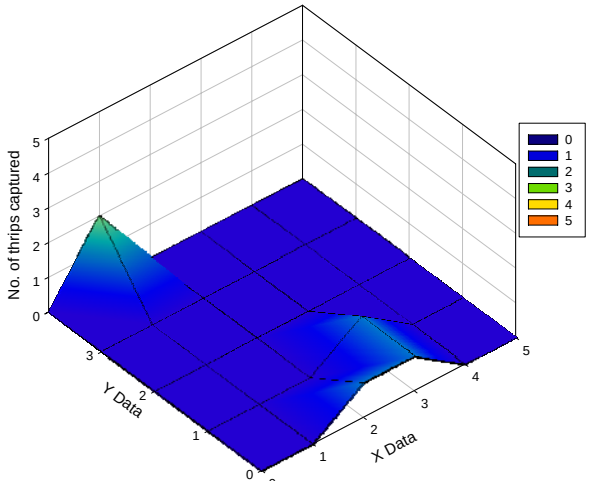
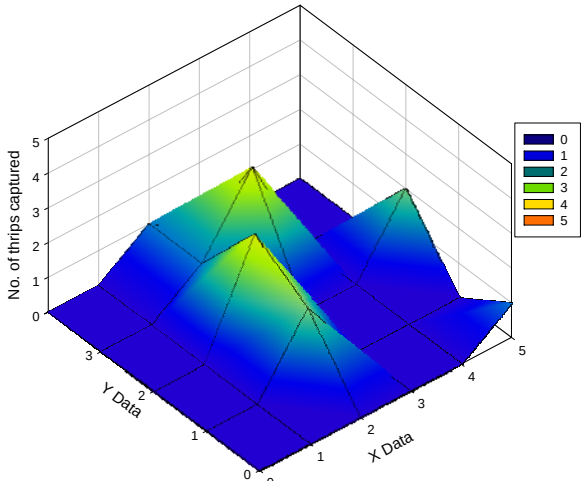


Figure 3-6: Continued

a.



b.



c.

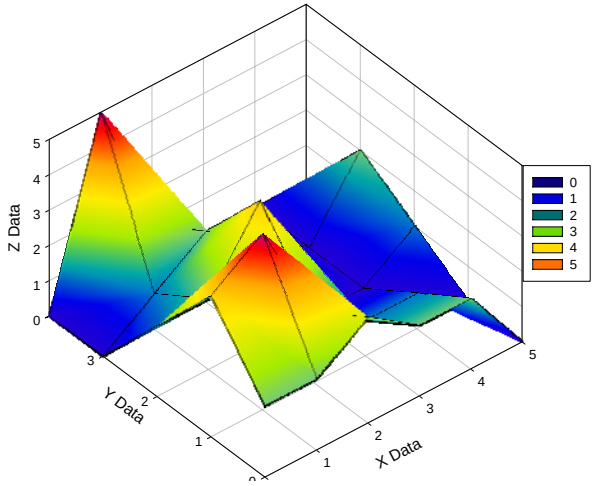
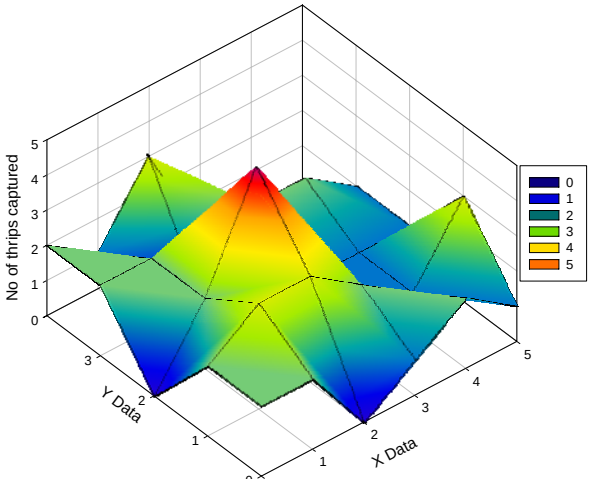
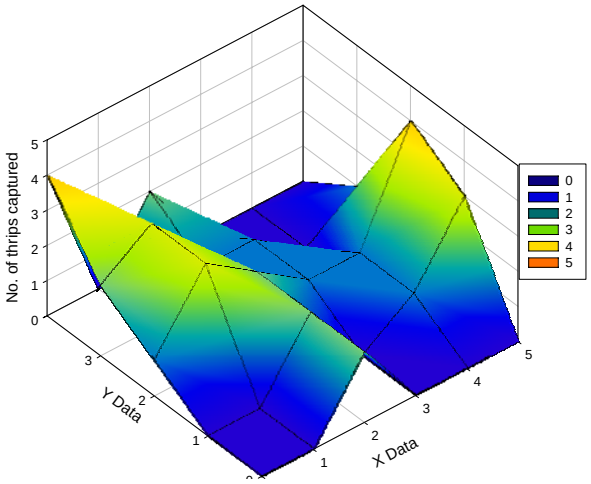


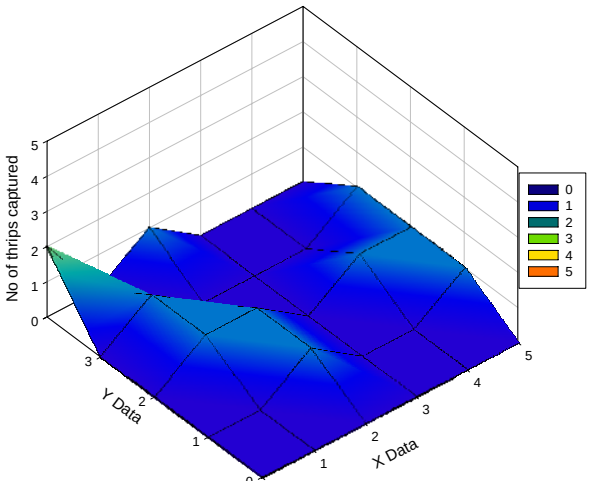
Figure 3- 7: Number of thrips captured on farm FL03 at 2 (a), 4 (b), 8 (c), 14 (d), 16 (e), and 20 (f), days after bloom in 2004



d.



e.



f.

Figure 3-7: Continued

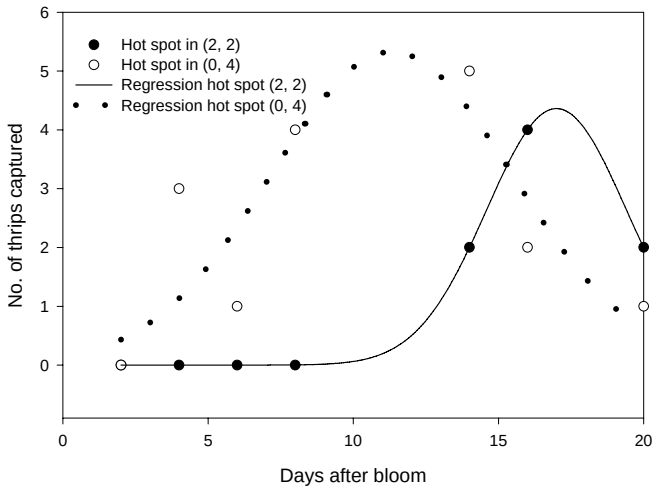
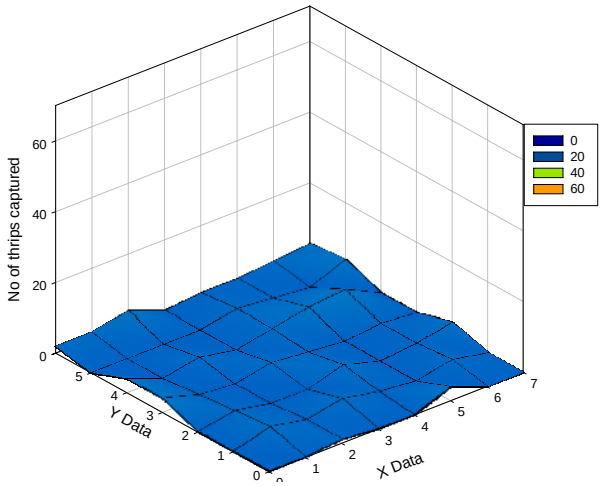
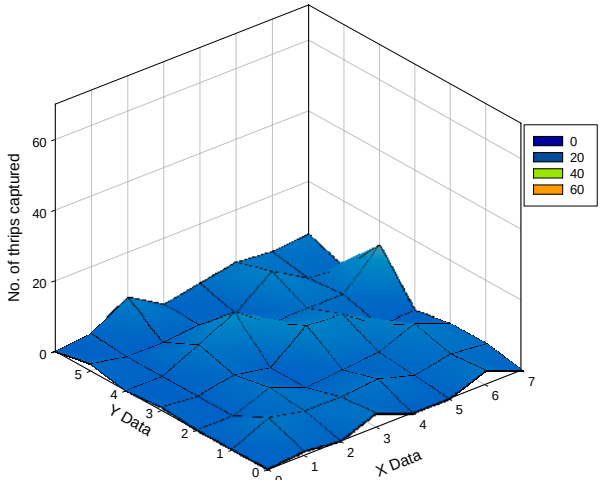


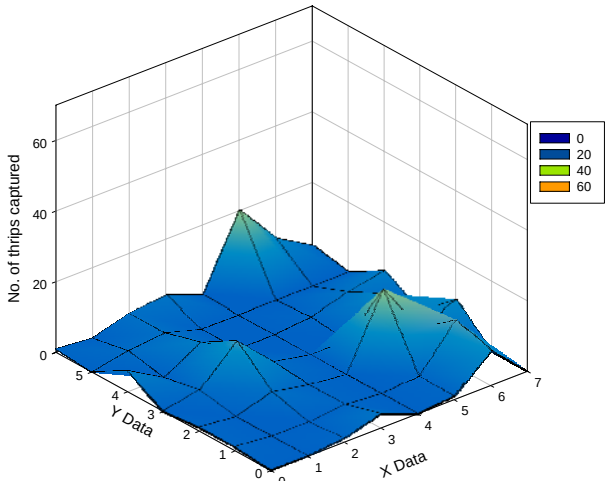
Figure 3- 8: Population dynamics inside the "hot-spots" in coordinates (2, 2), and (0, 4) of Figure 3- 7 in 2004 on the farm FL03 in Florida.



a.

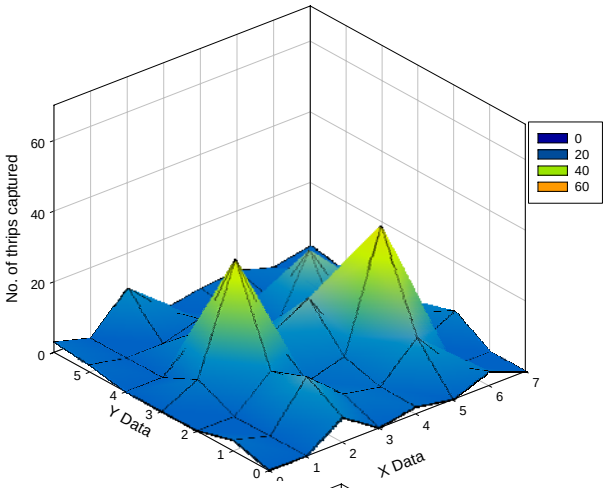


b.

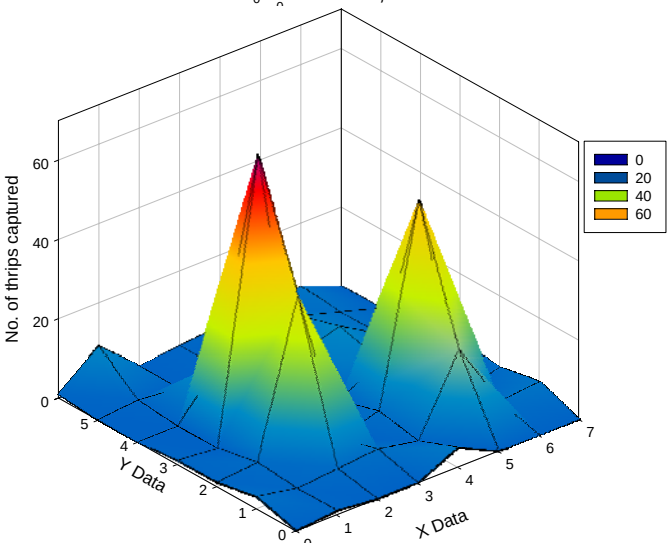


c.

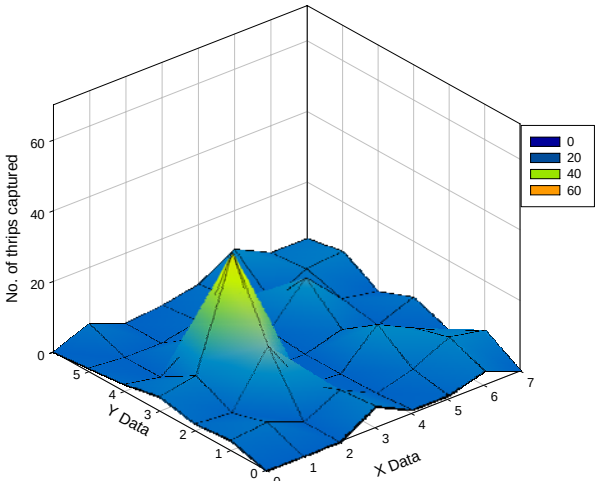
Figure 3- 9: Number of thrips captured on farm FL02 at 2 (a), 4 (b), 8 (c), 10 (d), 14 (e), 16 (f), 18 (g), and 22 (h) days after bloom in 2005.



d.

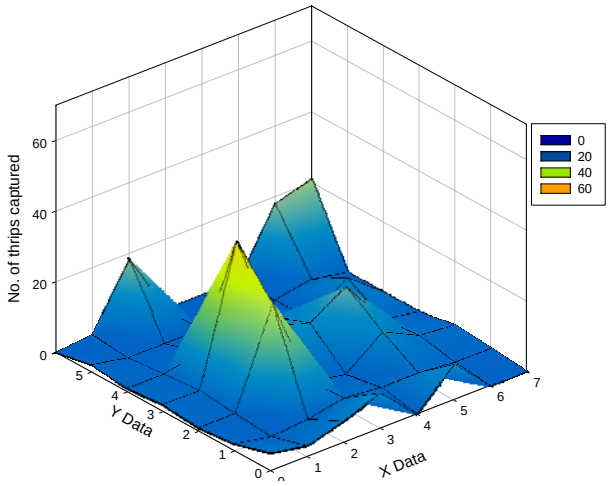


e.

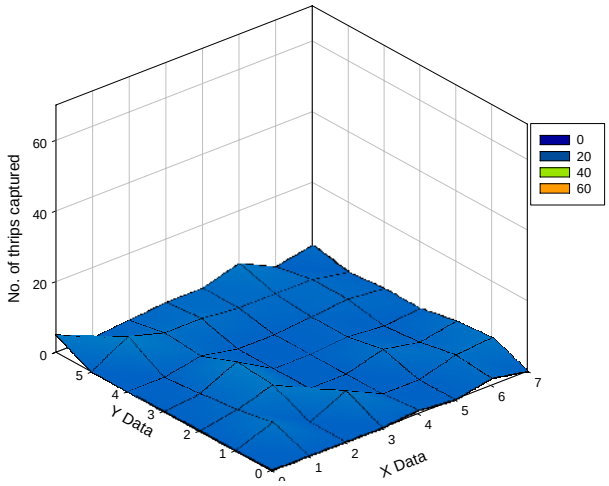


f.

Figure 3-9: Continued



g.



h.

Figure 3-9: Continued

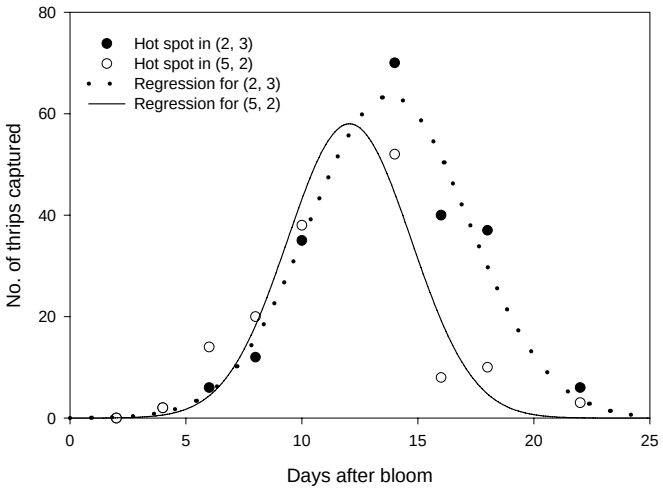


Figure 3- 10: Population dynamics inside the "hot-spot" in coordinates (2, 3), and (5, 2) of Figure 3- 9 on farm FL02 in Florida in 2005.

CHAPTER 4
PEST PHENOLOGY AND SPECIES ASSEMBLAGE OF FLOWER THRIPS IN FLORIDA AND SOUTHERN GEORGIA IN EARLY-SEASON BLUEBERRIES

The relationship between blueberries and flower thrips has not been studied because blueberries are a relatively new crop for Florida. Characterizations of thrips assemblage have been conducted in citrus, tomatoes, mangoes, and other crops. In north Florida tomatoes, Reitz (2002) found that the most commonly encountered species is *Frankliniella occidentalis* (Pergande), but during the spring and the fall, *F. tritici* (Fitch) was the most abundant. Other thrips species found in north Florida tomatoes include *F. bispinosa* (Morgan) and *F. fusca* (Hinds). Discussing his findings, Reitz (2002) emphasized the importance of studying individual species populations of thrips when developing a new sampling protocol or a management program for specific crops due to their differences in behavior, damage, and importance.

To understand the phenology of a pest, it is necessary to understand its relationship with its host plants. Plants can be divided into two groups depending on their relationship with thrips. The first type is a provisional or alternate host, which offers temporary shelter or food, but thrips do not reproduce in these plants. The second type is called a proper host because it offers food, shelter, a reproductive substrate, and alimentation for immature thrips (Mound 2005). Of the 5,300 thrips species worldwide, only 50 are recognized as economically important pest species. These species considered as crop pests are prolific and non-host-specific. For instance, *F. occidentalis*, western flower

thrips, has been reported on more than 500 plant species within 50 families (Moritz et al. 2004b). In this study, I described the phenology of flower thrips in relation to plantings across the early-season blueberry production regions of Florida and southern Georgia. I described the main species collected during the trials to facilitate the identification of these species. These results are part of the thrips management strategy that the Small Fruit and Vegetable IPM Laboratory is trying to develop as part of an IPM program for blueberries.

Materials and Methods

Two farms in Florida planted with southern highbush blueberries, SFL01 located in south-central Florida (N 28^{o} 04' W81^{o} 35'), and NCFL01 located in north central Florida (N 29^{o} 41' W 82^{o} 11'), as well as one farm in southern Georgia, SGA01 (N 31^{o} 32' W 82^{o} 28'), which was planted with rabbiteye blueberries, were selected to conduct the trials. These farms were sampled during the 2004 and 2005 blueberry flowering season to monitor thrips activity. In each of these farms, I randomly placed 10 white sticky traps (Great Lakes IPM, Vestaburg, MI) in one hectare of blueberries. The traps were collected weekly from flower opening to fruit set. I also collected five flower-clusters from the same bushes where traps were deployed. The traps and the flower samples were processed at the Small Fruit and Vegetable IPM Laboratory at the University of Florida. The number of thrips captured in the sticky traps was counted using a 20x magnifying glass, and the thrips inside the flowers were extracted using the shake and rinse procedure described in Chapter 3. I used the Pearson correlation coefficient to quantify the relationship between the number of thrips captured in flowers and sticky traps and the observed percentage of opened flowers in the field. I quantified the relationship between the dates of first thrips capture and dates of maximum capture with the latitude at which

these farms were located. To be able to correlate the dates, I transformed dates into a numerical system and used the general format of dates in Microsoft-Excel 2000® in which January 1, 1900 corresponds to 1, January 2, 1900 corresponds to 2 and so on, increasing by one with each day. The ten traps and ten flower samples per week were averaged to determine the population in the field. The results were graphed to determine any trends and show correlations.

A sample of 100 thrips per week from sticky traps was randomly collected to determine the thrips species assemblage present at each of the sampling sites. In the case of the flowers, I used as many thrips as I could extract from the five flower-cluster samples, to a maximum of 100 per week. To detach the thrips from the sticky traps I submerged the traps in 500 ml of CitroSolv™ (Fisher Scientific, Pittsburgh, PA) for four days. I used a squirt-bottle containing CitroSolv™ to rinse the insects that were still attached to the trap. The CitroSolv™ along with the thrips were then filtered through a basket-style coffee filter (Publix Supermarkets. Lakeland, FL). The insects in the filter were placed in a Quilted Crystal ® Jelly Jar (Jarden Corporation, Muncie, IN) containing CitroSolv™ for five more days to dissolve the remaining glue from the traps. Thrips were allowed to air-dry at room temperature and then re-hydrated using deionized water. The thrips collected from the flowers were preserved in 50% alcohol until I was able to slide- mount them for identification. The thrips from both traps and flowers were individually mounted on microscope slides using CMC-10 media (Masters Chemical Company, Elk Grove, IL). Vouchers of these specimens were sent to the Florida State Collection of Arthropods (FSCA) in Gainesville, FL. The thrips collected were divided into mature and immature. Mature thrips were then identified to species using taxonomic

keys (Mound and Marullo 1996, Moritz et al. 2001, Moritz et al. 2004b, Edwards Unpublished data). The percentage of thrips of each species was tabulated for comparison. A short key of the most common flower thrips species present in early-season blueberries in Florida and Georgia was constructed.

Results

Pest phenology:

Flower thrips populations in blueberry plantings were highly correlated with the latitude and percentage of opened flowers. The Pearson correlation coefficient for the relationship between the latitude and the date of first capture was 0.971 for the 2004 season and 0.957 for the 2005 season. I also determined the same coefficient for the relationship between the latitude and the date when the maximum population was recorded. The coefficients for this relationship were 0.999 for the 2004 season and 0.955 for the 2005 season. Independent of the latitude, flower thrips were first captured when 10 - 15 % of the flowers in the field were opened (Figures 4-1 to 4-6). Thrips populations peaked when 80 to 90 % of the flowers were opened. The population began to decline once the fruits started to form and the petals fell, leaving a reduced number of opened flowers in the field.

For the farm in south-central Florida SFL01, the first thrips were recorded between February 11, 2004; three weeks later (March 3, 2004) thrips populations reached their highest on sticky traps and flowers (Figure 4-1). However, for 2005 the first capture was registered on February 15, on March 8, the population reaches its highest point. The highest populations of thrips inside the flowers were recorded only two weeks after their first capture on the sticky traps (Figure 4- 2). The Pearson correlation coefficient between the average number of thrips captured in flowers and the sticky traps with respect to the

percentage of opened flowers was very high for both years (Table 4-1). An exception occurred for flowers in 2005 when it appeared that the highest population was reached a week earlier in the flowers (March 2, 2005) than in the traps (March 9, 2005).

The observations in north-central Florida follow the same trend as for south-central Florida. The first thrips captured on sticky traps in NCF01 was recorded, on average, 22 days after the observations in south Florida. The peak population was recorded two weeks after the first captures in both years (Figure 4-3 and 4-4). After thrips population reached its peak, the number of thrips captured declined with the decreasing number of opened flowers due to fruit formation. Correlation coefficients are high for sticky traps and flowers in both years in relation to the percentage of opened flowers (Table 4-1).

In southern Georgia, SGA01, the first thrips were captured between March 14th and 17th, on average 9 days after NCFL01 and 31 days after SFL01. Maximum populations during both years were very different from those in Florida. In the 2004 season, the maximum population was reached three weeks after first detection and averaged 255.4 ± 43.6 thrips per trap per week (Figure 4- 5). During the 2005 season, the maximum number of thrips captured on sticky traps per week reached 22.0 ± 3.3 two weeks after the first detection (Figure 4- 6). Despite these differences, Pearson's coefficients measuring the correlation between the percentage of opened flowers and the number of thrips captured in the traps and inside the flowers were high (Table 4-1).

A summary of the main variables observed at the various sites is presented in Table 4- 2. This table shows the high variability in the number of thrips captured among the various years and sites. For example, for south-central Florida the maximum population captured in traps was 65.4 ± 14.7 thrips per sticky trap per week while in 2005 the

amount of thrips captured with the same method was almost double, 123.4 ± 29.7 thrips per trap per week. Due to the variability in the populations and the distribution of thrips (Chapter 3), mean comparisons were not conducted since there was no homogeneity among the observed sites. At the same time Table 4- 2 and Figure 4- 7 show the correlation between latitude and dates of first capture and of maximum capture.

Species assemblage:

I repeatedly collected four species of thrips in Florida blueberry fields. These species were *F. bispinosa, F. fusca*, *F. occidentalis*, and *Thrips hawaiiensis* (Morgan). Other species were also recorded in Florida: *Haplothrips victoriensis* Bagnall, *F. kelliae* Salimura, and *T. pini* Uzel. The species with the highest number of individuals was *F. bispinosa* in the flowers as well as in the sticky traps deployed in Florida (Table 4-3).

The thrips species assemblage in Georgia is different from the one in Florida. The predominant species is *F. tritici*, followed by *F. occidentalis* and finally *T. pini*. These species were found in flowers as well as in sticky traps during the two years that the sampling was conducted (Table 4- 3). There is no appreciable difference in the species assemblage between the samples taken in 2004 and 2005 at the various sites. Between 14.75 and 27.8 % of the thrips recorded inside the flowers are immatures. The percentage of immature thrips was highest in SGA01, followed by SFL01 and finally NCFL01. Few immature thrips were found on sticky traps. This might be due to wind currents or immature thrips emerging from some of the flower materials and accidentally being caught in traps.

***Frankliniella bispinosa* (Morgan):** This species was the most abundant in Florida. It accounted for 78.89% (2005-NCFL01) to 88.96% (2004-NCFL01) of the adults captured inside the blueberry flowers. Furthermore, it represented between 82.51%

(2005-SFL01) to 95.37% (2005-NCFL01) of the total number of thrips captured in sticky traps (Table 4- 3). *Frankliniella bispinosa* was not captured in Georgia in flowers or in sticky traps.

***Frankliniella tritici* (Fitch):** This species replaced *F. bispinosa* in southern Georgia (SGA01) as the most commonly encountered species in blueberry fields. Between 60.01 % (in 2004), and 49.58 % (in 2005) of the adults captured in the flowers belong to this species. The percentage of *F. tritici* captured in traps was overwhelmingly higher than the other species. In 2004 adults of *F. tritici* accounted for 94.00 % of the population captured in sticky traps, while in 2005 they represented 92.00 %.

***Frankliniella occidentalis* (Pergande):** This species was found in Florida and Georgia. It was the second most abundant species in Georgia in sticky traps and flowers in both years, as well as in the flowers of north central Florida (NCF01) in 2005. It was the third most abundant in south-central Florida (SFL01) and in sticky traps at the NCFL01 site. In Georgia, the relative abundance of *F. occidentalis* as percentage of the adults captured was higher inside the flowers (36.61% for 2004 and 38.78 % for 2005) than in the sticky traps (4.4% in 2004 and 6.0% in 2005).

***Frankliniella fusca* (Hinds):** This species was the second most abundant species in SFL01 and the third most abundant in NCFL01 Flowers. Only two individuals of *F. fusca* were captured in Georgia (Other species Table 4-3).

***Thrips hawaiiensis* (Morgan):** This species was recorded only at the Florida sites. It was captured inside the flowers as well as on the sticky traps and apparently is more abundant in the southern regions (SFL01).

Rapid Determination of the Most common Species Found in Early-Season Blueberry Fields.

Based on the information from (Mound and Marullo 1996, Moritz et al. 2001, Moritz et al. 2004b, Edwards Unpublished data) and from personal observations a key is presented that can be used with a 40x compound microscope for the most commonly encountered species of thrips in blueberry fields.

Identification key to the flower thrips of blueberries in Florida and Georgia

1. Four or five pairs of elongated pronotal setae (Figure 1). Abdominal sternite VII has no discal setae. The first-vein setal-row in the forewing is complete and the setae are uniformly spaced (Figure 2)……...…….(*Frankliniella* spp.) 2

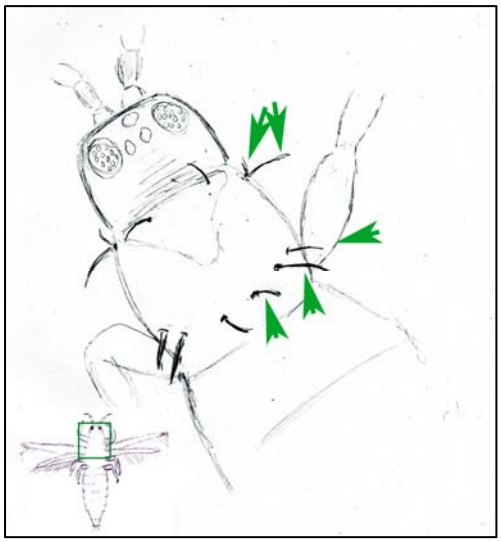


Figure 1

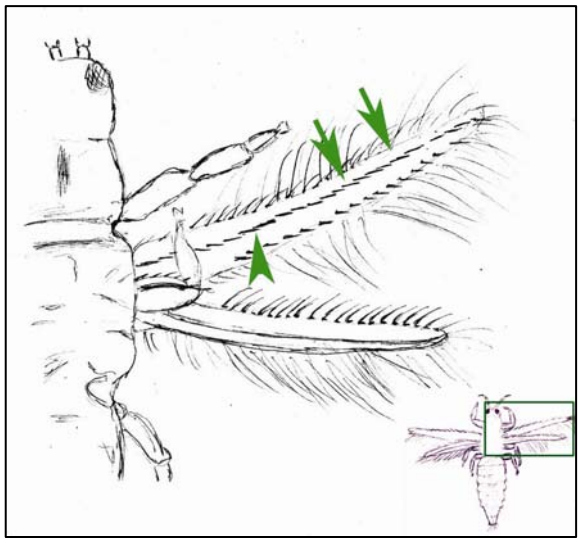


Figure 2

1'. Three or fewer pairs of elongated pronotal setae. Abdominal sternite VII has discal setae. The first vein setal row in the forewing is incomplete (Figure 3)…….....(*Thrips* spp.) 5

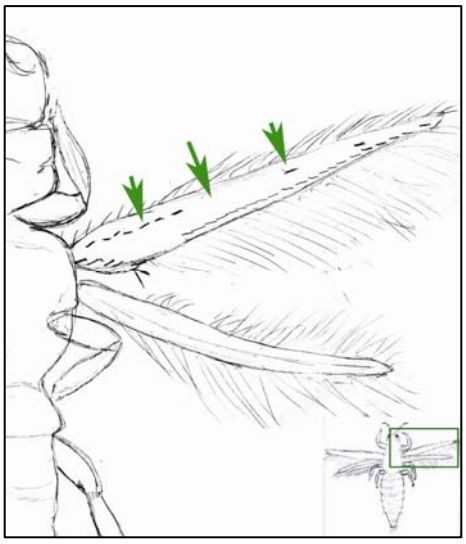


Figure 3

2. The postero-marginal comb of microtrichia is complete in the middle. The microtrichia are long and irregular and their bases are broadly triangular (Figure 4). Major post-ocular seta are more than ½ of the length of ocellar setae III, and usually extending clearly to the outside of the head (Figure 5)……..……..... *F. occidentalis*

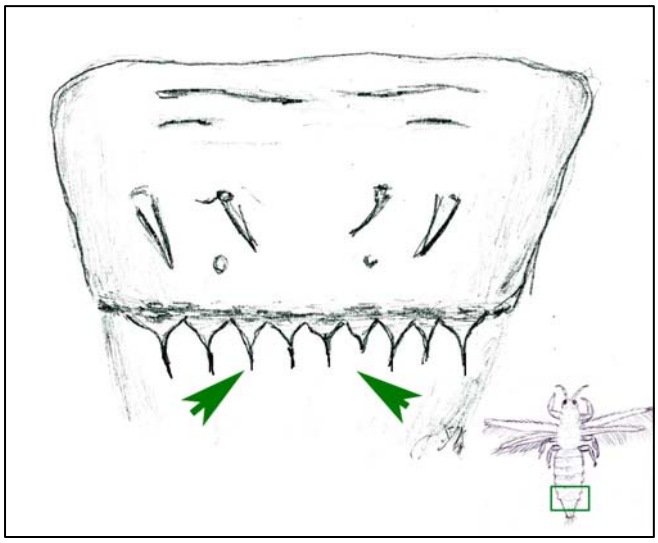


Figure 4

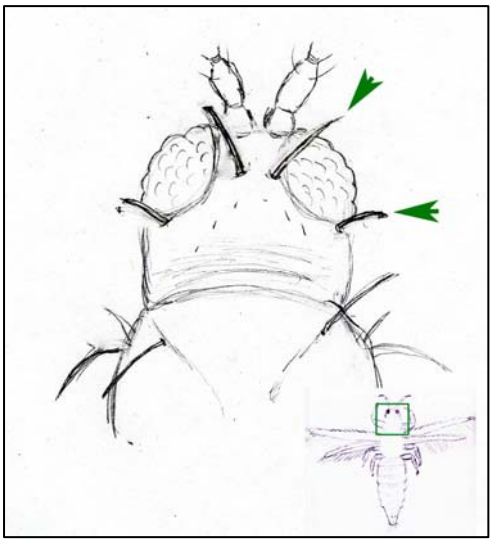


Figure 5

2’. With a different combination of characters from the ones described above……. 3

3. Base of the first antennomere restricted (Figure 6). The reticulation on the metanotum media area is equiangular. No post-ocular seta I. Wings might be absent in the adult stage……..……. *F. fusca*

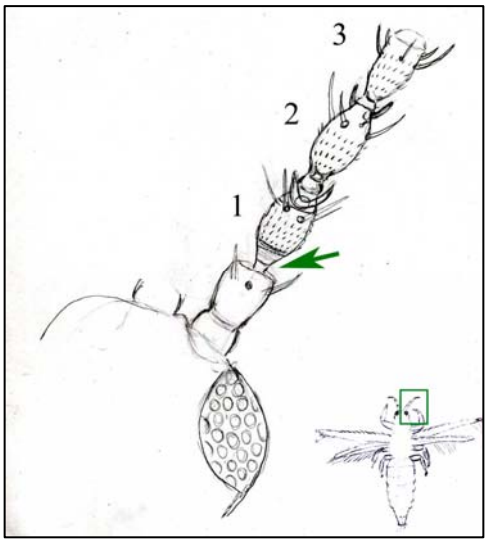


Figure 6

3’. Base of the first antennomere is swollen (Figures 7 and 8). The metanotum has no equiangular reticulations, but irregular longitudinal ones. Post-ocular seta I is present and adults always have wings ……..…….4

4. Base of the first antennomere is swollen and the edges are more or less sharp (Figure 7). It presents two well developed and sclerotised setae in the second antennal segment. This species is the most abundant in Florida, and very rarely found in Georgia……..…*F. bispinosa*

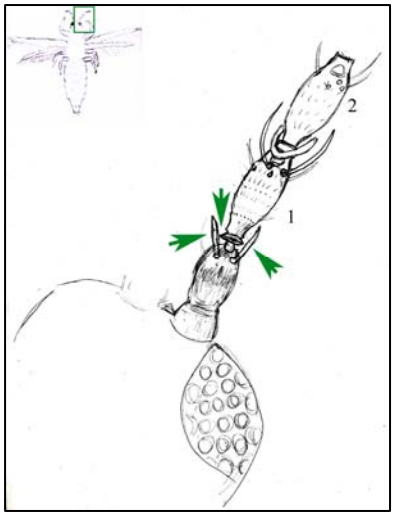


Figure 7

4’ Base of the first antennomere is swollen but the edges are not sharp. Setae are less developed and less sclerotized on antennal segment II than in *F. bispinosa* (Figure 8). This species is very common in blueberry plantings in Georgia ….....…….…*F. tritici*

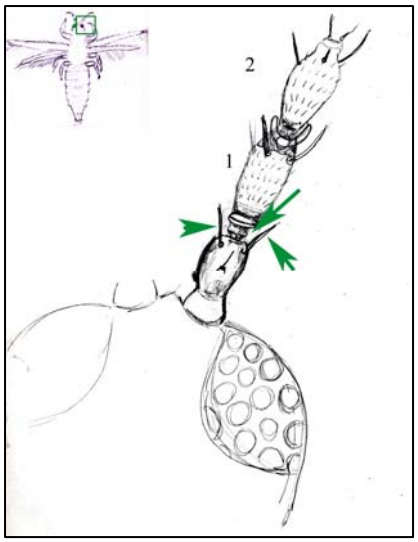


Figure 8

5. Seven or eight antennal segments. The postero-marginal microtrichia are short and irregular in length, they appeared to have their bases fused or more than one microtrichia per base (Figure 9). Sternite V has between 10 and 13 discal setae (Figure 10). Has no equiangular reticulation on the metanotum median area ……..*T. hawaiiensis*

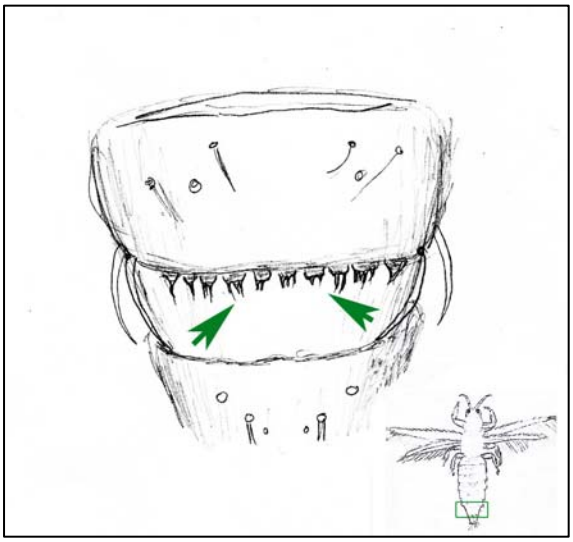


Figure 9

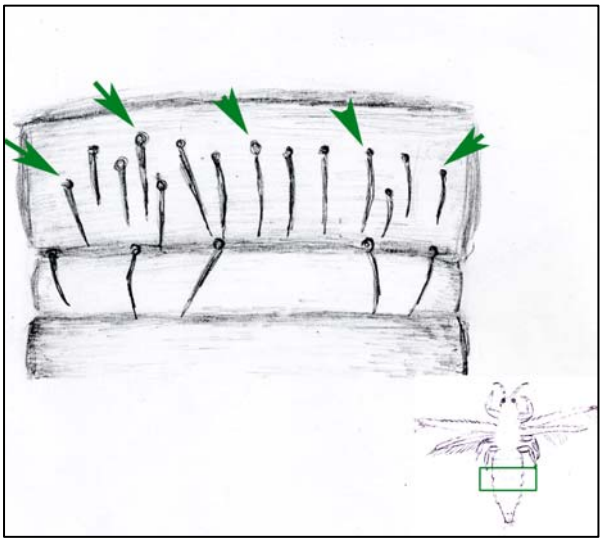


Figure 10

5’. Always with eight antennal segments. The postero-marginal microtrichia are long slender and irregular. Their bases are broad and clearly not fused at the base (Figure 11). Sternite V has between 3 and 9 discal setae (Figure 12). The metanotum median area presents some equiangular reticulation ……..……...……...*T. pini*

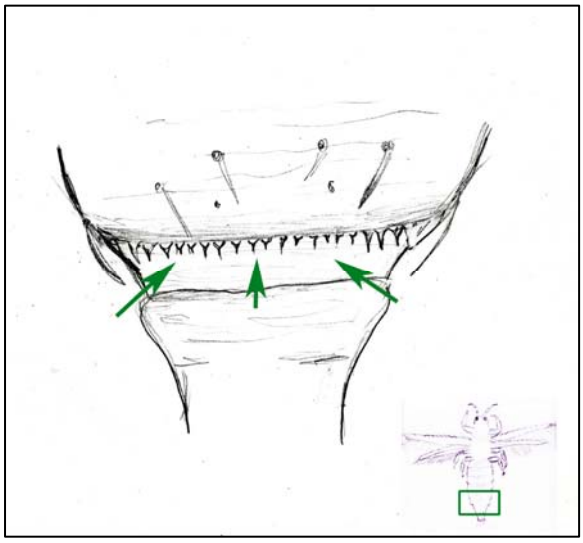


Figure 11

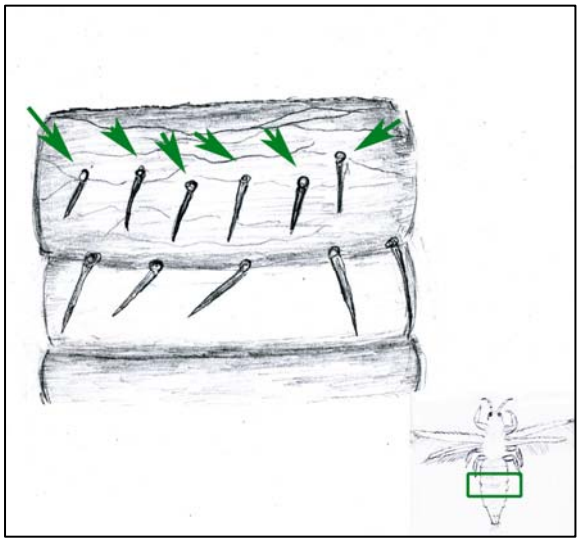


Figure 12

Discussion

This is the first time that a description of the thrips species assemblage and the phenology of flower thrips in relation to early-season blueberries have been investigated. Previous research on the relationship between flower thrips and blueberries has been limited to adequate monitoring techniques (Finn 2003). It is clear now that the presence of flower thrips on blueberry fields is highly correlated with the latitude and with the percentage of opened flowers in the field. Thrips were captured for the first time when close to 10 to 15% of the flowers were opened, independent of the latitude. Flowers and thrips appeared later in the season for northern sites compared with those recorded in southern areas. Despite the differences in the dates of blooming among the various sites, thrips populations followed the same pattern with respect to flower opening. The number of thrips captured inside the flowers, as well as the number of thrips captured in sticky

traps increased up to the point where the maximum number of flowers is opened in the field. After that time, thrips populations started to decrease when the petals of the flowers began to fall and the fruits start forming. This correlation between thrips populations with flower phenology as well as with latitude indicates that it might be a correlation between thrips populations and degree-days accumulation. To determine this correlation it will be necessary to establish a 'base-date' or conditions to begin the accumulation of the degree-days. Future research could be conducted to establish a more accurate model to predict thrips populations in blueberries based on weather patterns and temperature.

Among the thrips captured in Florida, *F. bispinosa* is the most commonly encountered species. This results complement the species descriptions made in citrus where 80 to 95% of the thrips captured belong to this species (Childers et al. 1990, Childers et al. 1994, Toapanta et al. 1996, Childers et al. 1998). In Georgia, I did not capture *F. bispinosa*. I found the most common species to be *F. tritici* followed by *F. occidentalis.* This difference might be related to environmental conditions. Other species found in the samples include: *F. fusca, T. hawaiiensis, T. pini*. A taxonomic key to distinguish the species commonly found in blueberries was developed. This key can be used by professionals who are trying to determine the species assemblage found in early-season blueberries. Almost all the thrips found belong to these six species. Other thrips encountered sporadically, fewer than 2 specimens collected in total, include *Haplothrips victoriensis*, *F. kelliae*, and *F. schultzei* (Trybom).

Blueberry growers will be able to use this information to predict when thrips are more likely to arrive to their fields, based on the percentage of opened flowers and the latitude at which the farm is located. The duration of the flowering season in blueberries

is on average 25 days and coincides with the time that flower thrips are captured in the fields. This period is not long enough for thrips to have multiple generations in the blueberry flowers because the life cycle is almost as long as the flowering period in blueberries (Childers et al. 1994, Moritz 1997). This led me to believe that most of the adult thrips collected in the flowers and in the sticky traps migrated into blueberry plantings from adjacent fields. Previous research indicated that the flower thrips species that were collected in blueberry fields are also found in citrus, wheat, and non-crop plants such as hairy vetch (*Vicia villosa* Roth), and crimson clover (*Trifolium incarnatum* L.) during both winter and spring (Toapanta et al. 1996). Adequate management of these alternative hosts for the flower thrips around blueberry fields might help to reduce the immigration of thrips into the plots.

Tables and Figures

Table 4- 1. Pearson correlation coefficients for the relationship between percentage of opened flowers and thrips population captured in sticky traps and inside five blueberry inflorescences.

Sample	SFL01 (n = 5)		NCFL01 (n = 4)		SGA01 (n = 5)	
	2004	2005	2004	2005	2004	2005
Sticky traps	0.807	0.838	0.784	0.953	0.994	0.874
Flowers	0.918	0.052	0.780	0.840	0.986	0.868

Table 4- 2. Dates, latitude, and principal characteristics of flower thrips population in 2004 and 2005 from the samples taken from south-central Florida to southern Georgia. SFL01 represents the farm in south Florida, NCFL01 represents the farm located in north-central Florida, and SGA01 is the farm located in southern GA.

Farm	Date of first capture*	Latitude (° ’)	Date of max. population[1]	Max. population per 5 flower clusters	Max. population per trap
SFL01	11-Feb-2004	N 28° 04’	3-Mar-2004	16.6 ± 4.7	65.4 ± 14.7
SFL01[2]	15-Feb-2005	N 28° 04’	9-Mar-2005		123.4 ± 29.7
SFL01[3]			2-Mar-2005	8.9 ± 2.5	
NCFL01	4-Mar-2004	N 29° 41’	18-Mar-2004	5.2 ± 1.8	31.6 ± 8.4
NCFL01	10-Mar-2005	N 29° 41’	24-Mar-2005	23.0 ± 7.5	86.5 ± 10.5
SGA01	14-Mar-2004	N 31° 32’	4-Apr-2004	25.2 ± 8.3	255.5 ± 43.3
SGA01	17-Mar-2005	N 31° 32’	1-Apr-2005	4.5 ± 0.4	22.3 ± 3.40

[1] Refers to the collection date for the traps which were placed in the field 7 days prior to this date.
[2] Information for the thrips captured on sticky traps in SGL01 in 2005
[3] Information for the thrips captured in flower-clusters in SGL01 in 2005

Table 4- 3. Distribution of the thrips species assemblage in Florida and southern Georgia.

		Percentage of thrips captured per season			
		2004		2005	
Farm	Species	Flowers	Sticky traps	Flowers	Sticky traps
SFL01	Immature	20.4	0.0	23.0	0.0
	F. bispinosa	67.2	83.6	61.2	82.4
	F. fusca	6.6	10.4	8.4	12.2
	F. occidentalis	4.4	5.8	5.8	3.6
	T. hawaiiensis	1.0	0.0	1.6	1.2
	Other species	0.4	0.2	0.0	0.6
NCFL01	Immature	18.5	0.0	14.7	0.3
	F. bispinosa	72.5	93.3	67.3	95.2
	F. fusca	3.7	5.0	8.5	3.0
	F. occidentalis	4.7	1.3	9.5	1.0
	T. hawaiiensis	0.5	0.2	0.0	0.3
	Other species	0.0	0.3	0.0	0.3
SGA01	Immature	26.8	0.0	27.8	0.2
	F. tritici	44.0	94.0	35.8	92.0
	F. occidentalis	26.8	4.4	28.0	6.0
	T. pini	2.4	1.2	8.4	0.4
	Other species	0.0	0.4	0.0	1.4

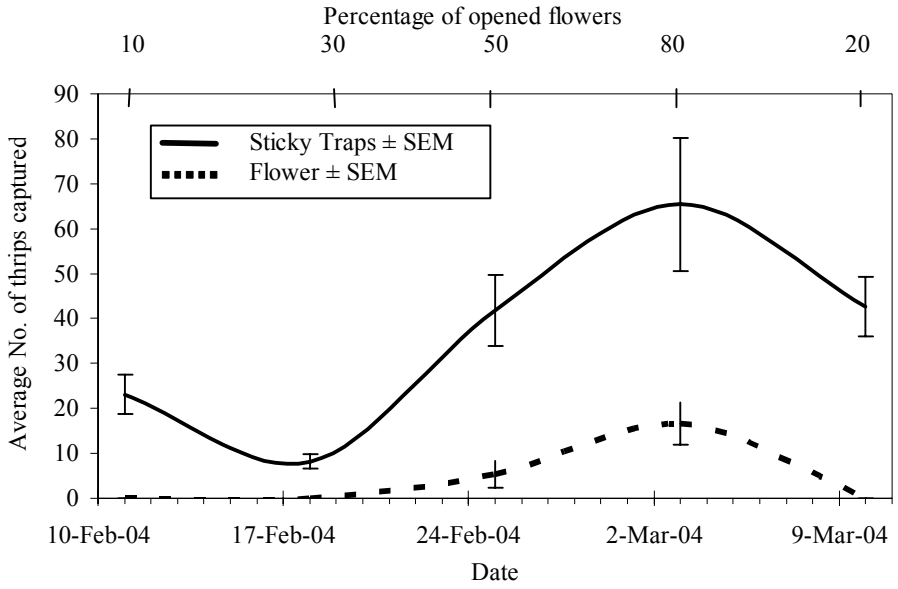


Figure 4-1. Phenology of thrips population on farm SFL01 in 2004. The graph represents average number of thrips captured per sticky trap and the average number of thrips in five blueberry flower-clusters ± SEM.

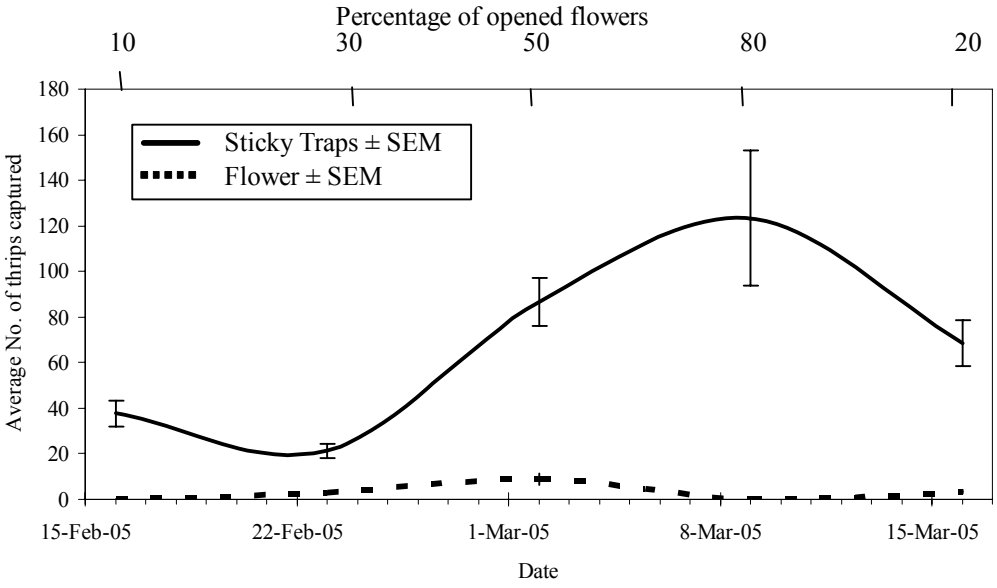


Figure 4-2 Phenology of thrips population on farm SFL01 in 2005. The graph represents average number of thrips captured per sticky trap and the average number of thrips in five blueberry flower-clusters ± SEM.

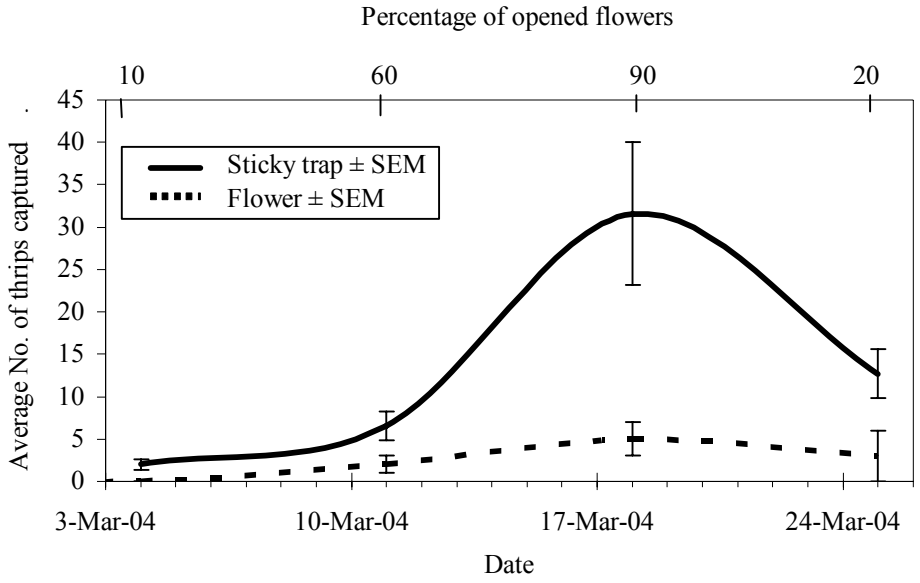


Figure 4- 3 Phenology of thrips population on farm NCFL01 in 2004. The graph represents average number of thrips captured per sticky trap and the average number of thrips captured in five blueberry flower-clusters ± SEM.

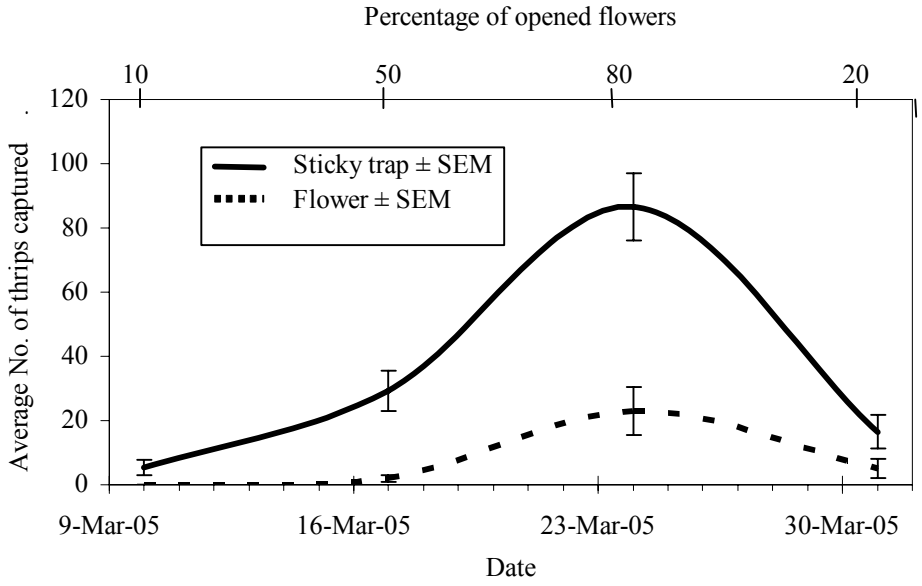


Figure 4- 4. Phenology of thrips population on farm NCFL in 2005. The graph represents average number of thrips captured per sticky trap and the average number of thrips captured in five blueberry flower-clusters ± SEM.

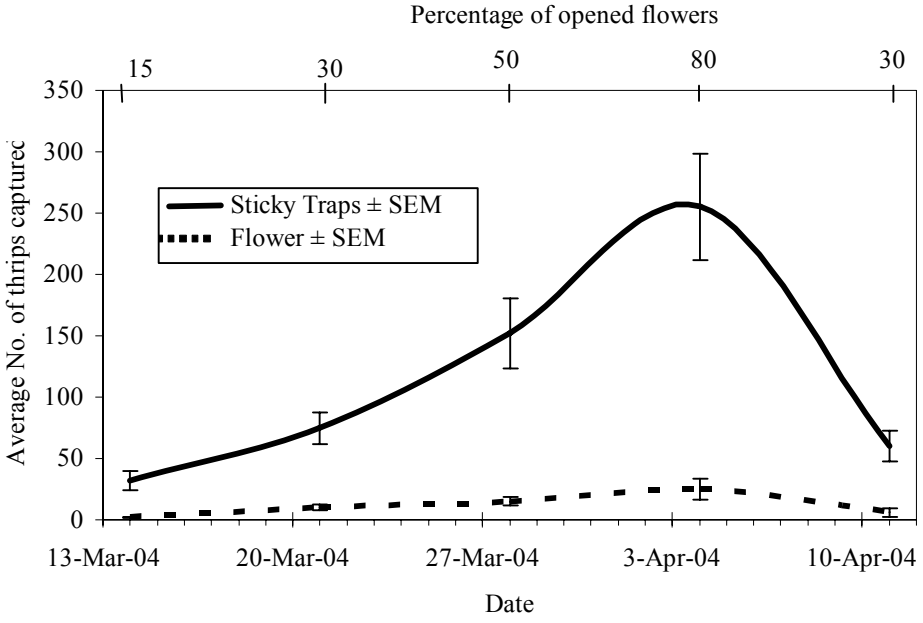


Figure 4- 5. Phenology of thrips population on farm SGA01 in 2004. The graph represents average number of thrips captured per sticky trap and the average number of thrips captured in five blueberry flower-clusters ± SEM.

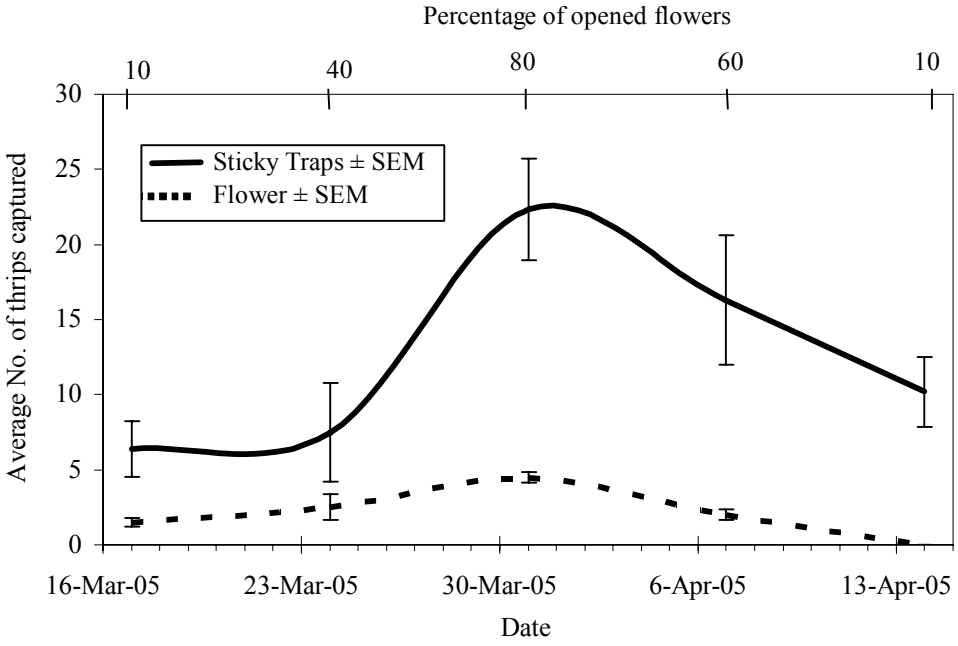


Figure 4- 6. Phenology of thrips population on farm SGA01 in 2005. The graph represents average number of thrips captured per sticky trap and the average number of thrips captured in five blueberry flower-clusters ± SEM.

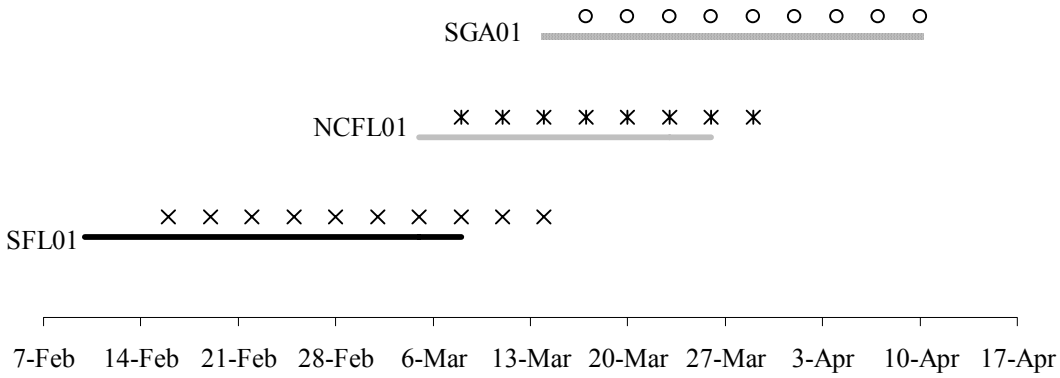


Figure 4- 7: Dates of first and last captures of flower thrips in the various blueberry sites. SFL01 represents south-central Florida, NCFL01 represents north –central Florida and SGA01 represents southern Georgia. Solid lines represent 2004 and dotted lines represent 2005.

CHAPTER 5
HOST STATUS, INJURY DESCRIPTION, AND DETERMINATION OF ECONOMIC INJURY LEVELS OF FLOWER THRIPS FOR EARLY-SEASON BLUEBERRIES

The recognition of injury and determination of Economic Injury Levels (EIL) are of major importance for the success of integrated pest management (IPM) programs. These concepts are the foundation of the decision-making process in agriculture. Nevertheless, few studies have been published concerning EIL for blueberries. This may be due to the variability of the factors involved in the calculation of EIL (Poston et al. 1983). Most EIL variables depend on market values, which can exhibit considerable variation. It is useful to have an EIL for flower thrips in early-season blueberries because this is a high-value crop and growers need to make important decisions, before economic losses are incurred.

For this study, I used definitions published by Stern et al. (1959). The authors define Economic Damage (ED) as "the amount of injury that will justify the cost of artificial control measures" and EIL as "the lowest population density that will cause this damage". Economic threshold (ET) was defined as "the density at which control measures should be initiated to prevent an increasing pest population from reaching the EIL".

Thrips are considered to be key pests for many crops and have been reported to affect more than 500 plant species (Moritz et al. 2001, Moritz et al. 2004b). Among blueberry producers, flower thrips is considered as one the key arthropod pests. However, there have been no descriptions of the injury and damage inflicted by flower thrips in blueberries. Mound (2005) explains the difference between proper hosts and alternative

hosts for thrips and why it is important to determine the type of hosts and their interactions with thrips. The author describes primary hosts or real hosts as plants where thrips feed, shelter, and reproduce. Secondary hosts are plants used by thrips as shelter and food but not as reproductive sites in the field.

There are a few publications dealing with the EIL of flower thrips in economically important plants. Shipp et al. (2000), determined the EIL for western flower thrips on greenhouse cucumber. Their results indicated that greenhouse cucumbers have a period of tolerance, which lasts until the eighth-week of production. Cucumbers appear to be more sensitive to primary damage inflicted by thrips (damage to the fruit) than by secondary damage (damage to the leaves).

The objectives of this study were 1) to determine the type of host, primary or secondary, that blueberries represent for flower thrips, 2) to describe for the first time the type of damage inflicted by flower thrips on early-season blueberries, and 3) to determine the EIL of flower thrips for the two most popular rabbiteye blueberry cultivars, 'Climax' and 'Tifblue'.

Material and Methods

Host status of early-season blueberry bushes for flower thrips

To clarify the host status of early-season blueberries 100 opened flowers from the two main species of early-season blueberries (50 southern highbush and 50 rabbiteye) were collected in commercial farms located in north-central Florida (N 29^{o} 41' W 82^{o} 11') and in south-central Florida (N 28^{o} 04' W 81^{o} 34'). This 2 x 4 factorial experiment has as main effects the blueberry species (rabbiteye and southern highbush), and the blueberry tissues (fruit, ovary, styles, petals). The flowers were brought for processing to the Small Fruit and Vegetable IPM Laboratory at the University of Florida in Gainesville.

The flowers were manually dissected into petals, ovary, and styles. The floral tissues were then placed into groups of ten in 100 x 15 mm polystyrene Petri-dishes (Fisher Scientific, Pittsburgh, PA). In addition, one wet circle of filter paper Qualitative P8 (Fisher Scientific, Pittsburgh, PA) was placed in each Petri-dish to keep the humidity high. Petri-dishes were left at room temperature (27°C) for 15 days, and all of the thrips that emerged over this period were counted and moved to another Petri-dish with green beans and Bee pollen (Y.S. Organic bee farms, Yonkers, NY) as food sources to allow them mature. The Petri-dishes were sealed using Parafilm M® (Pechiney Plastic Packaging, Chicago, IL) to prevent thrips from escaping. At the end of the blueberry flowering season, I collected green fruits and processed these using the same procedure as with the flowers to provide information about emergence of flower thrips. Every second day the Petri-dishes were opened and observed for the presence of first instar thrips. These larvae were counted and taken from the Petri-dishes. The number of larvae emerged in each Petri-dish was recorded and analyzed according with the design using LSD as test for mean separation. ($\alpha = 0.05$) (SAS Institute Inc. 2002).

Economic Injury Level and injury description

Two of the most popular cultivars of rabbiteye blueberries, 'Climax' and 'Tifblue', were selected for this study. Both cultivars were located in a commercial farm in southern Georgia (N 31^o 32' W 82^o 31'). The farm is managed with the standard practices used by commercial growers to maintain a blueberry crop. At the beginning of the flowering season (March 9, 2005 and March 8, 2006) I selected five flower-clusters with five flowers each per bush. Five non-consecutive bushes from each cultivar were used as blocks in a completely randomized block design. There were five replicates for each cultivar. The flowers were protected with bags made of antivirus/no-thrips screen (thread

count 81 x 81, BioQuip Products, Rancho Dominguez, CA). The screened bags were handmade measuring 10 x 10 cm, and were placed on the selected inflorescences. These bags were sealed using small ¾" binder clips (ACCO ™, Lincolnshire, IL), by folding the opened side three times and then placing the clip over the folding. Two weeks later when the flowers opened and were receptive, I manually pollinated them using a mixture of pollens collected earlier the same day from various cultivars present in the field to ensure cross-pollination and appropriate fruit setting. A known number of adult flower thrips, *Frankliniella* spp., was released inside the bags when pollination was conducted. For 2005, the treatments used were a control (no thrips), and 2, 10, or 20 thrips per flower. In 2006, my treatments include a control (no thrips), 4, 10, 20 thrips per flower. The thrips released in the bags were collected from various wild flowers and blueberry flowers the day before the releases. The thrips collected were separated into adults and immatures. Only the mature stages belonging to the genus *Frankliniella* were used in this trial. The formed fruits were collected in the green stage two to three weeks after the release of the thrips inside the bags and brought to the Small Fruit and Vegetable IPM Laboratory at the University of Florida for observation.

To determine the EIL, I used the definitions and formulas described by Pedigo (1986) (Equation 5-1). Based on the data collected, I conducted a linear regression between the number of thrips per flower released in the bags and the percentage of fruits formed inside the bags. The assumptions (cost of control, price, market values etc.) used to calculate the EIL were based on the 'growers' and 'experts' experience and on various publications (Food and Agriculture Organization of the United Nations (FAO) 2004, Pollack and Perez 2004, Lyrene 2005, NASS-USDA 2006b). These sources enabled us to

establish the most accurate and functional variables to estimate the EIL. I compared the slopes of the linear regressions between the number of thrips per flower and the number of flowers formed using a Student *t*-test ($\alpha = 0.05$) (Ott and Longnecker 2004). Fruits that presented signs of thrips injury were photographed and described. (Equation 5-1)

$$EIL = \frac{C}{V \times I \times D \times K} \qquad 5\text{-}1$$

Correlation between the number of thrips inside the flowers and on sticky traps

To facilitate the use of economic injury levels (EIL) by commercial growers and to find a non-destructive way to determine thrips populations affecting blueberries, I decided to correlate the number of thrips captured in sticky traps with the number of thrips recorded inside blueberry flowers. Two farms were selected in southern Georgia (N 31^o 32' W 82^o 28) and (N 31^o 32' W 82^o 31). In each farm, I deployed 10 white sticky traps, in 2004 and 2005, located inside the blueberry-bush's canopy (Chapter 3) and randomly distributed them in one ha. Traps were collected every week, simultaneously five inflorescences were collected from the same blueberry bush where the trap was placed. Traps were randomly rotated within the selected hectare every week for 4 weeks in 2004 and 3 weeks in 2005. The total number of thrips captured on the traps was counted. Thrips taken from the flowers were processed using the shake and rinse method described in chapter 3. The number of thrips from the flowers was tabulated. To linearize the relationship between the number of thrips captured in sticky traps for a week and the number of thrips inside the flowers, the data had to be transformed using the natural logarithm. The regression was performed using SigmaPlot ® (SYSTAT Software Inc. 2006).

Results

Host status of early-season blueberry bushes for flower thrips

The emergence of larvae from the blueberry tissues confirms that blueberries are a proper host for flower thrips. The analysis of the data collected showed no effect of the blueberry species on the number of thrips emerged from the flowers (F = 0.47; df = 1,92; P = 0.49) and no significant interaction between the blueberry species and the tissue from where the thrips emerged (F = 0.16; df = 3,92; P = 0.9235). The results obtained from this analysis and illustrated in Figure 5- 1 indicated that significantly more thrips emerged from the petals (11.3 ± 2.5 thrips per ten corollas) than from any other tissues in the flower (F = 13.28; df = 3, 92; $P < 0.0001$). The number of thrips that emerged from the ovaries (4.4 ± 1.2 thrips per ten ovaries) was significantly lower than the number emerged from the petals, but it was significantly higher than the number of thrips emerging from the styles (0.1 ± 0.1 thrips per ten styles) and the fruits (0.0 ± 0.0 thrips per ten fruits). Finally, there was no difference between the number of thrips emerging from styles and fruits, but both of these were significantly lower than the number of larvae emerging from petals and ovaries (Figure 5- 1). There is no differences between the number of thrips emerging from rabbiteye flowers (4.2 ± 1.1 thrips per ten flowers) and highbush flowers (3.1 ± 0.8 thrips per ten flowers) (F = 0.47; df = 1,92; P = 0.49).

Economic Injury Level and injury description

The results of the regression correlating the average number of thrips released per flower and the number of fruits formed in each treatment (Figure 5- 2), provides the information needed to calculate the value of the injury per insect 'I'. The value of the slope in the equation indicates a 0.4032 % reduction in production per adult thrips per flower in 'Climax' and 0.4515 % reduction in production per adult thrips per flower in

'Tifblue'. Using average densities (2,471 plants / ha), fruit weight (1.2 g per fruit), flower setting (60%), and average production (16,812 kg / ha), and 9,500 flowers per plant (P. M. Lyrene, personal communication) for rabbiteye blueberry commercial production. The value for injury per insect in 'Climax' (I_c) is approximately 1.71×10^{-10} proportion damage/[thrips/ha]. The value for the damage per unit injured for 'Climax' (D_c), is 16,812 (Kg/ha)/proportion damaged. For 'Tifblue' the value for 'I_t' is approximately 1.92×10^{-10} proportion damage/[thrips/ha] and the value for the damage per unit injured for 'Tifblue' (D_t) is equivalent to 16,812(Kg/ha)/proportion damaged.

$$EIL = \frac{C}{V \times I \times D}$$ Equation 5- 1:

The value for 'D' in both cases was calculated under the assumptions that flower thrips adults arrive at the flowers at the moment of pollination and that the plants have no mechanisms of compensation for fruits not formed due to thrips injury. The value of 'D' and the value of the total production per ha are equal. If the proportion of damage is equal to 1 (100% of the fruits) the damage per unit injured is equivalent to the total production. The injury per insect value 'I' is not very variable and depends on the tolerance of the inflorescences to thrips damage. When I compared the slopes of the regressions between the average number of thrips released inside the bags and the number of fruits formed, I found non-significant differences between the slope for 'Climax' and 'Tifblue' ($F = 0.66$; df = 1, 98; $P = 0.4205$).

Two of the most unpredictable variables that change from season to season in the calculation of EIL are the cost of the control 'C' and the value of the product 'V'. However, using the average cost of an application of Malathion 5EC, which is the most

commonly used insecticide for controlling flower thrips, the value for 'C' is approximately $185.32/ha (O. E. Liburd, Personal communication). The average value of blueberries for processing in Georgia for 2005 was $1.95 / Kg (NASS-USDA 2006b). Based on the collected data, the EIL for 'Climax' is 33,057,666 thrips / ha or approximately 14 thrips per 10 flowers. In the case of 'Tifblue', the EIL is 29,441,983 thrips per ha or approximately 13 thrips per 10 flowers. I also calculated the EIL for SpinTor 2SC because it is the most popular reduced-risk insecticide used to control flower thrips in blueberries (Liburd and Finn 2003). The value to control thrips using SpinTor 2SC (V_c) is approximately $249.17 / ha when all the other variables were kept constant. The value for the EIL using SpinTor 2SC as the control is approximately 44,447,327 thrips / ha or 19 thrips per 10 flowers for 'Climax' and 40,204,430 thrips / ha or 17 thrips per 10 flowers for 'Tifblue'.

After analyzing the fruits and the injuries inflicted by thrips, I found a wide range of injuries. The injuries inflicted by thrips could be divided into three categories: fruit dehydration, feeding injuries and oviposition injuries (which include larval emergence). Fruit dehydration damage was only found in inflorescences where 20 thrips per flower were released. The damage on the flower's ovary during fruit formation was severe and the fruits formed were dehydrated. A higher than usual portion of the fruits failed to set, which might explain in part the reduction in the blueberry production in inflorescences with flower thrips. Thrips' feeding damage is inflicted by adults and the two larval stages. The symptoms shown by this damage are similar to those found on mangoes when *F. occidentalis* have feed on the flowers [similar to the picture taken by M. Wysoky and shown in Childers (1997)] (Figure 5- 3b). Oviposition and emergence injuries are

inflicted when the females lay their eggs and the larvae emerge from the ovaries, respectively. This damage might be magnified with the cell division of the tissue and be more evident in formed fruits than in the ovary of the flowers (Figure 5- 3c) (Childers 1997, Kirk 1997a).

Correlation between the number of thrips inside the flowers and on sticky traps

Our regression shows a high correlation between the number of thrips in sticky traps and the number of thrips inside blueberry flowers. The equation that describes the line (Figure 5- 4) corresponds to Ln (T_f+1) = -0.06 + 0.709 x Ln (T_t+1) (F = 177.37; df = 1, 128; $P < 0.0001$). In the equation T_f represents the number of thrips recovered from 5 blueberry flower-clusters using the shake and rinse method (Chapter 3); T_t represents the total number of thrips captured in white sticky traps located inside the canopy of blueberry. Pearson's coefficient (r = 0.7621) indicates a high correlation between these two variables.

Based on the information presented in his study I was able to approximate the economic injury level to between 45 ('Tifblue') and 50 ('Climax') thrips per trap at the beginning of the pollination period in the 2005 season in the case of Malathion 5EC. In the case of SpinTor the EIL is between 64 ('Tifblue') and 73 ('Climax') thrips per trap at the beginning of pollination.

Discussion

These results confirmed that blueberry bushes are a true host for flower thrips. These thrips are reproducing in the flowers of blueberries and emerge before the full formation of the fruit. Thrips prefer to lay their eggs in mature non-expanding tissue to avoid having their eggs crushed by growing cells (Terry 1997). Flower thrips on blueberries have a similar oviposition behavior as flower thrips in citrus. As described by

Childers (1991), flower thrips lay their eggs principally in the pistil-calyx area and the petals in oranges. A similar situation was found on blueberry flowers where most eggs were laid either in the ovary or in the petals, while no larvae emerged from the fruits. The data indicate that flower thrips in blueberries prefer to lay their eggs in young flowers so that the eggs will have time to develop into larvae before fruit formation starts. I also found non-significant differences between the number of larvae emerging from the two blueberry species, southern highbush and rabbiteye, cultivated in southeastern U.S., which indicates that flower thrips do not show significant oviposition preference to either blueberry species in the field. Once I demonstrated that early-season blueberries are primary hosts of flower thrips, I studied the implications of the presence of these insects in commercial plantings. I began with the calculation of an EIL for which I used the two most popular cultivars of rabbiteye blueberries, 'Climax' and 'Tifblue'. I found that flower thrips are capable of reducing the yield of blueberries to economically damaging levels when high populations (2 thrips per flower on average) are found inside the flowers during the beginning of the pollination period. However, this EIL was calculated based on information from the 2005 season, while some of the variables used correspond to this year and will change in the future depending on market values. The cost of treatment 'C' varies depending on the cost of manual labor, the type of product applied, and the type of equipment used for the application (assuming that only chemical control is used). The value of 'V' changes with supply and demand, harvest time, product quality etc. Due to this variation, the actual value for an EIL is farm-, and year-specific.

The most important variable calculated and the least likely to change is the slope in the correlation between flower thrips density inside the flowers and the reduction in the

yield. This slope is the key factor in the calculation of 'injury per insect' (I), which is the variable less likely to change as it does not depend on the market. Some of the reasons for which 'I' may vary include changes that affect flower thrips interest in feeding or oviposition on blueberry flowers. This might include genetic improvement of the cultivars to produce feeding or oviposition deterrents, climatic conditions, presence of natural enemies etc. I found non-significant differences between the levels of injury inflicted by thrips in relation to the pest density when 'Climax' and 'Tifblue' where compared. This might indicate a reduced variation between cultivars of the same species. However, the evaluation of more cultivars is necessary to strengthen this conclusion.

I also determined that the damage associated with flower thrips in blueberries is not only linked to yield. Although reduction in the yield is the most important consequence of an unmanaged population of flower thrips, it seems that the quality of the fruits might also be compromised. Injuries to fruit, principally feeding injuries, might reduce the grade of the fruit because of their visibility. Oviposition-emergence injuries due to their color and size are almost invisible when the fruits mature, thus might not represent a big problem for growers and customers. However, these injuries have the potential to facilitate the acquisition of secondary infection such as *Botrytis cinerea*, which is the principal decaying agent for blueberries in post harvest (Sargent et al. 2006).

We found a high correlation between the number of thrips captured in sticky traps and the number of thrips found in blueberry flowers. This correlation will increase the accuracy for monitoring flower thrips in blueberry fields and reduce the effect of destructive sampling in commercial settings. The values for the EIL in flowers as well as in traps are very high. From field observations described in other chapters the number of

thrips captured during the week in which flowers are opening is very low. The usual values obtained for flowers are approximately 5 to 10 thrips per five flower-clusters, which means an average of 0.3 thrips per flower (Chapter 3). The differences observed in the EIL when calculated for Malathion 5EC and for SpinTor 2SC illustrates the variability of its value. Due to this variability, the calculations of EIL should be performed almost individually for each farm, depending on type of control, plant density, varieties, price of their product, etc.

Tables and Figures

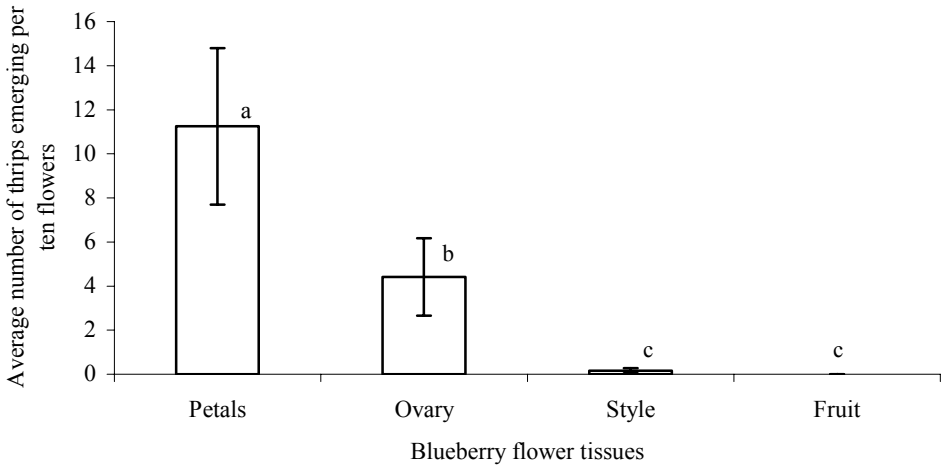


Figure 5- 1: Average number of larvae emerged from individual tissues of 10 flowers and fruits. Comparisons were conducted using LSD test $\alpha = 0.05$

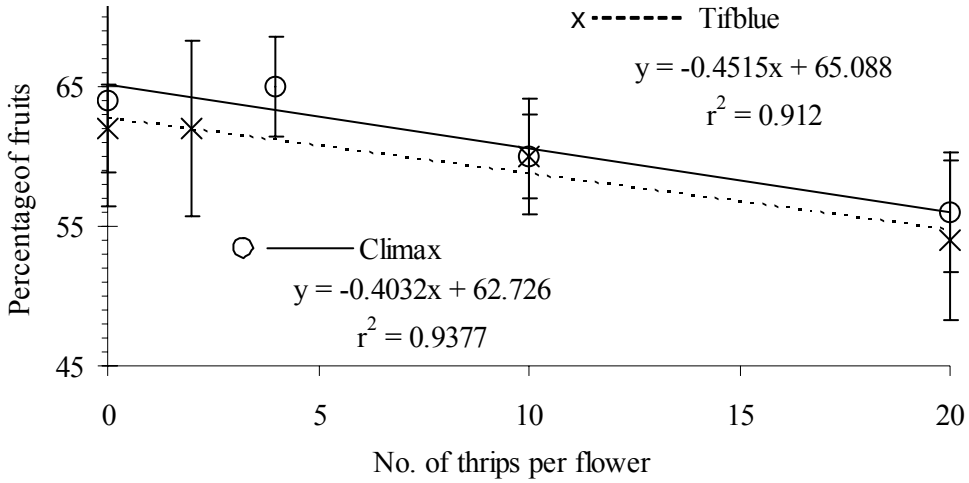


Figure 5- 2: Linear regression showing the average number of thrips released per flower and the percentage of formed fruits in two principal cultivars of rabbiteye blueberries 'Climax' and 'Tifblue'

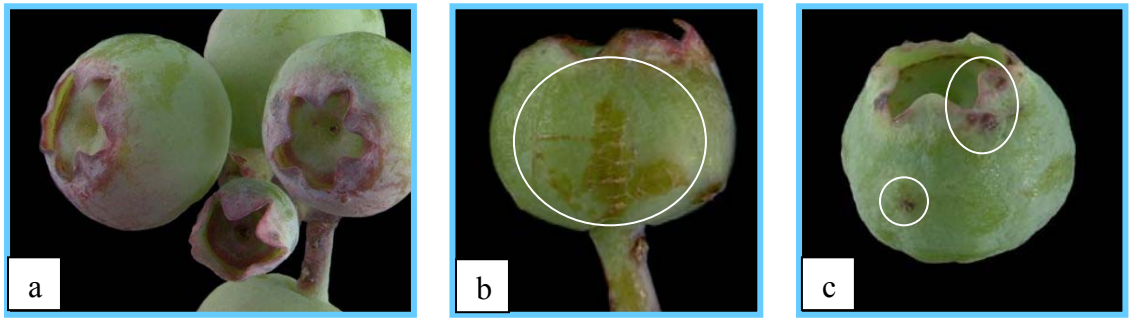


Figure 5- 3: Various thrips injuries inflicted by flower thrips in blueberry flowers. a) Represents a healthy fruit, b) Shows feeding injury, and c) Shows oviposition/emergence injuries

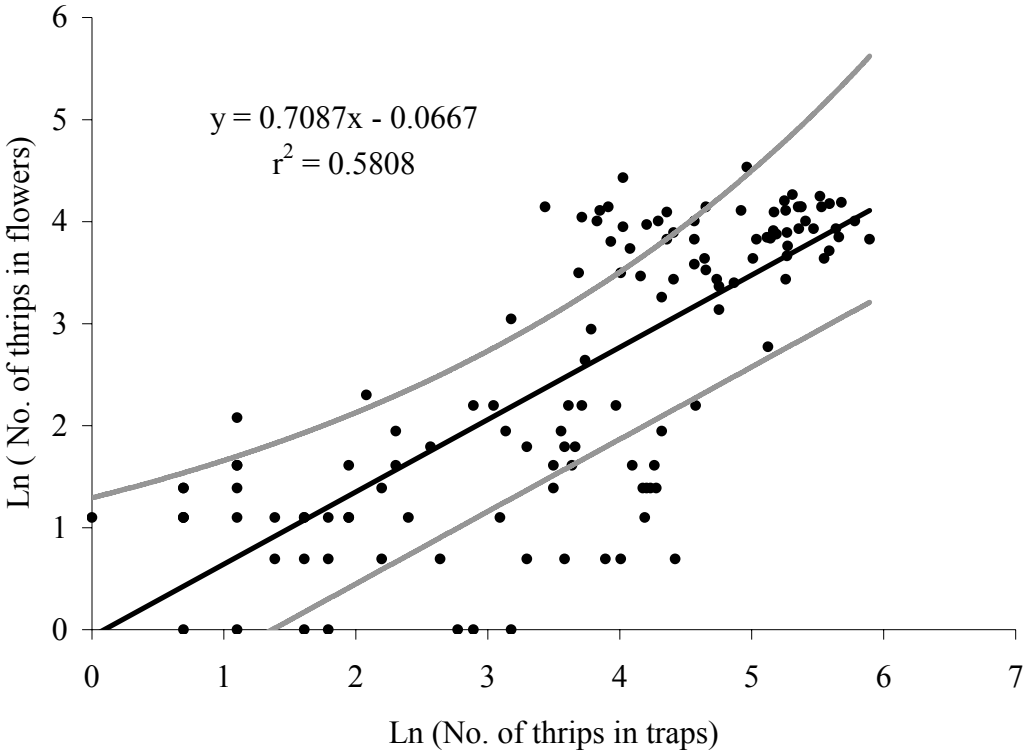


Figure 5- 4: Regression illustration the number of thrips captured on white sticky traps for a week in relation to the number of flower thrips captured in five inflorescences collected in the same bush. The graph represents the tendency ± SEM

CHAPTER 6
EFFICACY OF REDUCED-RISK INSECTICIDES TO CONTROL FLOWER THRIPS IN EARLY-SEASON BLUEBERRIES AND THEIR EFFECT ON *ORIUS INSIDIOSUS,* A NATURAL ENEMY OF FLOWER THRIPS

Flower thrips are among the most damaging insect pest in the production of early-season blueberries (Finn 2003, Liburd and Finn 2003, Liburd and Arévalo 2005, 2006, Liburd et al. 2006). The use of chemical means to control thrips began in the early 1900s. Since then, no insecticide has been developed to target exclusively thysanopteran pests. All of the insecticides used for thrips management were designed to control other insects and then tested on thrips. However, their effect on thrips might be limited due to differences in behavior and feeding habits compared with other major pests (Lewis 1997b). Insecticides recommended for thrips control by the manufacturers are usually systemic and stomach poisons. There are a few insect-growth regulators and contact-only insecticides but these are very limited (Lewis 1997b).

The United States congress (1996), warned of the use of traditional chemistries and encouraged the development of new chemistries that are less toxic to non-target organisms and to the environment in general. There are currently 60 chemistries that are considered as reduced-risk insecticides, biopesticides, and organophosphates (OP) alternatives as described in by the IR-4 project (IR 4 project 2006). Nine of these chemistries are labeled or in process to be labeled to be used in blueberries. Within this group, only five have shown potential to control thrips: flonicamid, novaluron, spinosad, thiamethoxam, and zeta-cypermethrin (United States Congress (104th) 1996, IR 4 project 2006).

Most of the chemical control for flower thrips in blueberries has relied on the use of malathion, an OP insecticide, and on spinosad, a reduced-risk naturalyte (O. E. Liburd, personal

communication). Malathion has been used to control flower thrips in various crops including garlic, leek, onion, cucumbers, endive, etc. (Micro Flo Company 2006). Spinosad is being used as an organic OMRI-listed insecticide in its formulation Entrust, or as non-organic formulation as SpinTor 2SC. Spinosad is labeled to control thrips in bushberries, citrus, *Brassica* vegetables, cucurbits, etc. (Dow AgroSciences 2006b, 2006a). However, concerns for the development of insect resistance due to the use of one chemistry and a limited number of modes of action, prevails. Several studies have reported various degrees of thrips resistance to several insecticides. Jensen (2000), compiled a list of *Frankliniella occidentalis* (Pergande) wild and laboratory populations, that have been reported as resistant to insecticides. The list includes seven OP, nine carbamates, eight pyrethroids and six other chemistries, which include endosulfan, DDT, and the OP-alternative imidacloprid. In a recent study in Australia, Herron and James (2005) reported resistance of *F. occidentalis* to chlorpyrifos, dichlorvos, and malathion. At the same time resistant individuals where detected for acephate, dimethoate, endosulfan, fipronil, mathemidophos, methidathion, and spinosad. Laboratory selections using fipronil and spinosad were successful rearing increasingly resistant populations of thrips, this was the first report of induced resistance to spinosad and fipronil to *Frankliniella* thrips.

Another consideration when using chemical alternatives to control thrips in integrated pest management (IPM) is the effect of these insecticides on non-target organisms, principally natural enemies. The effect of traditional and reduced-risk insecticides to non-target organisms is well documented. To mention a few examples, studies on natural enemies of thrips include *Geocoris punctipes* (Mizell and Sconyers 1992, Elzen et al. 1998, Elzen 2001, Myers et al. 2006), *Orius* spp. (Elzen et al. 1998, Ludwig and Oetting 2001, Studebaker and Kring 2003), and in *Amblyseius* spp. (Castagnoli et al. 2002). All these studies demonstrated the lethal and sub-lethal

effects of these chemical products on natural enemies. Selective insecticides will facilitate adequate biological control. Insecticides that have little effect on non-target organisms are desirable due to their compatibility with natural enemies, which is the basis for a successful IPM program. The present study shows the relationship between selected reduced-risk insecticides that have the potential to control flower thrips in early-season blueberries and to replace traditional insecticides in commercial fields. The results from the field were complemented with laboratory bioassays to determine the effect of these insecticides under controlled conditions on flower thrips and on *Orius insidiosus* Say, one of the most common and effective natural enemies for thrips control in Florida (Funderburk et al. 2000).

Material and Methods

Field Trials

Field experiments were conducted from 2004 to 2006 in four commercial blueberry farms located in Florida and southern Georgia. Three farms in Florida (IFL04 located at N 28^{o} 04' W 81^{o} 35', IFL05 located at N 27^{o} 30' W 81^{o} 31', and IFL06 N 29^{o} 40' W 82^{o} 11') and one farm located in Georgia (IGA04 located at N 31^{o} 31' W 82^{o} 27') were selected for these trials. Each year the insecticides that showed the most potential from previous season and a few more insecticides were compared. A selection of reduced-risk insecticides, traditional insecticides, and OP alternatives was selected to determine their efficacy. Treatments were sprayed after sunset because of the concerns about the effect of these insecticides on populations of honeybees used for blueberry pollination. The plot sized varied depending on the farm conditions and the areas where we were allowed to work during each one of the seasons.

To determine the effect of insecticides on thrips populations, I deployed a white sticky trap in the middle of each treatment and randomly collected 5 flower-clusters from the blueberry bushes holding the traps. Sticky traps were deployed in the field one week prior to the

application of the treatments. These traps were collected before the application and replaced by a new one, which was located in the same position and collected one week after the treatment. The experimental design in all cases was a completely randomized extended block design. The block in my experiments was represented by the application (first application and second application) and each one of the blocks had four replicates of each of treatment evaluated. Due to the highly aggregated pattern shown by flower thrips in early-season blueberry fields (chapters 3 and 4), I decided to analyze the effect of these insecticides using the growth rate (r). This growth rate (r) represents the change in thrips population due the insecticide application. An r value of 1 represents no changes in the population after the application of the treatment. If $r > 1$, then more thrips were captured during the week after the application than the week prior to the application; and a value of $r < 1$ represents a fall in the number of thrips in the week after the application compared with the week before the application. In the case of sticky traps, I used the total number of thrips captured during the week immediately after treatment divided by the total number of thrips captured at the same location the week prior to the treatment. To analyze the number thrips inside the blueberry flowers, I used the 'shake and rinse' method (Chapter 3) and divided the number of thrips extracted from five flower-clusters one week after the treatment by the number of thrips extracted from the same amount of flower-clusters collected the day of the treatment in the same blueberry bush. Comparisons were conducted using a one-way ANOVA and LSD tests for mean comparison (SAS Institute Inc. 2002). The experimental design in all cases was a completely randomized extended block design. The block in my experiments was represented by the application (first application and second application) and each one of the blocks had four replicates of each of treatment evaluated.

IFL04: This farm located in south central Florida was used for the trials conducted in 2004. Treatments were sprayed two-times during flowering of blueberry bushes with a 14 day interval between sprays as recommended by the Small Fruit and Vegetable IPM Laboratory at the University of Florida (O.E Liburd Personal communication). Insecticide treatments were applied at the doses recommended by the manufacturer. Treatments were sprayed using four-gallon backpack sprayers (Lowe's North Wilkesboro, NC). The sprayers were manually pumped to a maximum capacity and the handle was pumped once every five seconds to maintain a homogeneous pressure. A completely randomized extended block design with eight treatments, four replicates and two blocks were used to evaluate insecticides. The treatments used were: Malathion 5 EC at 139.8 g a.i. / ha, Calypso 480C (thiacloprid) at 116.92 g a.i. / ha, Assail 70WP(acetamiprid) at 112.78 g a.i. / ha, Novaluron 174.08 g a.i. / ha, SpinTor 2SC (spinosad) 105 g a.i. / ha, Knack (Pyriproxyfen) at 120 g a.i. / ha, GF968 (spinosad experimental insecticide) at 52.63 g a.i. / ha, and an untreated control. Each plot measured 84 m^2 with a 15 m buffer zones between plots. The selected plot was covered with black bird netting to reduce the attack of birds during harvest.

IGA04: This farm located in southern Georgia was planted in rabbiteye blueberries and the trial was conducted during the 2004 flowering season. Selected plots for this trial covered 193 m^2 with 12 m buffer zones between the plots. There were eight treatments and four replicates of each treatment using the same experimental design as above. Insecticides treatments were applied to plots using a 400 gal., tractor-mounted orchard airblast sprayer. Treatments evaluated included Malathion 5 EC at 139.8 g a.i. / ha, Calypso 480C (thiacloprid) at 116.92 g a.i. / ha, Assail 70WP(acetamiprid) at 112.78 g a.i. / ha, Pedestal (novaluron) 174.08 g a.i. / ha, SpinTor

2SC (spinosad) 105 g a.i. / ha, Knack (pyriproxyfen) at 120 g a.i. / ha, Actara 25WG (thiamethoxam) 78.80 g / ha, and an untreated control.

IFL05: Located in south Florida, this farm used low density southern highbush blueberries. Treatments were sprayed during the 2005 flowering season using an airblast sprayer as described above at the manufacturer recommended doses. The treatments included were Malathion 5 EC at 139.8 g a.i. / ha, SpinTor 2SC (spinosad) 105 g a.i. / ha, Assail 30SG (used as TD 2480 acetamiprid- experimental insecticide) 5.4 oz/acre, Assail 70WP (acetamiprid) 112.77 g / ha, Diamond .83EC (novaluron) 145.35 g / ha, Actara 25WG (thiamethoxam) 78.80 g / ha. Treatments were applied in plots of 471 m^2 with 9 m of buffer zone between treatments and 41 m between blocks of 7 treatments. Each treatment had four replicates.

IFL06: This farm was located in north-central Florida and was planted with southern highbush blueberries. Treatments were sprayed during the 2006 flowering season using a CO_2 sprayer calibrated at 23 PSI and using a Teejet hollow cone spray core D3 disk DC 25 (Spraying systems Co. Keystone Heights, FL). I used four replicates per treatment and the plots were distributed in a completely randomized extended block design. Each plot covered 219.46 m^2 and buffers between treatments were 30.4 m long with 4 m between rows. The treatments used in this farm were: Malathion 5 EC at 139.8 g a.i. / ha, SpinTor 2SC (spinosad) 105 g a.i. / ha, Diamond .83EC (novaluron) 145.35 g / ha, Assail 30 SG (acetamiprid) 113.48 g / ha, Actara 25WG (thiamethoxam) 78.80 g / ha, Coragen 20SC (rynaxpyr formally known as DPX-E2Y45) 98.63 g / ha, and an untreated control

Laboratory Trials

During the laboratory trials, I evaluated the eight most promising treatments studied in the field. Laboratory trials were divided into two parts 1) toxicity of insecticides to flower thrips and 2) the effect of the insecticides on non-target organisms. With regard to non-target organisms, I

selected *O. insidiosus* because it is one of the principal natural enemies of flower thrips in North America (Van de Veire and Degheele 1995, Funderburk et al. 2000, Shipp and Wang 2003, Liburd and Arévalo 2005).

Both organisms were tested in similar arenas, a 300 ml white polyethylene jar (B & A Products, Ltd. Co., Bunch, Oklahoma). The lids of these jars were modified in such a way that only the rim remained. The jars were covered with non-thrips mesh (Bioquip. Rancho Dominguez, CA) and the modified lids were screw-on over the mesh to prevent the insects from escaping. This modification allowed ventilation of the arenas. For both insects, two green beans were used as the substrate for each treatment. The green beans were cleaned using a solution of 0.6% sodium hypochlorite and de-ionized (DI) water for ten minutes, then rinsed with DI water and air dry for 2 h. Green beans were sprayed using a hand-held spray bottle that released 2 ml of solution per spray (two sprays per treatment). The green beans were then air-dried for two hours and then placed inside the arenas.

Ten *O. insidiosus* were released into each one of the arenas. The number of live *O. insidiosus* was recorded at selected times after the release. *Orius insidiosus* individuals were selected from a laboratory colony which started approximately 2 months prior to the start of the experiments. *Orius insidiosus* was initially obtained form Koppert Biological Systems (Romolus, MI). During this trial, I added five live adult thrips, which were not exposed to insecticides, to each one of the replicates every two hours. Thrips that were found dead inside the *O. insidiosus* arenas were removed. The thrips addition was done with the objective of feeding the predators as if they were under field conditions. Treatments were prepared at the same concentrations as in field experiments assuming 935 liters / ha (100 U.S gallons / acre) unless otherwise specified on the label. The treatments selected for *O. insidiosus* were Actara 25WG (thiamethoxam) at 78.80

g a.i. / ha, Assail 70WP (acetamiprid) at 112.77g a.i. / ha, Malathion 5EC (malathion) 139.8 g a.i / ha, and SpinTor 2SC (spinosad) 105 g a.i. / ha. These insecticides were either as the most commonly used or they have the highest potential to control thrips in blueberry fields as observed in the field experiments. This experiment was designed as a completely randomized experiment with six replicates. and analyzed hour by hour using a one-way ANOVA table and the treatments were compared using LSD mean separation tests ($\alpha = 0.05$).

Flower thrips were collected in blueberry fields in north-central Florida and brought to the laboratory for identification. *Frankliniella bispinosa* (Morgan) was selected because it was the most abundant thrips recorded in Florida according to our field survey (Chapter 4). Thrips were kept under laboratory conditions (27^{o}C and 70% RH) for two days before the trials began. The colonies were fed with a mixture of honey and pollen spread over green beans, which were cleaned using a 0.6% sodium hypochlorite and de-ionized (DI) water as described above. Active-adult thrips were selected for the trials and divided into groups of ten. These were randomly released into the arenas once the treated green beans were dry and in place. Experiments were organized in completely randomized designs with five replicates. the treatment tested on the thrips included Actara, Assail 70WP 112.7 g a.i. / ha, Calypso 480C at 116.9 g a.i. / ha, Kanck at 120 g a.i. / ha, GF 968 (an spinosad experimental) at 52.63 g a.i. / ha, Malathion at 5EC 139.8 g a.i. / ha, Novaluron, SpinTor 2SC at 105 g a.i. / ha and an untreated control. Analysis was conducted using ANOVA tables and LSD mean separation analysis ($\alpha = 0.05$) (SAS Institute Inc. 2002).

The experiments lasted until no more mortality was observed in the treatments, for thrips the laboratory experiment lasted 12 h and for *O. insidiosus* lasted 24 h. Preliminary experiments with *O. insidiosus* had indicated that the insecticides had a delay effect on these predatory

insects. During the preliminary experiments conducted under the same conditions, most of the deaths occurred between 10 and 20 h after exposure to the treated green beans. For this reason, most of the observations were taken during this interval.

Results and Discussion

Field trials

IFL04: When observing the effectiveness of the insecticide on the populations located inside the flowers in this farm, only two insecticides had a significantly lower *r* value than the control: Novaluron ($r = 1.1 \pm 0.8$) and Assail 70WP ($r = 0.55 \pm 0.08$) ($F = 9.24$, df = 7, 53; $P < 0.0001$). Novaluron's *r* value was significantly lower than Malathion 5EC, Knack, and GF968, but it was significantly higher than Assail 70W. Assail 70 WP (acetamiprid) was the only compound that reduced thrips population inside blueberry flowers as shown by $r < 1$(Figure 6-1). In the floating populations, those collected in the sticky traps, similar results were observed. Assail 70WP had the lowest *r* value and it showed to be significantly lower than all the other treatments including the control. The growth rate (*r*) for Novaluron and Malathion was significantly lower than SpinTor 2SC but not significantly different from any of the other treatments with exception of Assail, ($F = 5.22$, df = 7, 53; $P < 0.0001$). SpinTor had the highest *r* value in the sticky traps (Figure 6- 2).

IGA04: The results obtained in Georgia in 2004 did not show significant differences among the treatments ($F = 0.66$, df = 7, 54; $P = 0.7456$). However, the floating population in all of treatments decreased during this season in similar proportions, which might indicate that the reduction in thrips population was independent of the insecticide treatments.

IFL05: There was very limited activity of thrips during this flowering season on the selected farm. For this reason, it was not possible to collect enough data for a robust analysis to show the effect of these insecticides on thrips population inside the flowers. However, I observed

increasing number of thrips captured in the white sticky traps. In all the treatments, the populations increased possibly as a result of immigration, since the amount of thrips inside the flowers where they reproduce (Chapter 4) was very limited. None of treatments was significantly different from the control. However, Actara 25WG and Assail 70WPsignificantly reduced the population growth when compared with Malathion 5 EC, (F = 4.79, df = 6, 48; P = 0.0004), but they were not significantly different from any of the other treatments including the control (Figure 6- 4).

IFL06: On the experiments conducted in Florida in 2006, none of treatments was significantly different from the control when comparing the r value for the sticky traps (F = 4.01, df = 6, 48; P = 0.0016) or inside the flowers (F = 0.48, df = 6, 48; P = 0.7275). The r value for the thrips captured in the sticky traps increased overtime independent of treatment applications, with exception of Coragen 20SC (r = 0.93 ± 0.21), which was the only treatment with $r < 1$. Coragen 20SC had a significantly lower r value than Diamond .83EC. However, the comparisons of all other treatments were non-significant (Figure 6- 5). On the established populations collected from the flowers, the situation was similar to the situation encountered in the sticky traps. None of treatments significantly reduced the population growth (r) when they were compared (Figure 6- 6).

Laboratory Trials

Thrips bioassay

All the insecticides were effective against thrips in the laboratory. From 1h after the release of the thrips in the arenas, all the treatments had significantly less thrips surviving when compared with the control (F = 13.86; df = 8, 36; $P < 0.001$). After 1 h of contact with the treated green beans, all the insecticides killed half of the insects exposed to the treatments. Three of the treatments, Actara 25WG, Assail 70WP, and Malathion 5EC, reduced the population to

less than one third of the original size within the first hour (Table 6-1). The only insecticide that killed all the thrips exposed to it was SpinTor 2SC. This insecticide in less than four hours reduced the population to zero. However, this result was not significantly different to Assail 70WP, Knack, and Malathion 5EC. Six hours after the thrips were exposed to the treated green beans, all the treatments were not significantly different from each other except for the control. After 6 h of exposure to insecticides, all of the insecticides virtually eliminated the thrips in the arena.

***Orius insidiosus* bioassay**

Three of the four treatments tested killed more than 70% of the *O. insidiosus* used in the bioassays after 24 h. SpinTor 2SC was the insecticide that killed the lowest proportion of predators (Table 6- 2). The most lethal insecticide was Actara 25WG, which killed almost all the insects in the first 20 h. Throughout the duration of the experiment, Actara 25WG and Assail 70WP, had consistently the lowest survival rate compared with all the other treatments. Neither treatment (Actara 25WG and Assail 70WP) were significantly different from each other. Fast acting treatments, Actara 25WG and Assail 70WP started showing significant differences with the control one hour after exposure ($F = 4.87$; df = 4, 25; $P = 0.0016$). Ten hours later only one treatment, SpinTor 2SC, was not significantly different from the control ($F = 8.09$; df = 4, 25; $P < 0.001$). This situation was true for the initial 12 h after exposure ($F = 11.87$; df = 4, 25; $P < 0.001$). Fifteen hours after exposure SpinTor 2SC showed significant differences with the control, but was the chemical treatment with the highest proportion of survivors (0.73 ± 0.04) (Table 6- 2).

In this study, I tested nine commercial insecticides and three experimental insecticides under various locations, methods of application, and cultivars. Among the treatments used,

Assail (acetamiprid) in its two formulations, Assail 70WP (used in IFL04, IGA04, and IFL05), and Assail 30SG used in IFL05 (as experimental TD 2480) and in IFL06, were the most consistent of the insecticides in controlling the population growth rate (*r*) of flower thrips in blueberries. Assail 70WP is a reduced-risk insecticide labeled for thrips control in cotton, Cole crops and fruiting vegetables but it is not yet labeled for use in blueberries, but it is a potential candidate to be labeled to be used in blueberries (OE Liburd personal communication). Acetamiprid had been mentioned by Morishita (2001) as effective in thrips control under laboratory conditions. In the laboratory bioassays, Assail 70WP demonstrated to be fast acting insecticide reducing the number of thrips alive to one-forth of the initial population on the first hour of exposure. After 6 h of exposure the number of surviving thrips was virtually zero (Table 6-1). Assail 70WP appears to be toxic to *O. insidiosus* during the first ten hours of exposure. After 10 hours after the release the population declines rapidly from 63 % to 20 % in the next five hours. After 15 h, Assail 70 WP seems to have no effect on the surviving *O. insidiosus*.

SpinTor 2SC is another reduced-risk insecticide that has been used on thrips control in several crops including berries, cotton, grapes, and tubers among several others. In the laboratory experiments, SpinTor was the first insecticide that killed 100% of the thrips exposed to treated green beans. At the same time SpinTor was the most compatible treatment with *O. insidiosus*. In the laboratory, 70% of *O. insidiosus* survived after 24 h of exposure. Despite that the treatment had significantly less survivors than the control, SpinTor 2SC was the insecticide that had the least effect among the insecticides screened having significantly more survivors than any of the other treatments (Table 6- 2). The number of survivors was significantly lower than the control after 15 h of exposure to treated green beans. This ‘lag time’ has been observed with other

species such as *Geocoris punctipes* Say (Myers et al. 2006), and in blueberry maggot, *Rhagoletis mendax* Curran (Liburd et al. 2003).

In the field SpinTor 2SC did not have a significant effect on thrips populations. In all cases both populations exposed to SpinTor, floating and established, increased and were among the populations with the highest *r* values, with exception of the established population, collected from flowers, in 2004 at IFL04. However, it was not significantly different from the control or any of treatments used that year with exception of Assail 70WP, which was significantly lower (Figure 6- 1). The reduced effectiveness in the field might be related to the low residual activity of this insecticide. In field experiments in egg plants spinosad lost all activity after six days (McLeod et al. 2002). If the residual activity of SpinTor 2SC is similar in blueberries this will indicate that there is not enough residual time to protect the blueberry bushes for the time between applications (two weeks).

Malathion, a conventional insecticide, was not significantly different from the control in any of the observations conducted. In the laboratory bioassays, malathion was one of the fastest acting products. It killed more than two thirds of the population in the first hour. Four hours after the treatment, malathion killed almost all the thrips exposed to the treated green beans (Table 6-1). In the *O. insidiosus* bioassay, malathion killed significantly less predators than Actara at all times, but significantly more than SpinTor. On average malathion killed close to 70% of the *O. insidiosus* individuals after 24 h (Table 6- 2).

The use of growth rate (*r*) in the field, as the ratio of the population after the treatments divided by the population before the treatments, reduces the risk of misinterpretation of the data in cases where insect populations are not uniform or randomly distributed. In the case of flower thrips in blueberries, the distribution is highly aggregated (chapter 3), thus analysis of the final

number of thrips captured after the applications might be affected by the presence of a 'hot-spot' or aggregation sites in places where samples are taken. The use of *r* will reduce this problem by taking into consideration the initial populations inside the treatments before the applications. However, it assumes that external conditions, such as temperature immigration, rain, affect all the plots with in a block similarly. Apparently the population growth of thrips in blueberry fields is associated more with immigration than with the populations found in the fields. Every day more and more thrips arrive to the fields and the insecticides are active for short periods of time, for this reason in most of the cases the population rates after / before the application were more than 1. From my results, any of the reduced-risk insecticides tested in these experiments were as or more effective than malathion to control flower thrips in blueberries. Assail 70WP and Assail 30 SG were the most effective and consistent of treatments reducing the growth rate (*r*) of flower thrips in the field. These results were also corroborated by the results in the laboratory. SpinTor 2SC was as effective as any of the other treatments and at the same time the most compatible with *O. insidiosus* which is one of the main natural enemies, so it will be a good alternative in places where natural enemies are a high priority.

Tables and Figures

Table 6-1. Proportion of *Frankliniella bispinosa* surviving at various times after release into the bioassay arenas in 2004.

	Hours after the release (HAR) of *Frankliniella bispinosa* in 2004			
Treatments	1	4	6	12
Control	1.00 ± 0.00 (a)	1.00 ± 0.00 (a)	0.92 ± 0.02 (a)	0.92 ± 0.02 (a)
Actara	0.15 ± 0.04 (e)	0.02 ± 0.02 (d)	0.02 ± 0.02 (bc)	0.02 ± 0.02 (b)
Assail	0.25 ± 0.02 (de)	0.06 ± 0.03 (cd)	0.02 ± 0.02 (bc)	0.02 ± 0.02 (b)
Calypso	0.39 ± 0.04 (bcd)	0.11 ± 0.05 (bc)	0.06 ± 0.02 (bc)	0.02 ± 0.02 (b)
Knack	0.38 ± 0.05 (bcd)	0.04 ± 0.02 (cd)	0.04 ± 0.03 (bc)	0.02 ± 0.02 (b)
GF 968	0.41 ± 0.04 (bc)	0.12 ± 0.03 (bc)	0.03 ± 0.03 (bc)	0.03 ± 0.03 (b)
Malathion	0.29 ± 0.07 (cde)	0.04 ± 0.02 (cd)	0.02 ± 0.02 (bc)	0.02 ± 0.02 (b)
Novaluron	0.49 ± 0.07 (b)	0.16 ± 0.04 (b)	0.07 ± 0.04 (b)	0.03 ± 0.03 (b)
SpinTor	0.39 ± 0.08 (bcd)	0.00 ± 0.00 (d)	0.00 ± 0.00 (c)	0.00 ± 0.00 (b)

Means followed by the same letter within each column are not significantly different from each other when compared using LSD test ($\alpha = 0.05$).1 HAR ($F = 13.86$; df = 8, 36; $P < 0.001$); 4 HAR ($F = 47.08$; df = 8, 36; $P < 0.001$); 6 HAR ($F = 84.56$; df = 8, 36; $P < 0.001$); 12 HAR ($F = 115.00$; df = 8, 36; $P < 0.001$).

Table 6- 2. Proportion of *Orius insidiosus* surviving at various times after release into bioassay arenas.

	Hours after the release (HAR) of *Orius insidiosus*					
Treatments	1	10	12	15	20	24
Control	1.00 ± 0.00 (a)	1.00 ± 0.00 (a)	0.96 ± 0.03 (a)	0.96 ± 0.03 (a)	0.96 ± 0.03 (a)	0.93 ± 0.06 (a)
Actara	0.56 ± 0.06 (b)	0.56 ±0.06 (c)	0.36 ± 0.06 (c)	0.33 ± 0.04 (c)	0.06 ± 0.06 (d)	0.03 ± 0.03 (d)
Assail	0.63 ± 0.03 (b)	0.63 ± 0.03 (bc)	0.36 ± 0.13 (c)	0.20 ± 0.07 (c)	0.20 ± 0.07 (d)	0.20 ± 0.07 (cd)
Malathion	0.87 ± 0.04 (a)	0.80 ± 0.00 (b)	0.73 ± 0.04 (b)	0.66 ± 0.04 (b)	0.50 ± 0.07 (c)	0.30 ± 0.04 (c)
SpinTor	0.90 ± 0.04 (a)	0.90 ± 0.04 (a)	0.90 ± 0.04 (a)	0.73 ± 0.04 (b)	0.70 ± 0.04 (b)	0.70 ± 0.04 (b)

Means with the same letter within each column are not significantly different from each other when compared using LSD test (α = 0.05). for 1 HAR (F = 4.87; df = 4, 25; P = 0.0016); 10 HAR (F = *8.09*; df = 4, 25; $P < 0.001$); 12 HAR (F = 11.87; df = 4, 25; $P <$ 0.001); 15 HAR (F = 18.24; df = 4, 20; $P < 0.001$); 20 HAR (F = 17.42; df = 4, 20; $P < 0.001$); 24 HAR (F = 26.31; df = 4, 20; $P <$ 0.001);

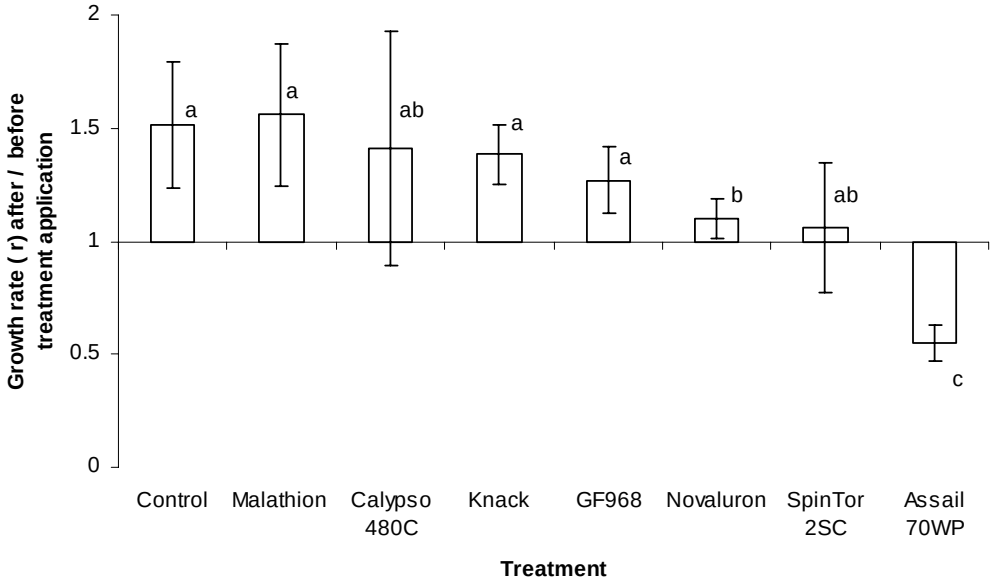


Figure 6- 1: Average growth rate (*r*) between the week before treatment application and the week after the application of the treatments. Thrips populations correspond to the thrips recovered from the flowers collected in IFL04. Significant differences with control are marked by [*] when compared using LSD test (α= 0.05).

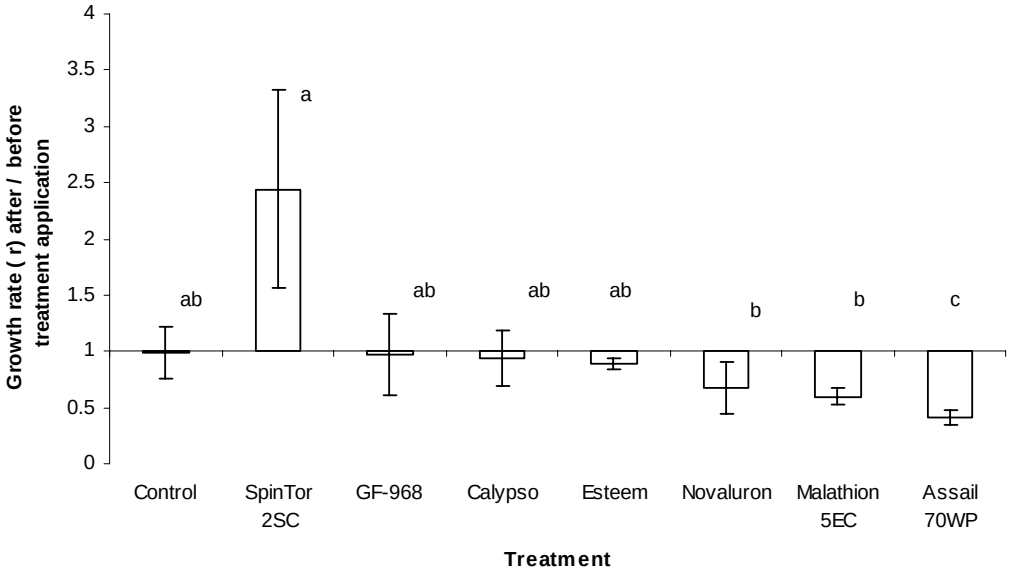


Figure 6- 2: Average growth rate (*r*) between the week before treatment application and the week after the application of the treatments. Thrips populations correspond to the thrips captured in white sticky traps collected in IFL04. Significant differences with control are marked by [*] when compared using LSD test (α= 0.05).

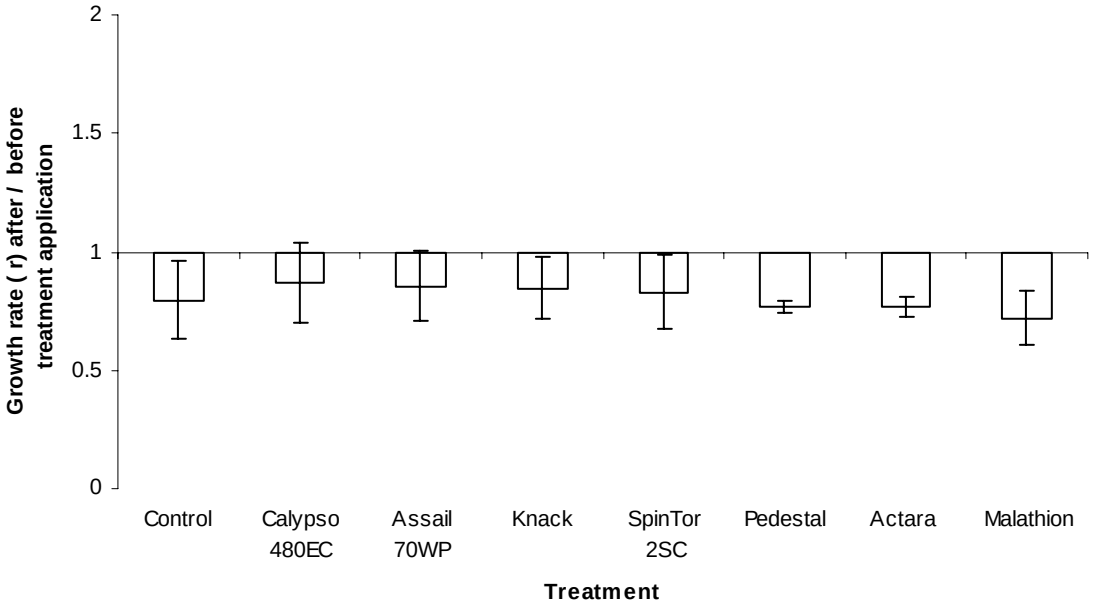


Figure 6- 3: Average growth rate (*r*) between the week before treatment application and the week after the application of the treatments. Thrips populations correspond to the thrips captured in white sticky traps collected in IGA04.

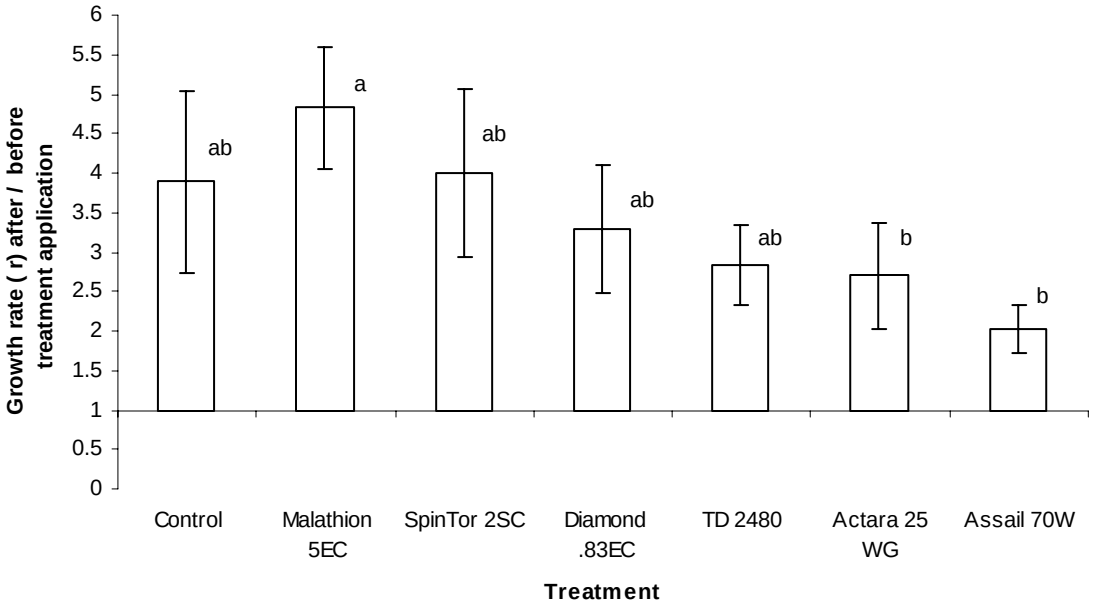


Figure 6- 4: Average growth rate (*r*) between the week before treatment application and the week after the application of the treatments. Thrips populations correspond to the thrips captured in white sticky traps collected in IFL05. Significant differences are represented by different letters when compared using LSD test (α= 0.05).

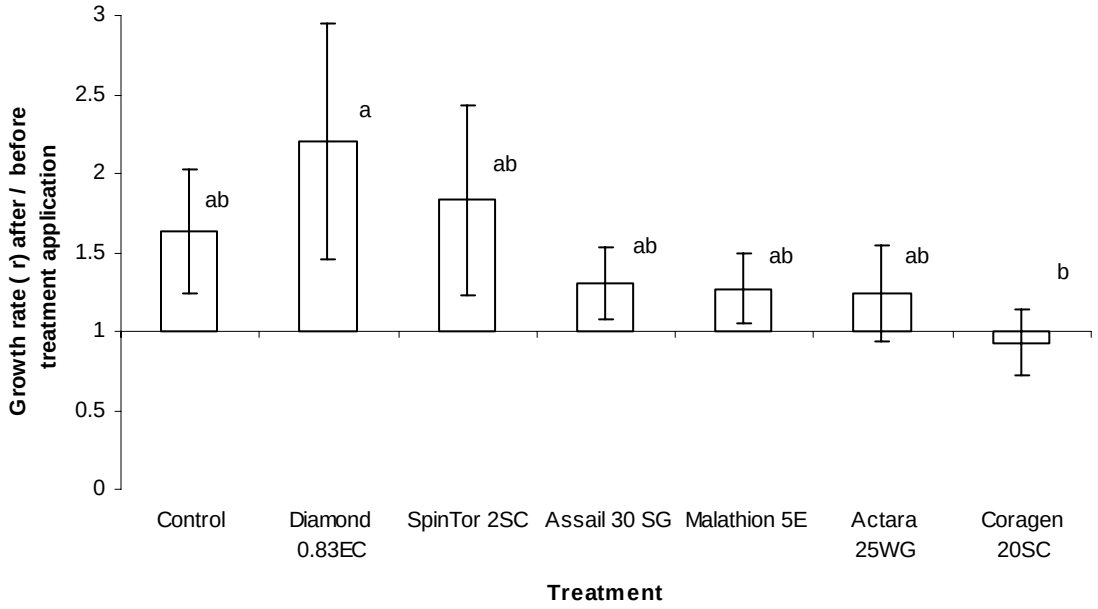


Figure 6- 5: Average growth rate (*r*) between the week before treatment application and the week after the application of the treatments. Thrips populations correspond to the thrips captured in white sticky traps collected in IFL06. Significant differences are represented by different letters when compared using LSD test (α= 0.05). 1/sqrt(x)

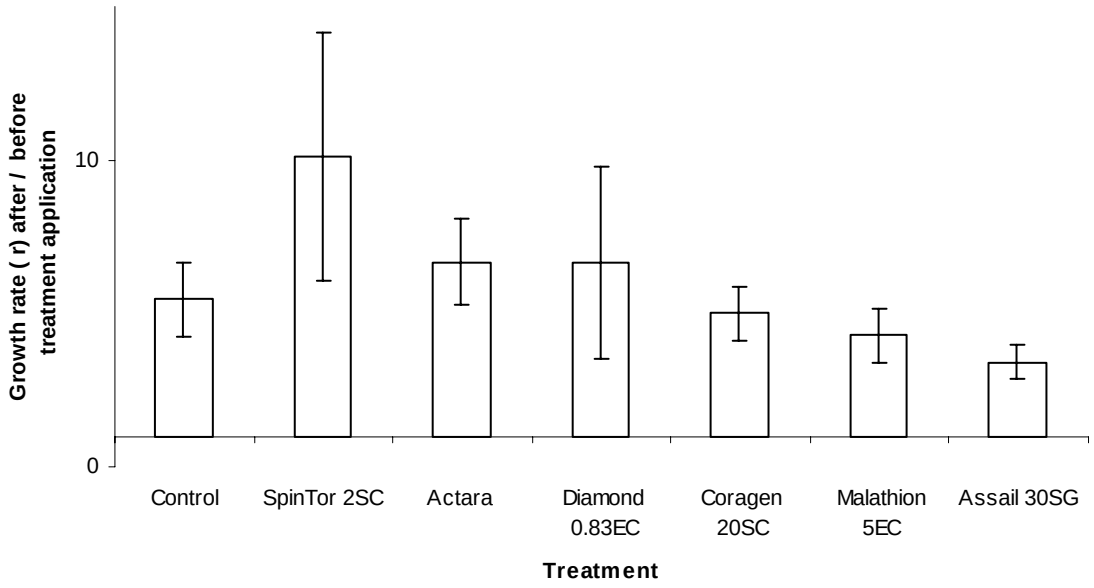


Figure 6- 6: Average growth rate (*r*) between the week before treatment application and the week after the application of the treatments. Thrips populations correspond to the thrips recovered from inside the flowers in IFL06. Significant differences are represented by different letters when compared using LSD test (α= 0.05). (F = 0.48, df = 6, 48; P = 0.7275)

CHAPTER 7
EFFECTIVENESS OF PREVENTIVE AND INUNDATIVE BIOLOGICAL CONTROL TACTICS TO MANAGE FLOWER THRIPS POPULATIONS IN EARLY-SEASON BLUEBERRIES

Thrips have many natural enemies that help to manage their populations keeping them under the economic injury level. There are 23 families distributed in eight insect orders and nine families of mites that have been reported as natural enemies of thrips (Sabelis and VanRijn 1997). However, the vast majority of these natural enemies is polyphagous and feed on a diversity of small insects including thrips. Most of the research studying these predatory arthropods has been conducted in greenhouses where the predator-prey interaction is localized and the environmental complexity is limited (Sabelis and VanRijn 1997). Hoy and Glenister (1991) showed that inundative releases of *Amblyseius* sp. are not effective enough to reduce thrips populations below the damage thresholds on field cabbage, despite the time of release and number of mites released.

Thrips are known to be prolific, polyphagous, have short generation time, a tendency to aggregate and they tend to exploit localized ephemeral optimal conditions, which characterize them as *r*-selected insects (Mound and Teulon 1995). Due to these characteristics, principally aggregation, flower thrips are able to dramatically increase their population in short periods of time (Chapters 3 and 4). One of the main objectives of biological control is to achieve long-term pest regulation, keeping the populations of the target organisms below injury levels (VanDriesche and Bellows 2001). My objective is to test the efficacy of commercially available natural enemies of flower thrips in early-season blueberry fields. Inundative-preventive and inundative-curative methods were

evaluated to determine if *O. insidiosus* and *A. cucumeris* are able to reduce the number of flower thrips in the field during the blueberry flowering season.

Materials and Methods

A farm located in north-central Florida (N 28^{o} 54' W 82^{o} 14) was selected to conduct the biological control trials. This farm uses minimum applications of pesticides and is planted with southern highbush blueberries. *Orius insidiosus* Say (Hemiptera: Anthocoridae) as 'Thripor-I' and *Amblyseius cucumeris* (Oudemans) (Acari: Phytoseiidae) as 'Thripex-plus' were selected as they are commercially recommended for flower thrips control (Koppert biological systems Romulus, MI). The farm was divided in 16 plots organized in four blocks of four 283 m^2. There were buffer zones of 17m between blocks and 5 m between plots with in a block.

The experiment was design as a completely randomized block with four replicates and four treatments. Treatments used in the experiments were 1) *O. insidiosus*, 2) *A. cucumeris*, 3) combination of both *O.* insidiosus and *A.* cucumeris in half doses, and 4) untreated control. The first year of the experiment (2005), I released the natural enemies as preventive tactic. Natural enemies were released one week after flowering started, before thrips population began to build-up and the "hot-spots" were defined (Chapter 3). I used the doses recommended for preventive control: *O. insidiosus* (Thripor-I) was released at 0.5 insects per m^2, *A. cucumeris* (Thripex-Plus) at 0.5 sachets of 1000 mites per m^2. For the combination treatment, I released half doses of each biocontrol agent.

The analysis conducted compared the population of flower thrips in each one of the sampling dates using one-way ANOVA tables and LSD mean separation test ($\alpha = 0,05$) for each one of the sampling dates (SAS Institute Inc. 2002).

During the second season, 2006, I tested the use of biocontrol agents as curative method for the control of flower thrips. I used the same set-up as the experiments conducted in 2005. A new randomization of treatments was conducted. The manufacturer recommended doses for curative control were: *O. insidiosus* (Thripor-I) 10 insects per m^2, and *A. cucumeris* (Thripex-Plus) 1.3 sachets of 1000 mites per m^2. The treatments were released on February 15, 2006 when the number of thrips on sticky traps was above 100 thrips per trap (Figure 7- 2). These treatments were compared with a control where no natural enemies were released. To discourage the movement of natural enemies between plots SpinTor 2SC (spinosad) 105 g a.i. / ha was sprayed in the buffer zones whenever natural enemies were released. In the center of each treatment a white sticky trap was deployed weekly. A sample of five flower-clusters was collected every week from each repetition and processed using the 'shake and rinse' method (chapter 3) to determine thrips population inside the flowers.

Differences between the treatments were analyzed using the LSD mean separation test ($\alpha = 0.05$) for each one of the sampling dates(SAS Institute Inc. 2002). At the same time an analysis of the population growth rate (r) comparing the increment of the population one week after the release, and two weeks after the release of natural enemies, with the population of thrips before the release (Chapter 6).

Results and Discussion

The trials conducted in 2005, indicated that releases of *O. insidiosus* or *A. cucumeris*, as well as the combination of both treatments as a preventive tactic does not reduce thrips populations in blueberries during the flowering period. One week after the release of natural enemies, February 5- 11, 2005, I found that thrips population in the control were on average significantly lower than in treatments of *O. insidiosus*, and *A.*

cucumeris alone. However, no significant differences were detected between the control and the combination treatment during the first week after release ($F = 7.13$; df = 3, 9; $P = 0.016$) (Figure 7- 1). The same situation was observed during the second week after the release February 12- 18, 2005 ($F = 2.83$; df = 3, 9; $P = 0.0988$). During the last week of sampling February 19- 25, 2005 the control had significantly less thrips than any of treatments in sticky traps ($F = 7.95$; df = 3, 9; $P = 0.0067$) (Figure 7- 1). Due to the low population of thrips in 2005, I could not collect enough thrips from inside the flowers to make a robust analysis.

In 2006 when curative releases of *O. insidiosus*, *A. cucumeris*, and the combination treatment of both natural enemies were conducted, I found no significant differences between the treatments of natural enemies and the control in the number of thrips caught on the sticky traps (Figure 7- 2) or inside the flowers (Figure 7- 3). I calculated the growth ratio (r) of thrips population for one and two weeks after the release of natural enemies in relation with the week before the release (Chapter 6). The results of this analysis showed no significant differences among the treatments in sticky traps (Figure 7- 4) or in flowers (Figure 7- 5). Despite that there was no a significant change in the r value inside flowers ($\alpha = 0.05$), we detected a significant reduction of r in all treatments when compared with the control one week after the release of natural enemies when $\alpha = 0.1$, but no differences among the treatments using natural enemies (Figure 7- 5).

My results were consistent with observations made by Mound and Teulon (1995) and by Parella and Lewis (1997). These authors concluded that the biological characteristics of thrips overcome the attributes of natural enemies in such a way that the participation of natural enemies in the regulation of field populations of thrips is minor.

Other authors argued that the use of natural enemies is enough to control thrips populations (Van de Veire and Degheele 1995, Shipp and Wang 2003).

Most of the studies that conclude that *Orius* spp. and *A. cucumeris* are efficient in controlling flower thrips were conducted under greenhouse conditions (Van de Veire and Degheele 1995, Jacobson 1997, Shipp and Wang 2003). One of the few successes in control of flower thrips under field conditions was reported by Funderburk et al. (2000). The authors showed that untreated fields and field treated with spinosad had a significantly higher population of *Orius* spp. and lower population of flower thrips than fields treated with acephate and fenopropathrin, which excluded the predator. The reduction in thrips population began between 55 and 60 days after transplanting, approximately 10 days after the first sampling. This period of time allowed the natural enemies to build their population, and have an effect on thrips population. The situation in blueberries is different i.e. thrips are only present for an average for 20 to 25 days, which correspond to the flowering period in blueberries (Chapter 3 and 4). This short period of time might not be long enough for the natural enemies to establish and reach a significant level of control. When the natural enemies were released as preventive method, I found that the control had significantly less thrips than the other treatments at the end of the season. I believe the reason for this difference relies in the polyphagy of natural enemies used. The natural enemies were released before thrips were present in the field. Hulsof and Vänninen (2001) mentioned that the presence of *Orius* spp. depends on the crop characteristics principally the viability of pollen and the presence of alternative preys. Since there was no pollen or thrips present in the blueberries at the time of the release of *Orius* spp. this natural enemies may have preyed on natural enemies and

competitors of flower thrips and emigrated from the field before thrips population was present. This situation might have created a niche free of natural enemies where thrips can reproduce more efficiently. At the same time, the low temperatures during the days following the release (-1^{o} C on February 5, 2005 and 3^{o} C on February 6, 2005) and the lack of pollen in the field might have had an effect on the survival of mites. These situations combined might have influenced an increase of the number of thrips in those treatments were the predators were released. These opinions are rather speculative. The exact reason for the increase in thrips populations in the non-control treatments is not known. More research about the interaction of flower thrips and their natural enemies in early season-blueberries needs to be conducted.

Tables and Figures

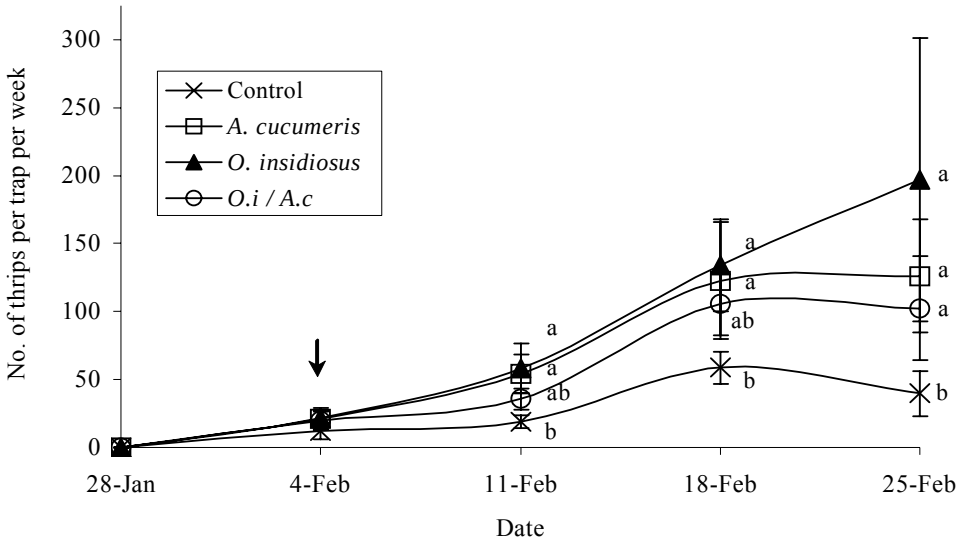


Figure 7- 1: Average number of thrips captured per week after the release of natural enemies, as a preventive measure, in white sticky traps located inside the blueberry bush in 2005. Treatments followed by the same letter are not significantly different when compared using LSD ($\alpha = 0.05$). The arrow represents the date of release. February 4, 2005 ($F = 1.52$; df = 3, 9; $P = 0.62$), February 11, 2005 ($F = 7.13$; df = 3, 9; $P = 0.016$), February 18, 2005 ($F = 2.83$; df = 3, 9; $P = 0.0988$), February 25, 2005 ($F = 7.95$; df = 3, 9; $P = 0.0067$)

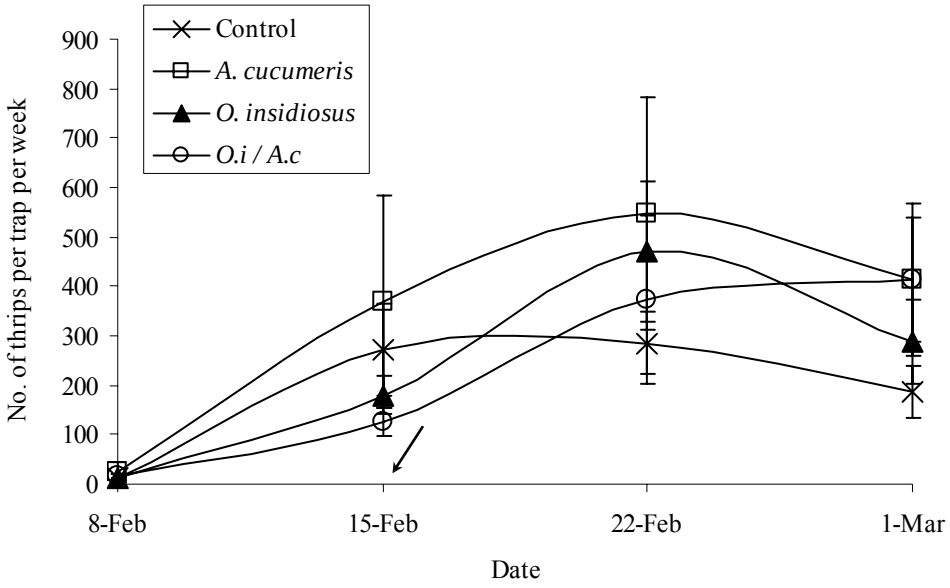


Figure 7- 2: Average number of thrips captured per week after the release of natural enemies, as curative measure, on white sticky traps located inside the blueberry bush in 2006. The arrow indicates the date of the release of natural enemies. Treatments followed by the same letter are not significantly different when compared using LSD ($\alpha = 0.05$). February 15, 2006 ($F = 0.95$; df = 3, 9; $P = 0.4549$), February 22, 2006 ($F = 0.54$; df = 3, 9; $P = 0.6639$), March 1, 2006 ($F = 1.79$; df = 3, 9; $P = 0.2185$).

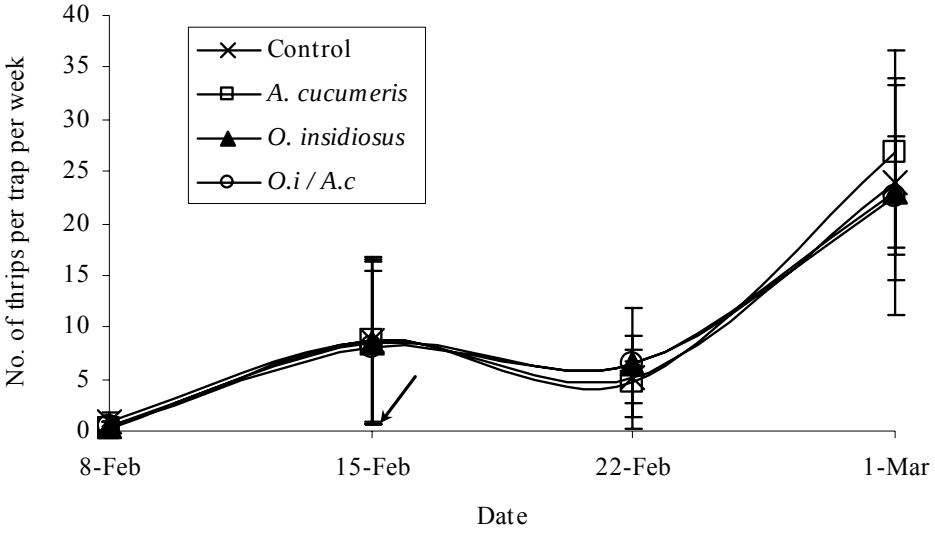


Figure 7- 3: Average number of thrips captured per week after the release of natural enemies, as curative measure, inside five flower-clusters collected from blueberry bushes. The arrow indicates the date of the release of natural enemies. Treatments followed by the same letter are not significantly different when compared using LSD ($\alpha = 0.05$). February 15, 2006 ($F = 0.05$; df = 3, 9; $P = 0.9821$), February 22, 2006 ($F = 1.42$; df = 3, 9; $P = 0.0.2992$), march 1, 2006 ($F = 0.06$; df = 3, 9; $P = 0.9781$)

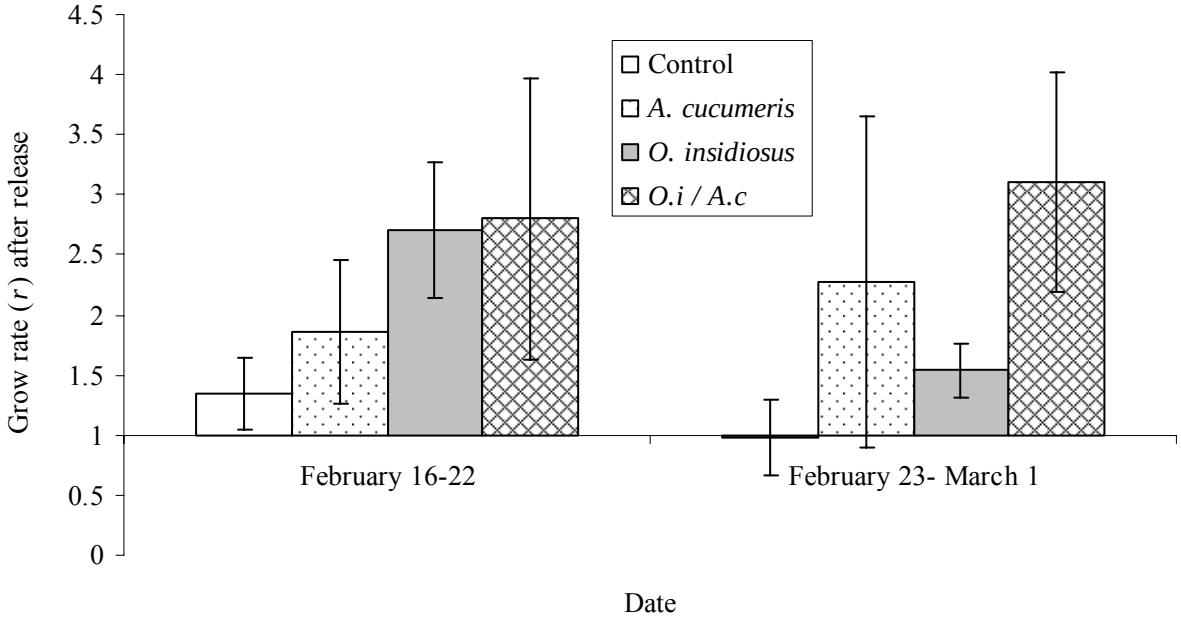


Figure 7- 4: Growth rate (r) of thrips populations captured in white sticky traps during the 2006 flowering season one and two weeks after the release of natural enemies as a curative alternative. February 16 – 22, 2006 (F = 1.01; df = 3, 9; P = 0.4339), February 23- March 1, 2006 (F = 1.53; df = 3, 9; P = 0.2737)

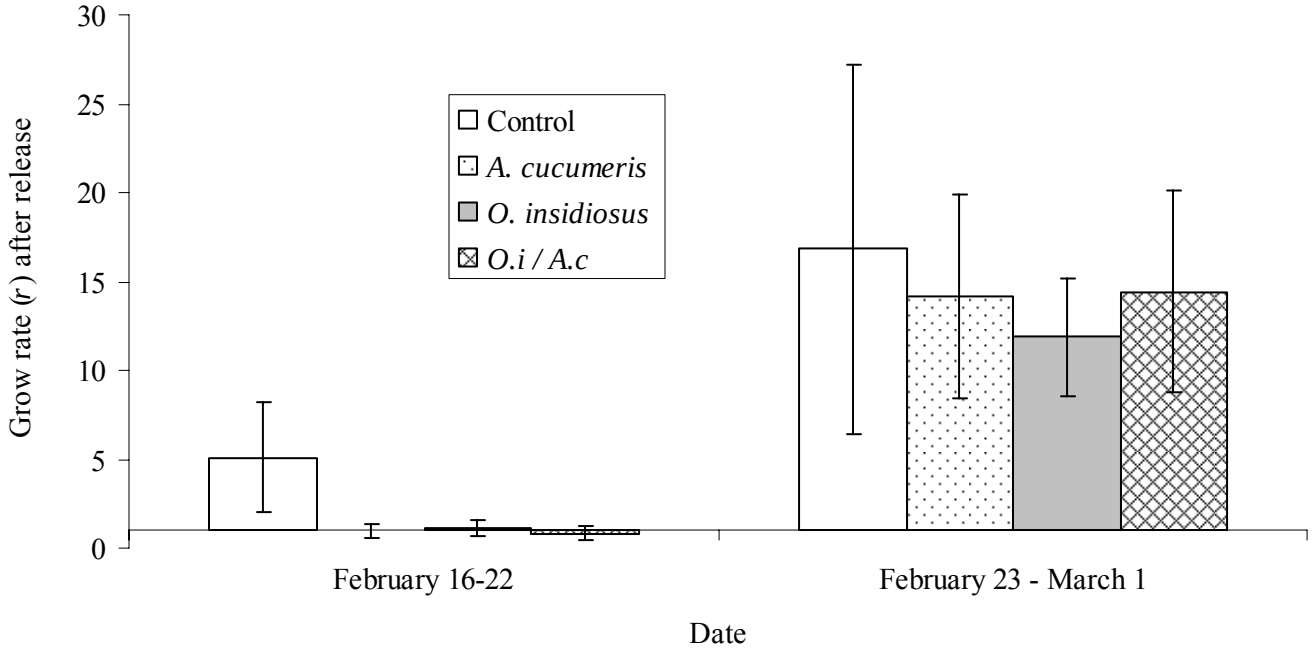


Figure 7- 5: Growth rate (*r*) of thrips populations collected inside blueberry flowers during the 2006 flowering season, one and two weeks after the release of natural enemies as a curative alternative. February 16– 22, 2006 ($F = 2.05$; df = 3, 9; $P = 0.1779$), February 23- March 1, 2006 ($F = 0.38$; df = 3, 9; $P = 0.7728$)

CHAPTER 8
GENERAL CONCLUSIONS AND EXPERIENCES WORKING WITH FLOWER THRIPS IN EARLY-SEASON BLUEBERRY FIELDS.

The development of an Integrated Pest Management (IPM) program is a complicated process than needs to consider all of the relevant information regarding the pest's biology, ecology behavior and the crop response to its presence. In this case, the relationship between blueberries and flower thrips was studied. Finn (2003) conducted a survey among blueberry growers in Florida and southern Georgia, where early-season blueberries are produced, to prioritize the arthropod pests that concerned them. One of the top three arthropods were flower thrips, along with the blueberry bud mite, *Acalitus vaccinii* (Keifer) and the blueberry gall midge, *Dasineura oxycoccana* (Johnson) (Diptera: Cecidomyiidae). Finn (2003) research involving monitoring and sampling formed the basis for this work. The current work refined some of the monitoring and sampling techniques evaluated by Finn (2003). To gather as much information as possible I decided to divide the work into two. The first group of experiments was designed to understand the biology, ecology and behavior of thrips with respect to early-season blueberries. The second set of experiments was designed to explore methods of control for flower thrips. Finally, it is necessary to organize all the information in such a way that farmers can apply the knowledge acquired during these three years to improve their management techniques and increase the efficiency managing early-season blueberries.

Flower Thrips Monitoring and Sampling

The use of white sticky traps has proven to be the more efficient method to monitor flower thrips. Finn (2003) demonstrated that there were no differences between white traps and other colors such as blue and yellow to monitor thrips in blueberry fields. Therefore, I selected white traps because the background contrast with the insects captured and it appears to attract predominantly thrips. Unlike white traps, yellow traps captured a high number of dipterans and other non-target organisms. The horizontal distribution of flower thrips with respect to the blueberry bush is also of importance to determine the best place to hang the traps. After comparing traps above the canopy, inside the canopy and above the soil, results showed that the highest number of thrips was captured inside the canopy. Traps inside the canopy were located in the middle of the bush between 1.50 and 1.60 m from the ground, and this is the position that was selected for the remaining of the experiments. I developed a procedure to extract thrips from inside blueberry flowers. This procedure is referred as the “shake and rinse method” (described in chapter 3). This method proved to be as efficient as manual dissection of the flowers, but less time consuming. This method could be a good alternative for researchers. As for growers, white sticky traps are a valuable tool and an efficient way of monitoring thrips populations in the field. The reliability of these sticky traps was improved when we were able to correlate the number of thrips inside the flowers and thrips captured on the trap. A regression between the number of thrips in five flower-clusters whit the number of thrips captured by a sticky trap located inside the canopy of the same bush allowed me to calculate the economic injury level (EIL) for flower thrips in sticky traps based on the EIL calculated in thrips per flower. Based on the number of

thrips captured in the traps, growers can make an informed decision of the timing to use the adequate controlling methods.

Flower Thrips in Blueberries

The observation of flower thrips in blueberries coincide with the remarks published by Mound (1997). Mound described thrips as *r* selected insects. This classification was given due to their success colonizing habitats that are suitable but brief, their successful use of a wide range of hosts (proper and provisional), their short generation time, vagility, parthenogenesis, and polyphagy. Flowering blueberry fields appear to be a perfect target for flower thrips. Blueberry blooming period lasts for approximately 25 days, from the beginning of flower opening to petal drop. During this period, the predominant color in the field is white to which several studies have pointed flower thrips are attracted to (Kirk 1984, Teulon and Penman 1992). This research demonstrated that flower thrips use blueberry plants as proper hosts. I was successful at obtaining larvae that emerged from flowers collected in the field. Flower thrips prefer to lay their eggs in the petals of the flowers, but I also obtained larvae from ovaries and stiles. While describing and comparing the injuries inflicted by flower thrips on the blueberry fruits, two types of injuries were found: feeding and emergence injuries. These injuries are very similar to injuries observed by other researchers in other fruits such as avocados, citrus, plums (Childers 1997, Kirk 1997a).

Captures of flower thrips in blueberries, on white sticky traps and flowers, begin with the opening of the flowers when they change from pink to white color, between stages five and six as defined by Spiers (1978). The ‘hot spots’ or sites of high aggregation begin to form between seven to nine days after the beginning of the captures and the peak of the population is reached seven to 10 days later. After this point, the

petals of the flowers begin to fall, the fruits begin to form, and thrips population starts to decline. The results obtained from various fields in Florida and southern Georgia indicated that flower thrips have highly aggregated populations in the field. Their level of aggregation is correlated with the number of individuals or the maximum population observed, when populations where high I observed the highest levels of aggregation.Very low populations show low levels of aggregation with a tendency to randomness.

During this work calculations of an economic injury level (EIL) for two of the most popular cultivars of rabbiteye blueberries 'Climax' and 'Tifblue' were conducted. However, due to the dynamic nature of EIL and its dependency on market values only one variable are dependent on plant health and thrips density and damage. These variables are the Injury per insect 'I' and damage per unit injured 'D'. Two of the main rabbiteye cultivars were selected to conduct the EIL determinations, 'Climax' and 'Tifblue'. For 'Climax' we determined that the value of 'I' was 1.71×10^{-10} proportion damage / [thrips/ha] and the value of 'D' was 16,812 (kg/ha)/proportion damaged. In the case of 'Tifblue' 'I' = 1.92 proportion damage/[thrips/ha] and 'D' had the same value as in 'Climax'. Based on the variables observed and the variables described in Figure 5-1 each producer will be able to calculate the EIL for the farm.

Nine thrips species in total were found in early-season blueberries. I developed an identification key for these six species to be used in future research. *Frankliniella bispinosa* (Morgan) was the predominant species in Florida captured inside the flowers and in the sticky traps. *Frankliniella tritici* (Fitch), 'eastern flower thrips', was the most abundant species in southern Georgia. *Frankliniella occidentalis* (Pergande), 'western flower thrips', was the second most abundant species in Florida and in Georgia. Other

species encountered include *F. fusca* (Hinds), *Thrips hawaiiensis* (Morgan), and *T. pini* Uzel.

Flower Thrips Control

The EIL calculated indicated that approximately 2 thrips per flower will be enough to reach the economic damage level in rabbiteye blueberries. Based on the correlation between the number of thrips in flowers and the number of thrips captured on sticky traps the EIL was between 45 (in 'Tifblue') and 50 (in 'Climax') if Malathion is used for control, and between 64 (in 'Tifblue') and 73 (in 'Climax') if SpinTor is used to control thrips. These numbers might seem very low; however, the timing for this EIL is also important. The time for which the EIL was calculated was at the opening of the flowers. During flower opening, or week one, in most of the trials conducted during this work the maximum number of thrips captured on sticky traps during the first week was 37.7 ± 5.5 (Figure 4-2). This number rather than the rule is an exception of an extremely high thrips population in this site. Most of the observations of week one during the three years that the trials were conducted were very low and rarely more than 20 thrips per trap were observed in the first week. None of the farms surveyed during these three years reached the EIL. Early monitoring is very important to use this EIL. Monitoring for flower thrips should begin when more than 50% of the flowers are in stage 5 and some are beginning stage six according to the descriptions made by Spiers (1978). Growers should not allow thrips populations to reach these values by using the adequate management techniques before the thrips reach this threshold. I explored the use of chemical and biological control to manage the populations of flower thrips. I screened 12 commercial and experimental insecticides with potential to control flower thrips. Among these insecticides, conventional insecticides, reduced-risk insecticides, and insect growth

regulators with the potential to be labeled for blueberry use were included. We conducted field and laboratory experiment to determine the efficacy of those insecticides that demonstrated to be successful in the field and compared them with non-treated controls and conventional insecticides. The active ingredient that demonstrated to be the most consistent and effective managing thrips in the field and in the laboratory was acetamiprid. Two formulations of acetamiprid were tested Assail 30SG and Assail 70W. Both formulations consistently demonstrated to control the growth of thrips populations better than the other chemistries evaluated in the field (measured as growth rate '*r*'). These low *r* values indicate that thrips population did not increased the same way as in the other treatments and in some cases the population decreased after the application ($r < 1$). The reasoning for the use of population growth rate is based on the high levels of aggregation of flower thrips, which in the field means high variances. The use of *r* as variable reduces the variance due to the presence of "hot-spots" in some treatments and not in others by taking into consideration the population before the applications instead of assuming that all the treatments started with the same population. SpinTor 2SC (spinosad) demonstrated in the laboratory to be efficient in controlling flower thrips and at the same time was the most compatible chemistry towards *Orius insidiosus.* In the biological control experiments we explored the use of commercial, *O. insidiosus* and *Amblyseius cucumeris* to control flower thrips. We evaluated preventive and curative releases of these natural enemies. Results showed that these natural enemies were not effective managing thrips populations. The short period that thrips are present in blueberry fields, the high mobility of *O. insidiosus* and slow action of *A. cucumeris*, combined with their polyphagy could explain in part the reason for the failure in to

manage flower thrips populations in commercial blueberry plantings. The success of these predators to manage flower thrips had been widely demonstrated mostly under greenhouse conditions (Van de Veire and Degheele 1995, Jacobson, 1997 #219, Shipp and Wang 2003). Some authors had found that biological control is not the best approach when dealing with flower thrips in open field situations (Mound and Teulon 1995, Parrella and Lewis 1997). Funderburk (2000) found *O. insidiosus* to be successful controlling thrips populations in peppers.

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BIOGRAPHICAL SKETCH

Hector Alejandro was born in Bogota, Colombia in 1977. After graduating from high school he began a career studying agronomy at the Universidad Nacional de Colombia in Bogota. During this degree his specialization and focus was in plant protection. In 2000, he moved to the United States to pursue his graduate education. He began studying English at the English Language Institute at The University of Florida, and six months later he was admitted into the master's program at the same university. During his master's, he worked in mole cricket biocontrol. He graduated with his masters in entomology, and he accepted a position to continue with his studies at the Small Fruit and Vegetable IPM Laboratory at the same university. During his PhD his research was focused in the interaction between flower thrips and early-season blueberries. The study included biology, population dynamics and control of this pest. He is planning to pursue a career as an entomologist in academia.