ECOLOGY AND MANAGEMENT OF FLOWER THRIPS IN SOUTHERN HIGHBUSH BLUEBERRIES IN FLORIDA

By

ELENA MARION RHODES

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To the glory of our Lord Jesus Christ, to my parents, and to my brother David

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By

Elena M. Rhodes

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In Florida, southern highbush (SHB) blueberries are grown for a highly profitable early season fresh market. Flower thrips are the key pest of these blueberries. *Frankliniella bispinosa* (Morgan) is the most common species found. They injure blueberry flowers by feeding and ovipositing in all developing tissues. These injuries can lead to scarring of developing fruit. The overall goal of this dissertation was to improve monitoring and management of flower thrips in southern highbush blueberries in Florida. To this end, five specific objectives were set up.

Objective 1 was to find alternate hosts of *F. bispinosa* and to determine if *F. bispinosa* moves into blueberry plantings from these hosts. Preliminary plant surveys conducted in the spring of 2007 and from November 2007 until March 2008 revealed several reproductive hosts of *F. bispinosa*, including: Carolina geranium (*Geranium carolinianum* L.), white clover (*Trifolium repens* L.), and wild radish (*Raphanus raphanistum* L.). Thrips population development was monitored in a blueberry planting and neighboring white clover field on a farm in Windsor, FL during early spring 2009 and 2010. The flower thrips population in the white clover and blueberries developed at

the same time with the highest numbers of thrips recorded from the center of the blueberry field in both years.

Objective 2 sought to determine the relationship between thrips and yield in different SHB blueberry varieties and determine an action threshold. It involved experiments during early spring 2007 and 2008 on three farms, two in Hernando Co., FL and the third at the Plant Science Research and Education Unit (PSREU) in Citra, FL. On the Hernando Co. farms, two treatment thresholds (100 and 200 thrips per trap) and an untreated control and four varieties (Emerald, Jewel, Millennia, and Windsor) were compared. At the Citra PSREU, the varieties Emerald, Jewel, Millennia, and Star were compared in 2007 and all but Star were compared in 2008. Thrips numbers exceeded the threshold on only one farm in 2007 and although there were no differences in thrips numbers among treatments, the threshold of 100 thrips per trap appeared to result in a significantly lower proportion of injured and malformed fruit compared with the control. Emerald consistently had more thrips per trap and per flower than the other varieties on all three farms. However, this did not always lead to an increase in fruit injury.

The third objective was to model thrips spatial distribution with geostatistical techniques and to use these models to determine optimum trap spacing. The study was conducted in early spring 2008 and 2009 on a farm in Inverness, FL. A grid of 100 traps spaced at 15.24-m intervals in 2008 and 7.61-m intervals in 2009 was set up with an additional 30 traps interspersed randomly throughout the sample area. Inverse distance weighting and kriging produced maps with similar accuracy. The semivariogram

analysis showed that traps should be spaced at least 28.8 m apart to insure spatial independence.

Objective 4 sought to determine if “hot spots” of high thrips density were correlated with flower density. The percent of open flower data were recorded from all rows in the Inverness 2009 study each week when traps were collected. Linear regression analysis revealed a positive relationship between percent of open flowers and thrips per trap on three of the five sampling dates.

Objective 5 was to examine the efficacy of several reduced-risk compounds, which were compared with malathion, SpinTor®, and an untreated control. During the course of the trials, one of these compounds, spinetoram, was registered in Florida blueberries as Delegate™. Rynaxypyr also reduced thrips numbers, while thrips numbers in the QRD-452 high dose treatment were higher than in the control.

CHAPTER 1
INTRODUCTION

Blueberries are a highly profitable crop in Florida. During 2009, 6.4 million kg (14.1 million lbs) of fresh market blueberries were harvested from 1295 ha (3,200 acres) at an average of $11.89 per kg ($5.40 per lb) (USDA 2010). The use of low chill varieties of Rabbiteye (*Vaccinium virgatum* Aiton) and the development of southern highbush (*V. corymbosum* L. x *V. darrowi* Camp) allows Florida growers to take advantage of this highly profitable early season market.

Rabbiteye blueberries are better suited for u-pick operations and local sales (Williamson and Lyrene 2004). Varieties of Rabbiteye can be classified as early-, mid-, or late season. During the early to mid 1980s, several North Florida producers attempted to grow early-season Rabbiteye varieties on >500 acres, but yields were very low. Improved management of insect pests, including blueberry gall midge (*Dasineura oxycoccana* Johnson) and flower thrips (*Frankliniella* spp.), have improved yield, but these blueberries do not ripen early enough in the season to be highly profitable. Rabbiteye blueberries are grown exclusively for u-pick and local sales (Williamson and Lyrene 2004).

The development of the southern highbush blueberry varieties in 1976 allowed Florida growers to take advantage of an untapped early season market (Williamson and Lyrene 2004). Southern highbush blueberries ripen 4-6 weeks before the early-season rabbiteye varieties. The various varieties of southern highbush are crosses between northern highbush blueberries (*V. corymbosum*) and wild blueberry species in Florida, including rabbiteye (Childers and Lyrene 2006). All blueberry acreage grown for fresh fruit shipping within and from Florida consists of southern highbush plantings

(Williamson and Lyrene 2004). In north Florida, frost protection is essential to avoid damage to flowers (Williamson and Lyrene 2004).

The two major insect pests of blueberries in Florida are blueberry gall midge (aka cranberry tipworm *D. oxycoccana*) and flower thrips (*Frankliniella* spp.) (O. E. Liburd personal communication). Blueberry gall midge females lay their eggs in developing blueberry buds. In Florida, they emerge in January or February and can produce up to six generations per year (Sampson et al. 2002). The larvae develop and feed in the bud eventually killing it (Finn 2003). Both floral and vegetative buds are attacked (Sarzymski and Liburd 2003). An unchecked infestation can kill up to 80% of floral buds while injury to vegetative buds distorts leaves and can reduce the number of berries a plant can support (Sampson et al. 2002). It is a difficult pest to control although systemic insecticides can reduce numbers (O. E. Liburd unpublished data). Blueberry gall midge is attacked by five species of parasitoids in the Platygastridae and Tetrastichinae (Eulophidae) families. The Tetrastichin is a species of *Aprostocetus.* The four Platygastridae species include two species of *Synopeas*, a species of *Inostemma*, and one species of *Platygaster*. (Sampson et al. 2006).

The blueberry bud mite {*Acalitus vaccinii* (Keifer)} and flea beetles are emerging pests (O. E. Liburd personal communication). Blueberry bud mites, in the family Eriophyidae, infest developing leaf and flower buds of both highbush and lowbush blueberries. Feeding by the bud mites causes the buds to redden early in the season, which prevents normal leaf and flower development. Severe infestations can cause yield reduction. Bud mites are difficult to detect because of their small size and the

injury they cause, which closely resembles frost injury. Bud mites can be managed with proper pruning and the use of horticultural oils (Weibelzahl and Liburd 2009).

Flea beetles are a post harvest pest of both southern highbush and rabbiteye blueberries. Flea beetles are foliage feeders. Large numbers of them can cause a significant reduction in photosynthetic productivity resulting in a decrease in yield for the following season. The blueberry leaf beetle, *Colaspis pseudofavosa* Riley, and the red headed flea beetle, *Systena frontalis* (Fabricius), are the two most common species found in Florida blueberries (O. E. Liburd unpublished data). However, there may be other species in the complex responsible for heavy defoliation in blueberries after harvest.

Chili thrips, *Scirtothrips dorsalis* Hood, were first reported from the Florida landscape on roses in Palm Beach Co. in October of 2005. By the end of 2005, it had spread to 15 counties on a number of different hosts (Silagyi and Dixon 2006). There are at least 100 recorded hosts of chili thrips (Hodges et al. 2006), and this number is increasing. Although blueberries are not a listed host, chili thrips were reported from blueberries in North-central Florida in the summer of 2008 (O. E. Liburd personal communication). Chili thrips are a pale bodied thrips with dark wings. They are primarily foliage feeders and do not feed on flower pollen (Hodges et al. 2005). Effective control measures on blueberries have not yet been studied. However, Chlorfenapyr, spinosad, and imidacloprid gave consistent control of chili thrips on pepper plants (Seal et al. 2006). In addition, the predatory mite *Amblyseius swirskii* (Athias-Henriot) maintained chili thrips populations below 1 per terminal leaf on pepper plants in the landscape for 63 days after they were released (Arthurs et al. 2009).

Several species of flower thrips, including the Florida flower thrips {*Frankliniella bispinosa* (Morgan)}, Eastern flower thrips {*F. tritici* (Fitch)}, Western flower thrips {*F. occidentalis* (Pergande)}, and Tobacco thrips {*Frankliniella fusca* (Hinds)} are pests of both rabbiteye and southern highbush blueberries in Florida and Georgia (Liburd and Arévalo 2005). *Frankliniella bispinosa* is the most common thrips found in Florida, while *F. tritici* is the dominant species in Georgia (Arévalo et al. 2006). They infest not only blueberries, but a wide variety of other crop and non-crop host plants.

In general, flower thrips are very small insects (~1 mm in length) with yellowish to orange coloration. They can be distinguished from other insect orders by their fringed wings and punch and suck mouthparts. They have a short life cycle that can occur in 18 to 22 days under ideal conditions. Thrips progress though two actively feeding larval instars and two inactive instars (often called pupae) before becoming adults (Lewis 1997).

Flower thrips damage flowers in two ways. Both larvae and adults feed on all parts of the flowers including ovaries, styles, petals, and developing fruit. This feeding damage can reduce the quality and quantity of fruit produced. Females also cause damage to fruit when they lay their eggs inside flower tissues. The newly hatched larvae bore holes in flower tissue when they emerge (Liburd and Arévalo 2005).

The overall goal of this project was to improve monitoring and management of flower thrips in southern highbush blueberries in Florida. The hypothesis is that a better understanding of flower thrips ecology in combination with the development of specific management tactics will accomplish this goal. The objectives of this dissertation were fivefold: 1) to examine blueberry plantings and adjacent fields for alternate hosts of

flower thrips and thrips dispersal from these host plants into blueberry plantings. 2) To determine the relationship between populations of thrips and yield in southern highbush blueberries and to determine an action threshold for thrips in southern highbush blueberries. 3) To model the spatial distribution of flower thrips in a blueberry planting utilizing geostatistical methods and to determine optimum trap spacing. 4) To determine if “hot spots” are correlated with flower density. 5) To determine the potential of using several experimental reduced-risk insecticides to manage flower thrips in Florida blueberries.

CHAPTER 2
LITERATURE REVIEW

Thrips

In general, thrips are very small insects (a few mm in length) with yellowish orange to brown coloration. They belong to the order Thysanoptera and are distinguished from other insect orders by their fringed wings and “punch and suck” mouthparts (Lewis 1997). Thrips are unique in having only one mandible, the left one. The right one is resorbed by the embryo (Mound 2005).

There are at least seven families of thrips, Adiheterothripidae, Aeolothripidae, Fauriellidae, Merothripidae, Heterothripidae, Thripidae, and Phlaeothripidae, which vary widely in their ecology. Aeolothripids are predators of mites and small insects, Merothripids are fungus feeders, and Adiheterothripidae, Heterothripids, and Thripids are primarily plant feeders (Lewis 1997). These six families belong to the suborder Terebrantia (Triplehorn and Johnson 2005). The Phlaeothripidae contains mostly fungal feeders, although a few species are predatory (Lewis 1997). Fauriellidae is a recently described family (Triplehorn and Johnson 2005). This family falls in the suborder Tubulifera.

Almost all of the major pest thrips belong to the family Thripidae. Major pest species in this family belong to several genera, including: *Frankliniella*, *Heliothrips*, *Scirtothrips*, *Taeniothrips*, and *Thrips* (Triplehorn and Johnson 2005). Thrips that are crop pests tend to be polyphagous and highly adaptable (Mound 2005). However, not all Thripidae are pests. For example, *Scolothrips sexmaculstus* (Pergande), the six-spotted thrips, is an important predator of phytophagous mites (Triplehorn and Johnson 2005).

Terebrantian thrips have a short like cycle that can occur in 18 to 22 days under ideal conditions (Lewis 1997). Females oviposit into the plant tissue on which they feed (Terry 1991). Eggs are inserted one at a time into an incision in the plant tissue created by the female's saw-like ovipositor (Terry 1991). Thrips progress though two actively feeding larval instars and two inactive instars (often called the propupa and pupa) before becoming adults (Lewis 1997). Many Terebrantian species drop off of their host plant and pupate in the soil (Lewis 1997).

Only a little is known about the mating behavior of Terebrantian thrips because of the ephemeral nature of their flowering host plants (Lewis 1997). Males of several species, including *Frankliniella occidentalis* (Pergande), *F. schultzei* (Trybom), *T. fuscipennis* Haliday, *T. major* Uzel, *T. flavus* Schrank, *T. atratus* Haliday, and *T. vulgatissimus*, form aggregations on the corollas of flowers, into which females will enter and mate (Milne et al. 2002). Females may use cues from the plants at a distance and then find the male aggregations via a sex pheromone produced by the males when they get closer to the plant. Milne et al. (2002) discovered that traps set among flowering plants and baited with conspecific males attracted significantly more females than unbaited traps placed among the plants. *F. occidentalis* males will fight to keep an area clear for a female to land. Females generally mate with the first male they come into contact with (Lewis 1997).

Many factors can influence development and reproduction, including temperature and host plant (Lewis 1997). Tsai et al. (1995) examined *Thrips palmi* Karny survival, egg production, and developmental time at three different temperatures: 15°C, 26°C, and 32°C. They found that *T. palmi* had the greatest survival and highest egg

production at 26°C, but had the shortest developmental time at 32°C compared to the other temperatures. They also investigated the effect of different host plants on survival and reproduction of *T. palmi*, both of which were much lower on bell pepper than on melon, eggplant, and cucumber. Alternatively, the Japanese strain of *F. occidentalis* can survive temperatures as low as 0°C (Tsumuki et al. 2007) for up to 40 d in the presence of food. Females survived longer than males (40 d vs. 30 d). Both sexes died within 48 h at temperatures below 0°C.

Population density and food availability can also play a role in regulating thrips' population growth (Nothnagi et al. 2008). Both competition for resources at high population densities and declining food availability can lead to sharp population declines in confined experiments. The same level of competition and declining food resources in a greenhouse or open field situation would most likely lead to migration (Nothnagi et al. 2008).

Terebrantian thrips use both visual and chemical cues to locate their host plants. Visual cues include floral color, shape, and size (Lewis 1997). In terms of color, blue, white, and yellow are much more attractive than other colors to *Frankliniella* spp. (Finn 2003). With respect to chemical cues, anisaldehyde odor significantly increased catches of seven polyphagous, flower inhabiting thripid species (Kirk 1985).

Although some thrips are specific to a few hosts, many are extremely polyphagous (Lewis 1997). However, it is often difficult to determine a particular species' true host range. Thrips will often alight, and even feed, upon many plants that they cannot reproduce on (Mound 2005, Paini et al. 2007). For example, the pear thrips, *Taeniothrips inconsequens* (Uzel), has been recorded from 242 species of plants, but

only 35 of these are breeding hosts (Teulon et al. 1994). Although *F. fusca* (Hinds), *F. occidentalis*, and *F. tritici* (Fitch) are found on tomato plants in Florida and can cause injury to these plants, only *F. occidentalis* reproduces on the tomato plants (Salguera Navas et al. 1994). Adults of several species of thrips are found in native orchids in Northern Florida and Southern Georgia, but the small numbers of larvae found indicate that the orchids are not a reproductive host for most thrips species (Funderburk et al. 2007).

The majority of pest thrips are highly polyphagous. They can reproduce on various weedy hosts and disperse into crops from these hosts. *Frankliniella* spp. prefer hosts that are flowering, so only flowering plants should be considered as sources of populations of these thrips (Northfield et al. 2008). In Japan, *F. occidentalis* reproduces in at least eight weedy species common in and around ornamental nurseries throughout the spring and summer (Katayama 2006). Cockfield et al. (2007b) found that native vegetation surrounding apple orchards supported *F. occidentalis* populations when apple trees were not flowering. These weedy hosts can also serve as reservoirs for tomato spotted wilt and other tospoviruses (Kahn et al. 2005). Therefore, weed control may be an important cultural tactic for control of pest thrips (Katayama 2006), but may not be effective in reducing injury without the use of other tactics (Cockfield and Beers 2008).

Thrips disperse in two main ways. They fly from field to field and are frequently transported long distances by humans moving plant material (Lewis 1997). When they fly, terebrantian thrips lock the cilia on their wings in the “open” position (Ellington 1980). “Open” refers to the fact that the cilia are at a much greater angle to the wing axes in

flight than at rest. This doubles the wing area. The cilia are opened by abdominal combing. They are closed by tibial combing. The wings lie parallel over the abdomen at rest (Ellington 1980). The distance thrips can fly is determined in large part by temperature and humidity (Lewis 1997). They desiccate much more quickly in hot, dry weather and thus cannot travel as far.

Because of their small size, thrips have little control over their flight and are carried readily on wind and air currents (Arévalo-Rodriguez 2006). Yudin et al. (1991) discovered that thrips dispersal can be hindered with mechanical barriers and that thrips were more numerous on the side of the field corresponding to prevailing wind direction. Thrips do, however, seem to have some control over landing (Lewis 1997). From a few observations, it is thought that thrips land feet first, close their wings, and begin quivering their antennae (Lewis 1997). Wingless thrips can also be dispersed by wind (Mound 2005).

Thrips cause damage to their host plants directly through feeding and oviposition and indirectly through the spread of tospoviruses (Arévalo-Rodriguez 2006). Thrips feed by “punching” into the plant tissue with their single mandible and sucking out cell contents with a pair of maxillary stylets (Lewis 1997). Both larvae and adults of *F. bispinosa* (Morgan) feed on all parts of ‘Naval’ orange (*Citrus sinensis* (L) Osbeck) flowers and on all parts of swollen buds (Childers and Achor 1991). Feeding causes cellular evacuation, necrosis, plasmolysis, and cellular collapse, which often spreads to nearby cells up to five cells deep. Some leaf feeding thrips can induce gall formation in plants (Mound 2005). Feeding on inflorescences can cause drooping and discoloration of petals (Rhainds et al. 2007).

Female *F. bispinosa* oviposit in all parts of the flowers and swollen buds of 'Naval' orange trees. However, Childers and Achor (1991) found that 73% of thrips larvae emerged from the pistil-calyx units of open flowers, which indicates a preference for these tissues. Ovipostion damage is localized and affects only cells directly adjacent to the oviposition site (Childers and Achor 1991). Large numbers of thrips can cause economic damage and even abortion of flowers (Arévalo-Rodriguez 2006). In contrast, oviposition by *F. occidentalis* causes pansy spot, a corky, raised scar surrounded by a pale halo, on apple (Cockfield et al. 2007a). Adult *F. occidentalis* are most abundant in apple blossoms from king bloom (bloom of the first, central flower in the flower clusters) to full bloom. Injury similar to pansy spot is caused when *F. occidentalis* oviposits in grapes and tomatoes (Cockfield et al. 2007a).

Thrips also feed on pollen. Kirk (1987) found that a single *T. imaginis* Bagnall or *T. obscuratus* (Crawford) could consume 0.2-0.7% of a kiwifruit {*Actinidia deliciosa* (A. Chevalier)} flower's pollen per day. They noted that this suggests that pollen damage could reduce crop yield or plant fitness in some cases. Ugine et al. (2006) found that adult female *F. occidentalis* were more abundant in greenhouse impatiens flowers that still contained pollen.

Tospoviruses are an extremely damaging group of plant viruses (Arévalo-Rodriguez 2006). To date, there are 16 known *Tospovirus* species in the family Bunyaviridae. Tomato Spotted Wilt Virus (TSWV) is one of the most well known species. It was thought to be a major factor in the 35% decline of crisphead lettuce (*Lactuca sativa* L.) and romaine (*L. satvia* var. *longifolia* Lam.) production in Hawaii in the late 1980s (Yudin et al. 1991). Thus far, 11 species of thrips in the family Thripidae

are known vectors. Both the viruses and their vectors have been spread around the world because of the difficulty of detecting both of them in plants in the process of being transported (Arévalo-Rodriguez 2006). Only early second instar larvae can acquire Tospoviruses (Moritz et al. 2004). During this stage of development, there is a temporary connection between the mid-gut, visceral muscles, and salivary gland due to the displacement of the brain into the prothoracic region by enlarged cibarial muscles (Moritz et al. 2004). Tospoviruses are transmitted by adults when they feed and may also be transmitted mechanically through excretion and oviposition (Moritz et al. 2004). In tomatoes sprayed weekly with insecticides to control thrips, the main source of TSWV was from immigrating thrips (Puche et al. 1995).

There are other microbes associated with thrips besides tospoviruses. Two groups of bacteria, one that has a shared ancestry with *Erwinia* and the other that has a shared ancestry with *Escherichia coli* (Migula), are found in the gut of *F. occidentalis* (Chanbusarakum and Ullman 2008). Both bacteria are facultative symbionts that infect thrips larvae. They parasitize the thrips when nutrients are abundant in the thrips' diet and supplement the thrips' diet if it is nutrient deficient (Chanbusarakum and Ullman 2008).

Thrips can also serve beneficial functions as pollinators and predators. *Taeniothrips* (*Amblythrips*) *ericae* Haliday is the major pollinator of *Erica tetralix* flowers (Hagerup and Hagerup 1953). Two thripid species, *F. diversa* and *F. insularis*, pollinate flowers of the Moraceae tree (*Castilla elastica*) and a new species of *Thrips* pollinates *Antiaropsis*, a genus of Moraceae in New Guinea (Mound 2005). The flowers of *Arctostaphyllos uva-ursi* are pollinated by several species of thrips, including

Ceratothrips ericae (Haliday) and *Haplothrips setiger* Priesner (García-Fayos and Goldarazena 2008). Though one thrips can carry only a small amount of pollen, large numbers of thrips can transport large amounts of pollen and thrips can occur in very high numbers in flowers (Mound 2005).

Some species of thrips, such as the six-spotted thrips (*S. sexmaculatus*), are primarily predators and feed on spider mites and other pests (Triplehorn and Johnson 2005). However, some phytophagous thrips species are also facultative predators of spider mites. *Thrips imaginis* Bagnall, *T. tabaci* Linderman, and *F. Schultzei* consume twospotted spider mite (*Tetranychus urticae* Koch) eggs in early season cotton in Australia, which causes mite outbreaks to occur later in the season then they would if this did not occur (Wilson et al. 1996). In California, *F. occidentalis* preys on spider mite eggs in cotton and *F. tritici* is listed as a predator of spider mite eggs in peanuts (Trichilo and Leigh 1986).

Thrips in Blueberries

Various thrips species inhabit blueberry flowers, leaves, and both leaves and flowers (Childers and Lyrene 2006). *Frankliniella vaccinii* Morgan and *Catinathrips kainos* O'Neil are the most common pestiferous leaf inhabiting species. Flower thrips include *F. occidentalis* and *F. bispinosa*, while *F. tritici* and *Scirtothrips ruthveni* Shull attack both leaves and flowers (Childers and Lyrene 2006). Uncultivated *Vaccinium* species in southern Georgia are host to several species of gall-forming leaf thrips (Braman et al. 1996). These gall thrips could become pestiferous if susceptible uncultivated *Vaccinium* species are bred with cultivated species (Braman et al. 1996).

Flower thrips are the key pest of early-season blueberries in Florida. *Frankliniella bispinosa* is the most common species with an average of 84% of the total thrips

collected from flowers and 89% from sticky traps. The other 16% and 11% are made up of *F. fusca*, *F. occidentalis*, and *T. hawaiiensis* (Morgan) in order of decreasing abundance (Arévalo-Rodriguez et al. 2006). A similar situation exists in Florida oranges, where *F. bispinosa* comprises 84 to 99% of thrips species collected from soil emergence traps (Childers et al. 1994) and in other varieties of citrus where *F. bispinosa* accounted for 92% of thrips found in closed buds and open flowers (Childers et al. 1990).

Thrips move into crops from other cultivated plants that flower earlier, like citrus in the case of blueberries (Childers et al. 1994), and from wild plant species (Chellemi et al. 1994, Topanta et al. 1996). In wild plant species adjacent to tomato fields in north Florida, *F. tritici* was the most abundant species in March, May and August, *F. bispinosa* in June and July, and *F. occidentalis* in February and April. Thirty-one of the 37 plant species examined contained thrips (Chellemi et al. 1994). Paini et al. (2007) found that *F. occidentalis* used two different weedy plant species as reproductive hosts in April and May in North Florida. *Frankliniella bispinosa* also used two weedy species as reproductive hosts from May to August. In contrast, *F. fusca* and *F. tritici* used 12 and 18 weedy species as reproductive hosts respectively in April and May.

In blueberries, flower thrips tend to aggregate and this aggregation is most pronounced when the population density is the highest (Arévalo-Rodriguez 2006). Thrips populations tend to form one or a few “hot-spots” on blueberry farms, which are small areas of comparatively high thrips numbers (Arévalo and Liburd 2007). These “hot-spots” begin forming about 7-10 days after bloom initiation, peak between 12 and 15 days after initiation when the majority of the flowers are open, and decline until about

22 days after bloom initiation when most of the flowers have become fruit and the thrips population all but disappears (Arévalo and Liburd 2007). *Frankliniella occidentalis* and *F. tritici* tend to aggregate on tomato plants while *F. fusca* was aggregated one year and randomly dispersed the next year (Salguero Navas et al. 1994).

In blueberries, the highest numbers of thrips are caught on sticky traps placed in or just above the blueberry plant canopy (Arévalo-Rodriguez 2006). Similarly, Reitz (2002) and Salguero et al. (1991) found more adult *F. occidentalis* and *F. tritici* in the upper part of the tomato plant canopy, but they found more larvae in the lower part of the canopy. In apple orchards, the density of *F. occidentalis* decreases with increasing distance from the edge of the orchard (Miliczky et al. 2007).

Flower thrips both feed and reproduce in blueberry flowers. These activities can cause the developing fruit to be scarred and misshapen (Arévalo-Rodriguez 2006). In his experiments, Arévalo-Rodriguez (2006) found that significantly more thrips larvae emerged from petals than from any other flower part. Also, significantly more thrips larvae emerged from ovaries than from styles and fruits. He concluded that flower thrips prefer these flower parts because the tissue is mature. Therefore, their eggs will not be crushed by growing cells (Arévalo-Rodriguez 2006). There are no known Tospoviruses that infect blueberries (Arévalo-Rodriguez 2006).

Flower Thrips Monitoring and Management

Monitoring

In blueberries, thrips are monitored using sticky traps or by directly sampling the flowers. Finn (2003) found that more *F. bispinosa* were caught on white and blue sticky traps compared to yellow and green traps. Yellow traps often caught more than green traps. Chu et al. (2006) also found that color is an important cue for thrips, catching

more *Frankliniella* spp. in white and blue plastic cup traps than in yellow cup traps. Although white, yellow, and blue traps attract thrips, white traps are the best to employ. Yellow traps attract a large number of other insects and the dark coloring of the blue traps can make it difficult to see the thrips that are present on them (Arévalo-Rodriguez, 2006).

Flowers can be sampled in several ways. The simplest method involves gently tapping the flowers and allowing the thrips to fall onto a white sheet below for counting. Flowers can also be collected in a vial or plastic bag and then dissected in the laboratory.

Arévalo and Liburd (2007) developed a “shake and rinse” method that is as accurate as dissecting flowers and much more efficient. This method involves collecting the flowers in alcohol-filled vials, shaking the vials, placing the flowers on a metal screen over a plastic cup, rinsing the flowers with water, and counting and collecting the thrips in the rinse liquid.

Sixteen to 18 flowers were needed to estimate thrips densities at the 25% precision level on tomato plants (Salguero Navas et al. 1994). Twenty to 25 flowers give an accurate estimate of thrips numbers in blueberry flowers (Arévalo-Rodriguez 2006).

Arévalo and Liburd (2007) found a strong correlation ($r = 0.7621$) between thrips per flower and thrips per trap in rabbiteye blueberries. Thrips per flower was estimated from five flower clusters sampled using the “shake and rinse” method. The sticky traps were hung inside the blueberry canopy. Rodriguez-Saona et al. (in press) found that sticky trap data were useful for predicting thrips’ flight activity and monitoring for the timing of insecticide applications.

Economic injury levels (EILs) are an integral part of integrated pest management (IPM) strategies. Several terms are important in understanding this concept, including: economic damage (ED) and economic threshold (ET). Stern et al. (1959) defines ED as "the amount of injury that will justify the cost of artificial control measures." The EIL is "the lowest population density that will cause this damage" and the ET is "the density at which control measures should be initiated to prevent an increasing pest population from reaching the EIL." The EIL can be calculated using the equation EIL = C/ (V * I * D), where C is the cost of control, V is the value of the product, I is the injury per insect value, and D is the damage per unit injured (Pedigo et al. 1986). Arévalo-Rodriguez (2006) used this equation to determine the EILs for 'Climax' and 'Tifblue' rabbiteye blueberries in Georgia, which are approximately 13 and 14 thrips per 10 flowers respectively when Malathion 5EC (Micro Flo Company LLC, Memphis, TN) is used as the control measure and 17 and 19 thrips per 10 flowers respectively using SpinTor® 2SC (spinosad) (Dow Agrosciences, Indianapolis, IN). Using his regression equations, Arévalo-Rodriguez (2006) calculated this to be 45 for Tifblue and 50 for Climax when malathion is applied and 64 for Tifblue and 73 for Climax when SpinTor® is applied.

Chemical Control

Economic Injury Levels (EILs) for flower thrips on many crops are very low because of these thrips' ability to transmit TSWV (Arévalo-Rodriguez 2006). For this reason, one of the main strategies used to control thrips is insecticide application (Morishita 2001). Morishita (2001) found that the organophosphates dichlorvos, sulprofos, profenofos, malathion, chlorpyrifos-methyl, chlorfenvinphos, fenthion, and phenthoate, the carbamate methomyl, the insect growth regulators (IGRs) lufenuron, chlorfluazuron, and flufenoxuron, and two other chemistries, chlorphenapir and

spinosad, caused greater than 90% mortality to *F. occidentalis* in the laboratory. The other carbamates and all pyrethroid compounds were not as effective as these.

In blueberries, flower thrips are currently managed with applications of malathion and SpinTor® (Arévalo-Rodriguez 2006). Malathion is a conventional, organophosphate insecticide with broad-spectrum activity. SpinTor® is a reduced-risk insecticide. Its active ingredient is spinosad (spinosyn), which is derived from the fermentation of the soil bacterium *Saccharopolyspora spinosa* Mertz and Yao. Spinosad, which must be ingested, kills insects via rapid excitation of the nervous system (IPM of Alaska 2003). It shows equal toxicity towards *F. bispinosa*, *F. occidentalis*, and *F. tritici* (Eger 1998) in the laboratory. However, Reitz et al. (2003) showed that it reduced *F. occidentalis* numbers, but did not reduce *F. tritici* numbers in field grown peppers in Florida. Spinosad has also been shown to be effective against *F. occidentalis* in field grown strawberries in Australia (Broughton and Herron 2007).

On blueberry farms, these insecticides are usually applied early in the morning or late at night to minimize the impact on pollinating bees (Arévalo-Rodriguez 2006). However, growers still report problems with bee toxicity, especially when malathion is applied (O. E. Liburd personal communication). Growers have also reported problems with SpinTor® relating to its poor residual activity (O. E. Liburd personal communication).

The exclusive use of only two compounds also raises questions of resistance development. Morse and Brawler (1986) found that the citrus thrips, *S. citri* (Moulton), appeared to be developing resistance to all of the insecticides they tested against them. Resistance to acephate, chlorpyrifos, dichlorvos, dimethoate, endosulfan, fipronil, malathion, methamidophos, methidathion, methomyl, and spinosad has been detected

in *F. occidentalis* populations in Australia (Herron and James 2005). However, no resistance to abamectin, methiocarb, or pyrazophos was detected in these populations (Herron and James 2005). *Frankliniella occidentalis* can rapidly develop resistance because it has a short generation time, high fecundity, and a haplodiploid breeding system (Jensen 2000). Spinosad resistance in *F. occidentalis* has been detected in many parts of the world (Dağh and Tunc 2007, Bielza et al. 2007). Resistance in *F. occidentalis* seems to be polyfactorial, involving: reduced penetration of the exoskeleton, increased detoxification by P450-monooxygenases, esterases, and glutathione *S*-transferases (GSTs), altered, insensitive, and increased AChE, and knockdown resistance (insensitive sodium channels) (Jensen 2000). The resistance appears to be unstable under field conditions (Bielza et al. 2008) and can be managed by minimizing the use of insecticides and using strategies that take resistance mechanisms and cross-resistance into consideration (Bielza 2008).

Spinetoram (Dow Agrosciences, Indianapolis, IN), a new spinosyn, was effective in controlling *F. occidentalis*, *F. bispinosa*, and *F. tritici* on tomatoes in north Florida. Like spinosad, spinetoram is a fermentation product of the soil bacterium *S. spinosa*. It has very low toxicity to many beneficial insects, humans, and the environment (Srivastava et al. 2008). During the course of this project, spinetoram was registered for use in blueberries as Delegate™; in large part due to efficacy trials conducted as part of the project (see chapter 7).

For these reasons, a part of the ongoing IPM research on flower thrips control in blueberries has begun to focus on finding other effective reduced-risk insecticides. Arévalo-Rodriguez (2006) found that Coragen® 2SC (Rynaxypyr) (DuPont, Wilmington,

DE) showed some control of *F. bispinosa* in Florida blueberries. Rynaxypyr is a reduced-risk insecticide with a novel mode of action. It is a ryanidine receptor agonist, causing the release of Ca^{2+} from muscle cells. The insects lose the ability to regulate muscle function and die via muscle paralysis (Ribbeck 2007). It shows no toxicity toward non-target organisms (Marchesini et al. 2008), including bees, no phytotoxicity, and shows some translaminar activity (Ribbeck 2007).

Surround® WP (kaolin clay) (Engelhard Corporation, Iselin, NJ) has also shown promise for flower thrips control in blueberries. It was the only compound that reduced thrips numbers in a field study in Florida in 2003 (Liburd and Finn 2003). Spiers et al. (2005) found that it reduced the number of flower thrips by half in rabbiteye blueberries, was nontoxic to pollinating bees, and showed no phytotoxic effects. However, it is white in color when it dries and this can attract large numbers of adult thrips from surrounding areas (Arévalo-Rodriguez 2006).

Biological Control

Predators

Members of 23 families of insects distributed among 8 orders and 9 families of mites have been reported to prey on thrips (Arévalo-Rodriguez 2006). The most commonly studied predators are *Orius insidiosus* Say (Hemiptera: Anthocoridae) and various *Amblyseius* spp. (Acari: Phytoseiidae). *Orius insidiosus* is an important predator of thrips on field grown peppers in Florida. It can significantly suppress populations of *F. bispinosa*, *F. occidentalis*, and *F. tritici*, the three flower thrips species found in the pepper flowers (Funderburk et al. 2000). However, *O. insidiosus* at the rate of 10 adults per plant bi-weekly did not reduce *F. occidentalis* numbers to economically acceptable levels on greenhouse tomatoes (Shipp and Wang 2003). Reitz et al. (2006) determined

that although *O. insidiosus* can prey on both *F. bispinosa* and *F. occidentalis*, it preferentially captures *F. occidentalis*. This may be due to the fact that *F. bispinosa* can evade predation better than *F. occidentalis* because it is smaller and more active. *Orius insidiosus* is mass reared and sold by Koppert Biological Systems (Romulus, MI).

Amblyseius cucumeris (Oudemans) is also available from Koppert. In contrast to *O. insidiosus*, *A. cucumeris* significantly reduced *F. occidentalis* numbers to economically acceptable levels on greenhouse tomatoes (Shipp and Wang 2003). Hoy and Glenister (1991) determined that inoculative releases of *A. barkeri* (Hughes) and *A. cucumeris* could provide control of onion thrips, *Thrips tabaci* Lindeman, on field-grown cabbage in the northwestern United States.

Other control tactics, particularly pesticide applications, can impact the effectiveness of predators. Reitz et al. (2003) found that UV-reflective mulch reduced both the abundance of *O. insidiosus* and early season *F. occidentalis* adults. They also found that spinosad was the least disruptive insecticide towards *O. insidiosus* compared to esfenvalerate and acephate. A combination of predatory mites {*A. cucumeris* and *Hypoaspis aculeifer* (Canestrini)} and soil applied NeemAzal-U (17% azadirachtin) was highly effective in controlling *F. occidentalis* on beans (*Phaseolus vulgarus* L.) (Thoeming and Poehling 2006). This emphasizes the importance and need of integrated control tactics.

Unfortunately, biological control of flower thrips in Florida blueberries with predators has proven unsuccessful. Arévalo et al. (2009) released *O. insidiosus* and *A. cucumeris* singly and in combination as both preventative and curative releases. Neither the preventative nor curative releases of any treatment reduced thrips numbers below

those found in the control. The shortness of the flowering season in blueberries may not give these natural enemies enough time to establish and control thrips populations in Florida blueberries.

Entomopathogenic fungi

Several species of entomopathogenic fungi have been shown to attack various species of thrips (Ekesi et al. 1998). *Beauveria bassiana* (Bals.-Criv.) Vuill. is a promising control agent for *Thrips palmi* (Castineiras et al. 1996), *T. tabaci* Lindeman (Jung 2004), *F. intonsa* (Trybom), *F. occidentalis* (Pergande), *T. coloratus* Schmutz, and *T. hawaiiensis* (Abe and Ikegami 2005).

Thrips are infected by *B. bassiana* when they come into contact with conidia. These asexual, nonmotile spores stick to the insect's integument, where they germinate and eventually penetrate into the insect's body cavity. The resulting infection kills the insect in 3-7 days (Bradley et al. 1998). Under optimal temperature and relative humidity an epizootic can occur, which is when a high percentage of a thrips population becomes infected, causing significant reductions in the population size (Murphy et al. 1998).

Along with their ability to cause epizootics, entomopathogenic fungi like *B. bassiana* have several desirable characteristics. One advantage the fungi have over traditional biological control is that they can be applied using standard spray equipment as long as adequate coverage is achieved (Murphy et al. 1998). Other advantages include host specificity and low toxicity towards non-target organisms (Murphy et al. 1998, Jacobson et al. 2001). Yet another advantage is that bumble bees can vector fungal conidia to crops in greenhouses with no adverse effects on the bumble bee colonies (Al-mazra'awi et al. 2006).

Like all living organisms, entomopathogenic fungi have an optimum temperature and humidity range. Optimum temperature can vary between 15°C and 30°C depending on species and strain. Optimum humidity for *B. bassiana* is reported as 95%, but this can vary with strain (Ekesi et al. 1999).

The use of entomopathogenic fungi for flower thrips control in blueberries is not likely to be effective in Florida because the blueberry flowering season occurs in January and February. The cool temperatures and lower relative humidity would most likely prevent an epizootic from occurring.

Entomopathogenic nematodes

Frankliniella occidentalis is susceptible to several species of steinernematid and heterorhabditid nematodes (Georgis et al. 2006). Previous studies have shown promising results with foliar applications on ornamental plants, which target mainly larval and adult *F. occidentalis*. Frequent applications utilizing an optimum spray volume, a wetting agent, and an adjuvant are essential for suppression of the pest (Georgis et al. 2006). However, Ruttenhuns and Shipp (2005) found that only *F. occidentalis* propupae and pupae were susceptible to *Steinernema feltiae* (Filipjev). Clearly, more research is needed before these nematodes become a viable control tactic.

Geographic Information Systems (GISs) and Geostatistics in Pest Management

Until recently, studies of the spatial distribution of insect populations have been limited to using various dispersion indices (Faris et al. 2003, Florez and Corredor 2000, Liebhold et al. 1993, Midgarden et al. 1993, Park and Tollefson 2005, Schotzko and O'Keeffe 1990, Wright et al. 2002). However, these dispersion indices only describe the frequency distribution of a set of samples; they do not take into account the spatial

relationship of the points (Midgarden et al. 1993). With the advent of Geographic Information Systems (GISs) and geostatistics into the world of insect ecology, these spatial relationships can now be studied (Liebhold et al. 1993).

A GIS is a computer system that can assemble, store, manipulate, and display geographically referenced data such as insect densities, crop type, soil type, soil moisture, etc. (Liebhold et al. 1993). Each data set can be used to form a map layer or theme. Collections of themes from similar areas form a GIS database. Thus, the GIS is a powerful tool for analyzing spatial interactions within and among these spatially referenced data themes (Liebhold et al. 1993).

Geostatistics provide the tools to characterize and model spatial patterns (Liebhold et al. 1993). The cornerstone of geostatistics is called the variogram (Webster and Oliver 2001). To construct a variogram, the semivariance of each pair of data points in a data set must be calculated. A semivariance is defined as ½ of the average squared difference between data values at the same separation distance. A semivariogram plots the semivariance on the y-axis and the specified distance between sample pairs, the lag, on the x-axis (Wright et al. 2002). Since it is very difficult to fit a model to a semivariogram where each individual semivariance is plotted, the semivariance is averaged for each of several lags (Webster and Oliver 2001). This is expressed mathematically as $\gamma(h) = \{1/2m(h)\} \Sigma \{z(x_i) - z(x_i + h)\}^2$, where $\gamma(h)$ is the semivariance at lag h, m(h) is the number of data point pairs separated by lag h, and $z(x_i)$ and $z(x_i + h)$ are the data values (z) a places separated by h (Webster and Oliver 2001). The important features of semivariograms are the sill, range, lag, and nugget (Fig. 2-1), which are defined as the value of the semivariance when it stops increasing, the

distance at which spatial independence is reached, the distance between sample pairs, and the semivariance value when x = 0 respectively. The nugget variance is a combination of measurement error and variation over distances less than the shortest lag distance sampled for all continuous variables (Webster and Oliver 2001).

Semivariograms have been used to examine and describe the spatial relationship of several corn pests, including western corn rootworm adults on yellow sticky traps in corn (Midgarden et al. 1993), corn rootworm injury to corn (Park and Tollefson 2005), and European corn borer larvae and their damage in whorl stage corn (Wright et al. 2002). Semivariograms have also been used to examine and describe the spatial relationships of three species of *Xylella fastidiosa* (Wells) sharpshooter vectors on citrus (Paulo et al. 2003) and of *Lygus hesperus* (Knight) in lentils (Schotzko and O'Keeffe 1990). Florez and Corredor (2000) used semivariogram along with other geostatistical analyses to examine the spatial dependence of *F. occidentalis* in a covered strawberry crop at Bogota plateau. Spatial dependence was found in 3 of 12 sampling weeks. They found that although thrips colonies were aggregated at first, over time the pattern changed toward a random pattern. This change was caused by thrips movement to neighboring quadrants.

The advent of geostatistics has also brought with it more sophisticated interpolation tools. Interpolation allows researchers to estimate the continuous properties of something in the environment from a finite number of sampled points (Webster and Oliver 2001). Four commonly used interpolation techniques are natural or nearest neighbor, local average, inverse distance weighting (IDW), and kriging (Ess and Morgan 2003). Natural neighbor is the simplest interpolation method. The value at an

unknown point is set equal to the value of the nearest sample point (Ess and Morgan 2003). Local average uses a simple average of known values around the unknown point to predict the value at the unknown point. Either a fixed number of points or all of the points within a fixed distance are used in the average (Ess and Morgan 2003). IDW is, in effect, a weighted average. Sample points closer to the unknown point are given a higher weight than those farther away (Ess and Morgan 2003).

Kriging is a geostatistical interpolation method. Semivariogram models are used to predict values at unsampled locations. Ordinary kriging is the most common kriging method used in most applications (Webster and Oliver 2001). In ordinary kriging, the overall mean of the population is assumed to be unknown. Like IDW, ordinary kriging uses a weighted average to estimate unknown values. However, the weights are based upon the semivariogram model.

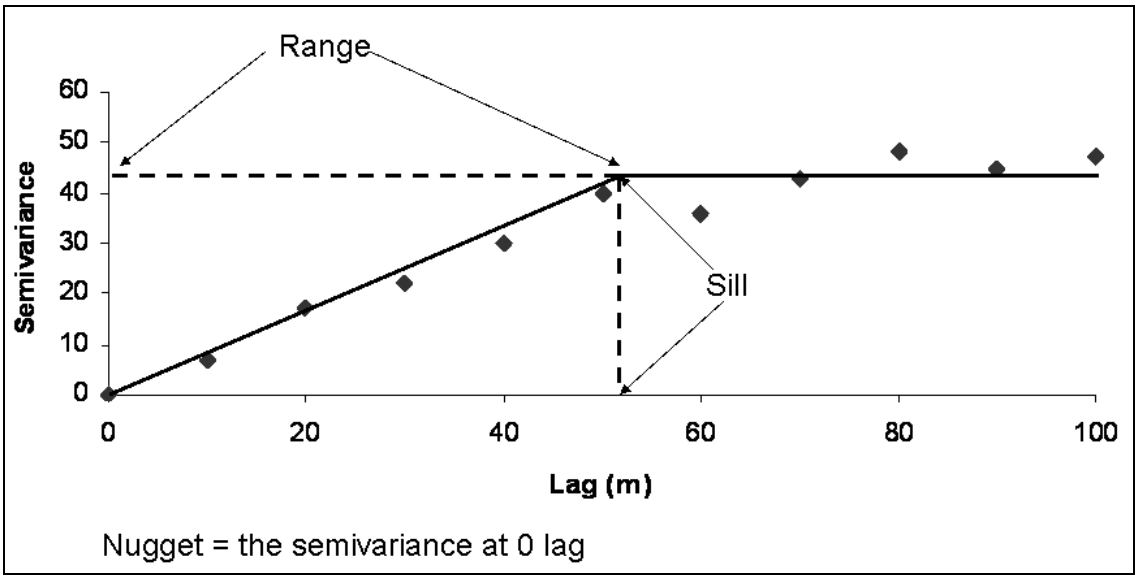


Fig. 2-1. Example of an ideal semivariogram with a nugget value of zero.

CHAPTER 3
EXAMINING THRIPS DISPERSAL FROM ALTERNATE HOSTS INTO SOUTHERN HIGHBUSH BLUEBERRY PLANTINGS

Introduction

A complex of flower thrips species causes injury to southern highbush (SHB) blueberries (*V. corymbosum* L. x *V. darrowi* Camp) in Florida (Arévalo-Rodriguez 2006). *Frankliniella bispinosa* (Morgan) is the most common species, accounting for approximately 90% of the adult thrips collected from both traps and flowers (Arévalo and Liburd 2007). Flower thrips feed and reproduce on all parts of developing blueberry flowers. The resulting injury can be magnified into scars when the fruit form, which make the fruit unsalable on the fresh market (Arévalo-Rodriguez 2006).

Thrips move into crops from other cultivated plants that flower earlier and from wild plant species that also serve as hosts (Chellemi et al. 1994, Topanta et al. 1996). Chellemi et al. (1994) found that 31 of 37 plant species adjacent to tomato fields contained thrips. Paini et al. (2007) found that *F. bispinosa* used two weedy species as reproductive hosts from May to August in north Florida. Cockfield et al. (2007b) found that native vegetation surrounding apple orchards supported *F. occidentalis* populations when the apple trees were not flowering.

It is often difficult to determine the true host range of a particular thrips species because thrips will often alight and feed upon many plants on which they cannot reproduce (Mound 2005, Paini et al. 2007). For example, although *F. fusca* (Hinds), *F. occidentalis* (Pergande), and *F. tritici* (Fitch) are found on tomato plants in Florida and can cause injury, only *F. occidentalis* reproduces on the tomato plants (Salguera Navas et al. 1994).

The objectives of this study were twofold. 1) To examine blueberry plantings and adjacent fields for alternate hosts of thrips. 2) To examine thrips dispersal from these host plants into blueberry plantings. The hypotheses of this study were: 1) flowering plants support and sustain *F. bispinosa* populations when blueberry plants are not flowering and 2) thrips disperse into blueberry plantings from these flowering plants when the blueberries begin to flower.

Materials and Methods

Preliminary Plant Surveys

In the first survey, flower samples from three of the most common flowering plants found at the Plant Science Research and Education Unit (PSREU) in Citra, FL, were collected, which included cutleaf evening primrose (*Oenothera laciniata* Hill), white clover (*Trifolium repens* L.), and wild radish (*Raphanus raphanistum* L.). Eight primrose flowers, 6 clover flowers, and 25 wild radish flowers were collected and placed in vials containing 70% ethanol. Thrips adults and larvae were sampled from the flowers using the “shake and rinse” method developed by Arévalo and Liburd (2007). In this method, each vial was shaken vigorously for 1 min. Then the contents of the vial were emptied onto a metal screen with 6.3 x 6.3-mm openings placed over a 300-ml white polyethylene jar. Flowers were gently opened and rinsed with water. The rinsate was then examined under a dissecting microscope. The numbers of thrips and other arthropods present were recorded. The thrips and other arthropods were stored in 100-cc glass vials. The flowers on the screen were emptied into another 300-ml polyethylene jar containing 10 ml of water. Once the lid was placed on the jar, the jar was shaken vigorously for 1 min. The rinse procedure was repeated as before except that the flowers were rinsed with 70% ethanol. If thrips were found in the second rinse

water, the procedure was repeated for a third time (shaking the flowers in 70% ethanol and rinsing with water). Thrips adults were identified to species using a key developed for Florida SHB blueberries by Arévalo et al. (2006). Thrips that did not match the character descriptions in the key were sent to the Division of Plant Industry in Gainesville, FL. for identification.

In the second survey, several flowering plant species within the 0.52-ha blueberry planting and the area surrounding it at the Citra PSREU were flagged and sampled to determine whether or not they were suitable hosts for *F. bispinosa*. For the purposes of this study, a suitable host was defined as one in which *F. bispinosa* reproduces and is abundant. Plants were identified to genus and species (if possible).

Ten 27-m transects were taken. Two were on the border of the blueberry field and eight were within the field (Fig. 3-1). Flowering plants within a 0.6-m (2-ft) radius were sampled every 3-m (10-ft). The height and maximum width of the plants and percent coverage were measured. Plant samples were collected in small press and seal bags and brought back to the laboratory for identification.

Samples were taken during the first and third full week of the two months prior flowering and during the two months of the blueberry flowering season. Twenty flowers were collected from each plant species and placed in 50-ml plastic vials containing 70% ethanol. If less than 20 flowers were present, then all available flowers were collected. The samples were brought back to the laboratory at the University of Florida in Gainesville, FL. The “shake and rinse” method was used to collect the thrips from the flowers. Adults and larvae were counted and adults were identified to species as detailed previously.

Flower samples were also collected from an adjacent strawberry field to the west of the blueberry planting and from the blueberry bushes themselves. Ten strawberry flowers were collected from each of four rows. This was done once a month in December, January, and February. Four blueberry flower clusters (~ 20 flowers) were collected from each plot on each sample collection date.

Field Study

This study was conducted at a farm in Windsor, Florida, during the spring of 2009 and 2010. White clover, *Trifolium repens* L., grows in the grassy areas all over this farm. The study area consisted of a field of white clover and part of a large blueberry planting on the farm that contained plants approximately 7 years in age. In 2009, six sampling sites in a 625-m^2 area in the clover and 12 sampling sites in the blueberry planting, in four rows of three sites in a 2400-m^2 area, were selected. Four traps were placed in the corners of the clover sampling area and the other two were placed in the center 8-m apart. Traps were spaced 10-m apart in each blueberry row and the rows were 15-m apart. In 2010, the setup was expanded to include ten sampling sites in the clover (660-m^2) and four rows of five sites (2464-m^2) in the blueberry planting. All of the traps in the clover were spaced 10-m apart. The traps in the blueberry rows were spaced as in 2009. The rows were labeled 1 to 4, with 1 closest to the clover field and 4 farthest away from it. Each row was considered a treatment.

In 2009, white sticky traps (Great Lakes IPM, Vestaburg, MI) were set out every week and collected weekly for five weeks from January 31 to March 5 in the clover and blueberries. In 2010, traps were set out every week and collected weekly for seven weeks from Feb. 4 to March 25. When the traps were replaced, flower samples were

collected from both the clover and blueberries adjacent to traps. Three to five clover flowers and four to five blueberry flower clusters (~20-25 flowers) were collected each week.

The treatments, which included the clover only in the sticky trap data set, were compared each week using a one-way analysis of variance (ANOVA) (SAS Institute 2002) and means were separated using the least significant differences (LSD) test. Sticky trap data (x) were $\log_{10}x$ transformed to meet the assumptions of the analysis. In 2009, the $\log_{10}(x+1)$ transformation was also used for thrips adults per flower (x), while thrips larvae per flower were transformed using the equation $1/\sqrt{}$ (thrips per flower +1). For the 2010 flower sample data, transformation was not enough to cause the data to meet the ANOVA assumptions. Therefore, the nonparametric Friedman, Kendall-Babington Smith test (Hollander and Wolfe 1999) for general alternatives in a randomized complete block design was used to analyze the data.

Results

Preliminary Plant Surveys

In the first survey, both adults and larvae were collected from the clover and wild radish flowers, while only adults were collected from the primrose flowers (Fig. 3-2). All adults collected were *F. bispinosa*.

Twelve different species of plants were found in the blueberry planting during the second survey (Table 3-1). Of these, 8 flowered at some point during the sampling period and thrips were sampled from 3 {Carolina geranium (*Geranium carolinianum* L.), hairy indigo (*Indigofera hirsuta* L.), and pusley (*Richardia* sp.)}. Thrips were also found in the blueberry and strawberry flowers.

Both thrips adults and larvae were found in the Carolina geranium, pusley, strawberry, and blueberry flowers (Fig. 3-3). All of the adults found in the Carolina geranium were *F. bispinosa*, while *F. fusca* (Hinds) and *Haplothrips graminis* Hood were found in the pusley and strawberry flowers. Only *H. graminis* adults were found in the hairy indigo flowers. Most of the thrips adults in the blueberry flowers were *Thrips* species, either *T. hawaiiensis* (Morgan) or *T. pini* Karny. *Frankliniella bispinosa*, *F. fusca*, *Franklinothrips* sp., and *H. graminis* were also present in the blueberry flowers in small numbers.

Field Study 2009

On Feb. 12, there were significantly more thrips per trap in row 3 compared with the clover, row 1, and row 4 ($F = 3.92$, df = 4, 17, $P = 0.0267$, Fig. 3-4A, B).

There were no significant differences in thrips adults (all $F \leq 1.51$, df = 3, 11, $P \geq 0.29$) or thrips larvae (all $F \leq 1.45$, df = 3, 11, $P \geq 0.30$) per flower among rows on any sampling date (Fig. 3-5A, B). Thrips adults and larvae were present in the clover field throughout the blueberry flowering period (Fig. 3-6). Larval numbers remained low throughout the flowering period, while adult numbers increased as the flowering period progressed.

In the clover and row 2, all of the thrips sampled were *F. bispinosa*. In rows 1 and 4, 96% of the thrips sampled were *F. bispinosa* and 2% were *T. pini*. The remaining 2% were *T. hawaiiensis* in row 1 and *Franklinothrips* sp. in row 4. In row 3, 98% of the thrips sampled were *F. bispinosa*. The remaining 2% were *Franklinothrips* sp.

Field Study 2010

On Feb. 11, there were significantly higher numbers of thrips per trap in the clover field compared with rows 1 and 4 ($F = 3.12$, df = 4, 29, $P = 0.0327$, Fig. 3-7A, B). On

Feb. 25, there were significantly more thrips per trap in rows 2 and 3 compared with the clover field (F = 2.89, df = 4, 29, P = 0.0429). On March 11, there were significantly higher numbers of thrips per trap in rows 2, 3, and 4 compared with row 1 and the clover field (F = 5.95, df = 4, 29, P = 0.0017). On March 25, there were significantly higher numbers of thrips per trap in row 3 compared with all of the other treatments and in row 4 compared with row 1 and the clover field (F = 6.86, df = 4, 29, P = 0.0007).

There were no significant differences in thrips adults (all $S' \leq 6$, k, n = 5, 4, $P > 0.1$, Fig. 3-8A) or larvae (all $S' \leq 6.43$, k, n = 5, 4, $P \geq 0.09$, Fig. 3-8B) per flower on any sampling date. Thrips adults were present in the clover flowers on Feb. 11, March 18, and March 25 (Fig. 3-9). In contrast, only a single larva was collected from the clover flowers on Feb. 18.

As in 2009, most of the thrips collected during the blueberry flowering period in 2010 were *F. bispinosa*. All of the thrips sampled from rows 2, 3, and 4, 82 % of those sampled from row 1, and 67% of those sampled from the clover were *F. bispinosa*. Several *Franklinothrips* sp. and a single *Limnothrips* sp. that was caught during the first week of sampling made up the remaining 18% of row 1. A single *F. fusca* and 3 unknown thrips made up the remaining 33% found in the clover.

Discussion

Flower samples were collected from Carolina geranium, hairy indigo, narrowleaf cudweed (*Gnaphalium falcatum* Lam.), oldfield toadflax (*Nuttallanthus canadensis* (L.)), pusley, spurge (*Euphorbia* sp.), thistle (*Circium* spp.), white clover, and wild radish. It appears that only Carolina geranium, white clover, and wild radish are reproductive hosts of *F. bispinosa* during the sampling period due to presence of immature stages. Northfield et al. (2008) also found that white clover and wild radish are reproductive

hosts of *F. bispinosa*, especially in the spring (April - June). In contrast, Paini et al. (2007) found only adult *F. bispinosa* on wild radish (white clover was not sampled in this study). Carolina geranium was not sampled in either of these studies. Cutleaf evening primrose appears to be only a feeding host, since no larvae were found in the flowers.

Several other species of thrips were found on other plants that flowered during the sampling period. Hairy indigo had only *H. graminis* adults, which are predatory and may have been feeding on the large number of aphids also present in the flowers (data not shown). *Haplothrips graminis* adults were also frequently found in the pusley flowers. A single *F. fusca* adult was also found in the pusley flowers, as were a number of thrips larvae. Whether the *H. graminis* were feeding on the thrips larvae or other insects present in the flowers is not known. The same two species of adult thrips and a few thrips larvae were also found in the strawberry flowers.

In 2009, the thrips population in the clover appeared to develop at the same time as the population in the blueberry planting. Two extreme cold events, one in late January and the second in early February, may have contributed to this population growth pattern. The cold may have reduced the thrips population in both the clover and blueberry flowers to very low levels, which then rebounded together.

The difference in thrips per trap occurred on Feb. 12, approximately 1 week after the second extreme cold event. Row 3, which had higher numbers of thrips compared with rows 1, 4, and the clover, is in the center of the sampled blueberry block. It is possible that the thrips were better sheltered from the cold there.

Thrips numbers were low throughout the 2010 SHB blueberry flowering season. Thrips adults were collected from the blueberry flowers in low numbers throughout the

flowering season, but the population did not begin to increase until March 11. In the clover flowers, a single adult unknown was collected on Feb. 11. Thrips adults were not found in clover flowers again until two unknowns and a *F. bispinosa* were collected on March 18. All of the adults collected from the clover flowers on March 25 were *F. bispinosa* with the exception of a single *F. fusca*. Thrips larvae were not collected from blueberry flowers until March 18 and the only larvae collected from the clover flowers was found on Feb. 18.

The flowering season itself began later than the average and was extended till the end of March. Both of these factors were most likely due to the extended extreme winter temperatures that occurred during January and February of 2010 (FAWN 2010).

Despite their low numbers, there were some statistically significant differences in thrips per trap on Feb. 11 and 25 and March 11 and 25. As in the previous year, thrips numbers were higher in the middle of the field. However, in 2010, they remained higher instead of equalizing as occurred in 2009.

From these studies, it would appear that clover is not a significant source of *F. bispinosa* in SHB blueberry fields. This is supported by Northfield et al. (2008) who found that *F. bispinosa* uses white clover as a reproductive host in the spring, particularly in April and May. Since they are found almost exclusively in flowers (Northfield et al, 2008), *F. bispinosa* may move from one or a few hosts to different hosts as they flower. *Frankliniella occidentalis* exhibits this pattern of behavior in Washington apple orchards (Cockfield et al. 2007b).

Further research is needed to determine which plants are sources of *F. bispinosa* for SHB blueberry plantings. Controlling these plants could reduce flower thrips numbers in blueberry bushes.

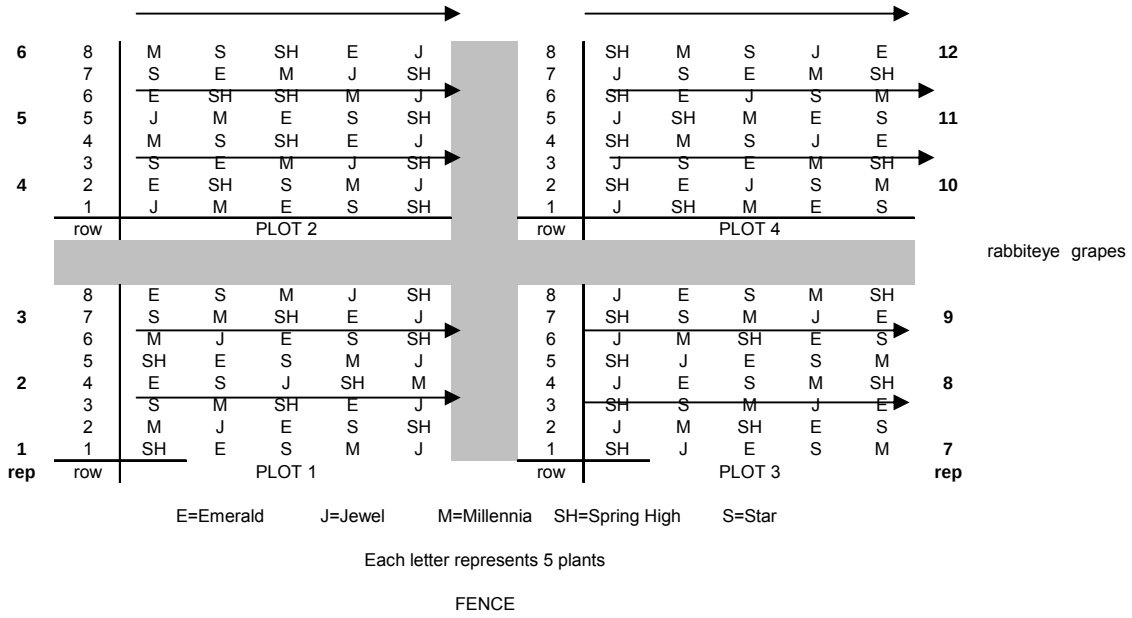


Fig. 3-1. Locations of transects (arrows) in blueberry planting. (E = Emerald, J = Jewel, M = Millennia, S = Star, and SH = Spring High)

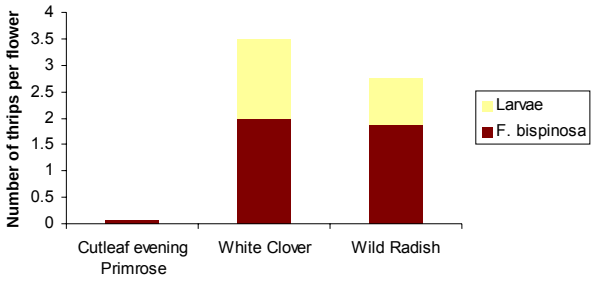


Fig. 3-2. Numbers of each thrips species per flower collected from each plant during the first survey.

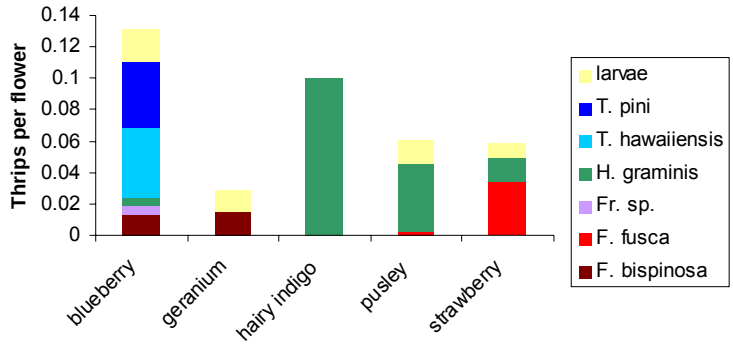
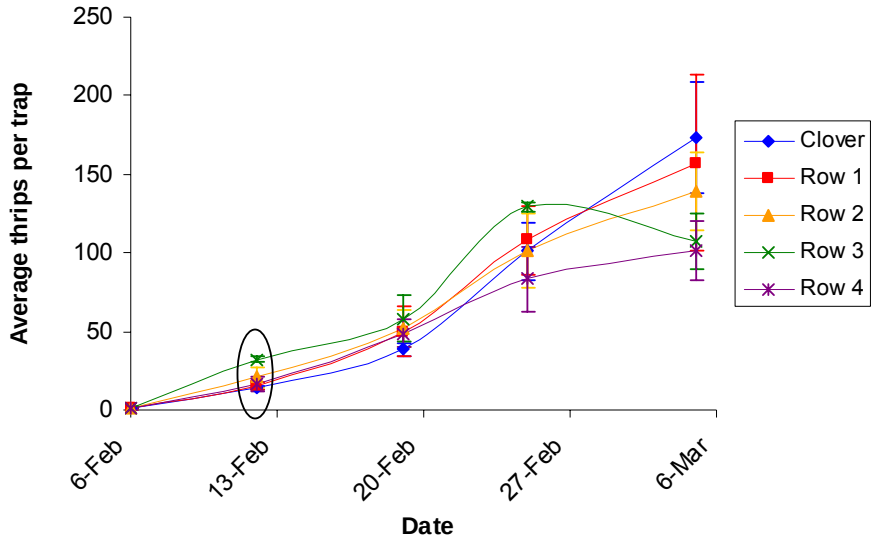
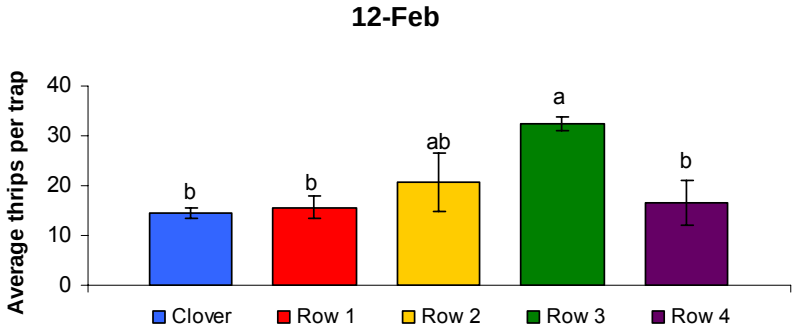


Fig. 3-3. Numbers of each thrips species per flower collected from each plant during the second survey.

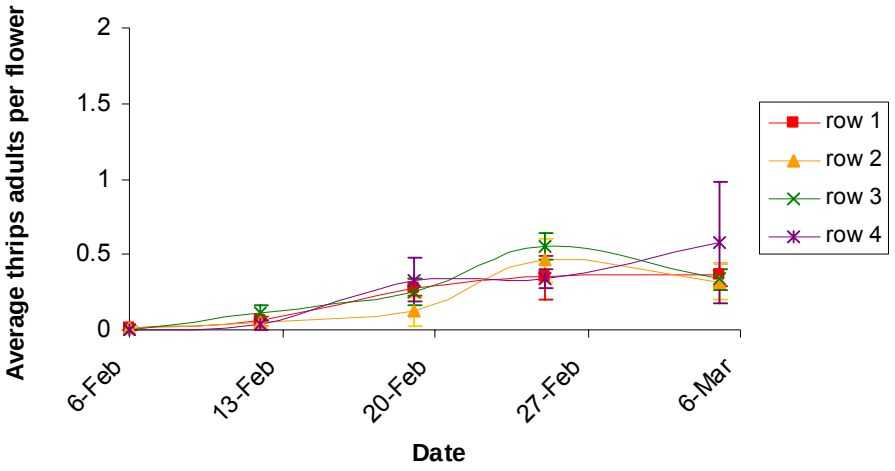


A

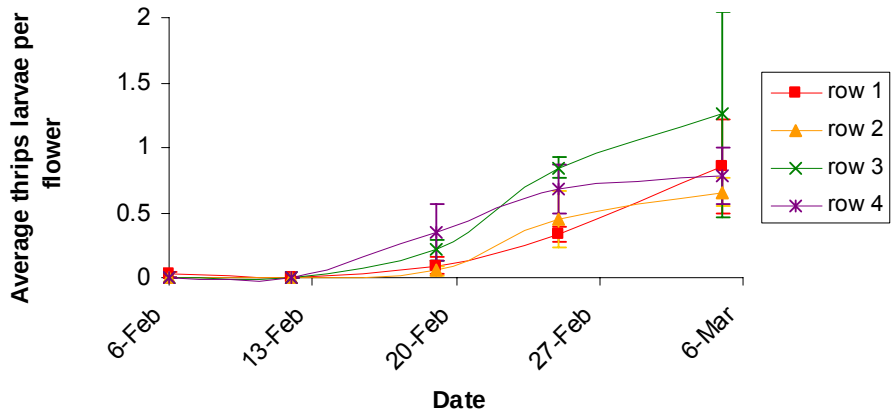


B

Fig. 3-4. A) Average thrips per trap in each treatment on each sampling date in 2009. Circled data indicate significant differences. B) Average thrips per trap on Feb. 12, 2009. Means with the same letter are not significantly different from each other at $P < 0.05$. Error bars indicate standard error of the mean.



A



B

Fig. 3-5. Average thrips A) adults and B) larvae per flower on each sampling date in 2009. Error bars indicate standard error of the mean.

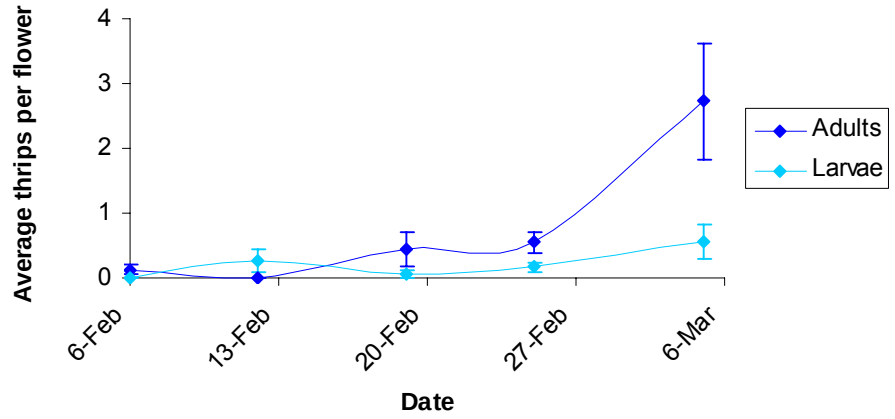
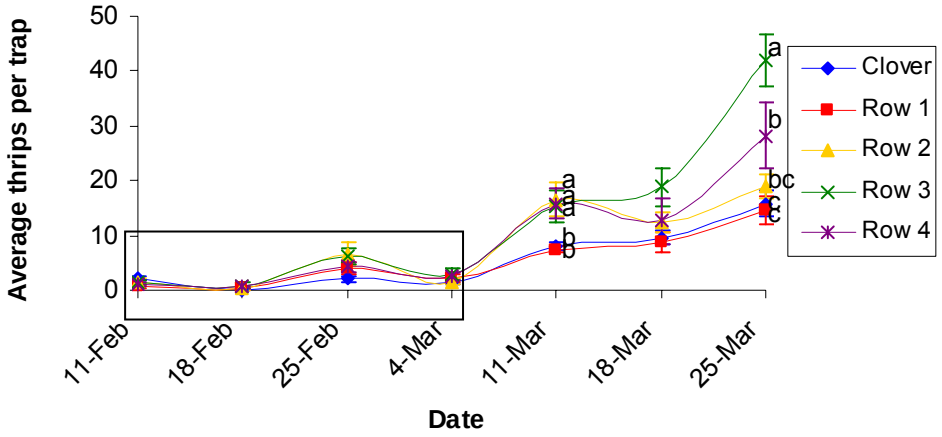
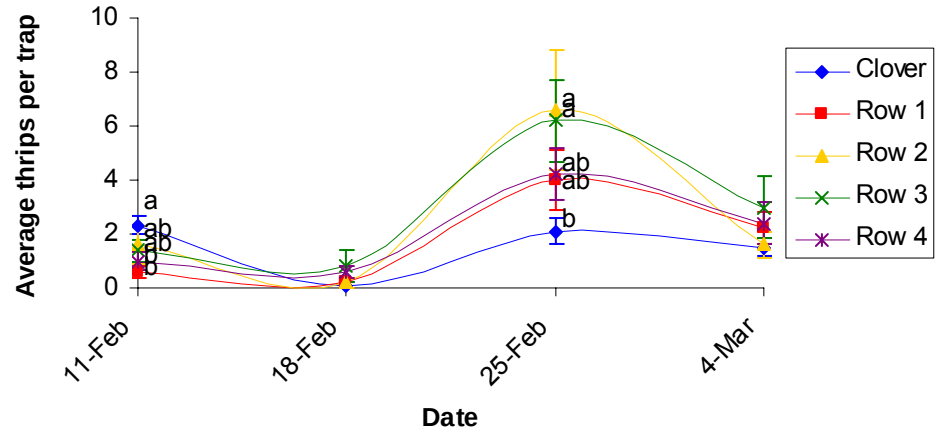


Fig. 3-6. Average thrips per flower in the clover field on each sampling date in 2009. Error bars indicate standard error of the mean.

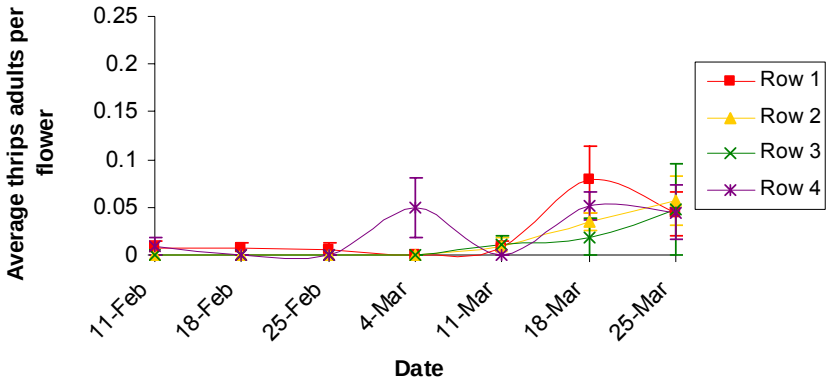


A

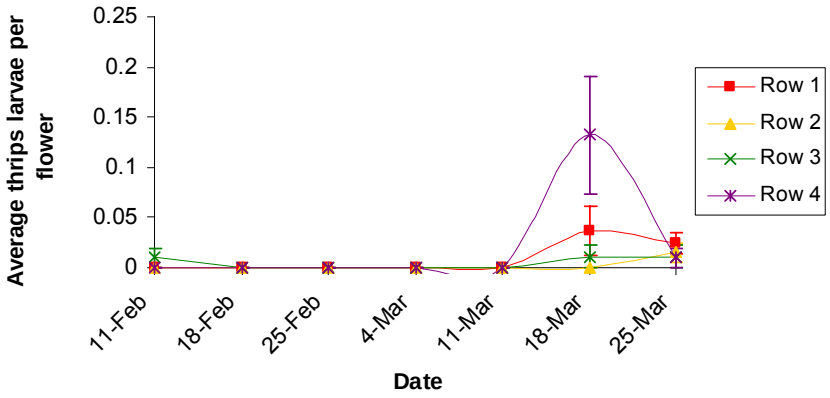


B

Fig. 3-7. Average thrips per trap A) throughout the flowering period and B) during the first 4 weeks of the flowering period (indicated by the box in A) in 2010. Treatments with the same letter are not significantly different from each other at P = 0.05. Error bars indicate standard error of the mean.



A



B

Fig. 3-8. Average thrips A) adults and B) larvae per flower on each sampling date in 2010. Error bars indicate standard error of the mean.

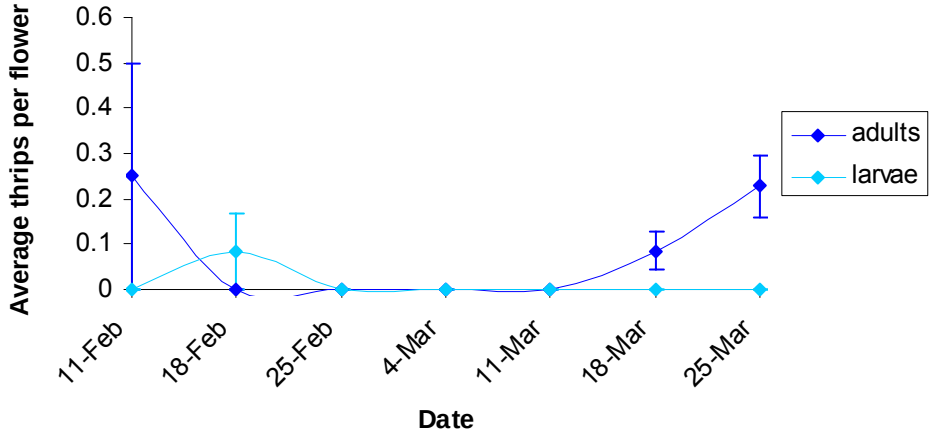


Fig. 3-9. Average thrips per flower in the clover field on each sampling date in 2010. Error bars indicate standard error of the mean.

Table 3-1. Common and scientific names of the plants found in the blueberry planting each month

November	December	January	February	March
Carolina geranium *Geranium carolinianum* L.	Carolina geranium *Geranium carolinianum* L.	Carolina geranium *Geranium carolinianum* L.	Carolina geranium *Geranium carolinianum* L.	Carolina geranium *Geranium carolinianum* L.
coffee senna? *Senna occidentalis* L.	hairy indigo *Indigofera hirsuta* L.	narrowleaf cudweed *Gnaphalium falcatum* Lam.	narrowleaf cudweed *Gnaphalium falcatum* Lam.	narrowleaf cudweed *Gnaphalium falcatum* Lam.
hairy indigo *Indigofera hirsuta* L.	narrowleaf cudweed *Gnaphalium falcatum* Lam.	oldfield toadflax *Nuttallanthus canadensis* (L.)	oldfield toadflax *Nuttallanthus canadensis* (L.)	oldfield toadflax *Nuttallanthus canadensis* (L.)
pennywort (dollarweed) *Hydrocotyle umbellata* L.	pennywort (dollarweed) *Hydrocotyle umbellata* L.	pennywort (dollarweed) *Hydrocotyle umbellata* L.	pennywort (dollarweed) *Hydrocotyle umbellata* L.	pennywort (dollarweed) *Hydrocotyle umbellata* L.
pigweed? *Amaranthus* sp.	pusley *Richardia* sp.	pusley *Richardia* sp.	pusley *Richardia* sp.	pusley *Richardia* sp.
pusley *Richardia* sp.	thistle *Circium* spp.	red sorrel *Rumex Acetosella* L.	red sorrel *Rumex Acetosella* L.	red sorrel *Rumex Acetosella* L.
spurge *Euphorbia* sp.	wandering cudweed *Gnaphalium pensylvanicum* Willdenow	thistle *Circium* spp.	thistle *Circium* spp.	thistle *Circium* spp.
thistle *Circium* spp.		wandering cudweed *Gnaphalium pensylvanicum* Willdenow	wandering cudweed *Gnaphalium pensylvanicum* Willdenow	wandering cudweed *Gnaphalium pensylvanicum* Willdenow
wandering cudweed *Gnaphalium pensylvanicum* Willdenow				

Highlighting indicates when plants were flowering and a question mark indicates uncertainty in identification.

CHAPTER 4
EFFECTS OF BLUEBERRY VARIETY AND TREATMENT THRESHOLD ON THRIPS POPULATIONS

Introduction

Several species of flower thrips, including the Florida flower thrips {*Frankliniella bispinosa* (Morgan)}, western flower thrips {*F. occidentalis* (Pergande)}, eastern flower thrips {F. tritici (Fitch)}, and *Scirtothrips ruthveni* Shull, have recently become known as pests of cultivated blueberries (Spiers et al. 2005). The three *Frankliniella* species are pests of both rabbiteye (RE), *Vaccinium virgatum* Aiton, and southern highbush (SHB), *V. corymbosum* L. x *V. darrowi* Camp, blueberries in Florida (Liburd and Arévalo 2005). *Frankliniella bispinosa* is the key pest and by far the most abundant, while the others are occasional pests (Arévalo et al. 2006). They infest not only blueberries, but many other crop and non-crop host plants (Arévalo et al. 2006).

Flower thrips injure flowers in two ways. Larvae and adults feed on all parts of the flowers including ovaries, styles, petals, and developing fruit (Arévalo-Rodriguez 2006). This feeding injury can reduce the quality and quantity of fruit produced. Females also cause injury to fruit when they lay their eggs inside flower tissues. The newly hatched larvae bore holes in flower tissue when they emerge.

The objectives of this study were to: a) determine the relationship between populations of thrips and yield in several different SHB varieties and b) to determine an action threshold for thrips in SHB blueberries. In Florida, several SHB varieties are grown together on the same farm. These varieties differ in fruit and flower characteristics and in the timing and length of flowering period (Williamson and Lyrene 2004). This may lead to differences in thrips numbers and thrips injury among the

varieties. If this is the case, economic injury levels may need to be developed for each variety or among varieties with similar flowering periods.

Materials and Methods

Citra PSREU

This experiment was conducted at the University of Florida Plant Science Research and Education Unit in Citra, FL. There were four 0.13 ha plots of SHB blueberries that contained eight rows of blueberry bushes. Five bushes of each variety are planted in each row. The experimental setup was a completely randomized block design with 12 replicates (four rows from each plot) of four (2007) or three (2008) varieties. In 2007, four Southern Highbush varieties: Emerald, Jewel, Millennia, and Star were sampled. In 2008, only Emerald, Jewel, and Millennia were sampled because many of the Star plants were small and produced too few flowers to provide consistent samples. There were five plants per variety in each replicate. The plants were approximately four years old in 2007.

Four sticky traps (Great Lakes IPM, Vestaburg, MI) were placed in each replicate (one per variety for a total of 48 for the experiment). The traps were hung from the center plant in each variety and were replaced weekly. Each week, 10 flowers were sampled from the middle bush and placed in 50-ml plastic tubes containing 15 ml of 70% ethanol. In 2007, samples were collected for seven weeks from Jan. 29 until March 12. In 2008, samples were collected for five weeks from Feb. 14 until March 14.

The traps and flower samples were brought back to the Small Fruit and Vegetable Laboratory at the University of Florida in Gainesville where the number of thrips per trap and per flower was counted. Flowers were sampled using the “shake and rinse” method developed by Arévalo and Liburd (2007). Adult thrips were identified to species using a

key developed for Florida SHB blueberries by Arévalo et al. (2006). Thrips that did not match the character descriptions in the key were sent to the Division of Plant Industry in Gainesville, FL for identification.

At harvest time, 30 berries per variety in each replicate were examined for thrips injury and marketability. Ten berries were taken from each of the three middle plants. The number of total injured and unmarketable fruit was divided by 30 to give proportion of total injured and unmarketable fruit per plant. Total injured fruit included both those that were still marketable and the unmarketable fruit.

Average thrips per trap, average thrips larvae and adults per flower, and average proportion of injured and unmarketable fruit were transformed as necessary to meet the assumptions of the analysis and compared among varieties using a one way analysis of variance (ANOVA) test (SAS Institute 2002). Means were separated using the least significant difference (LSD) means separation test. Thrips per sticky trap, thrips larvae per flower, and thrips adults per flower were analyzed by date.

Data were also examined for a linear relationship between numbers of thrips (larvae and adults) per flower pooled over all dates vs. proportion of total injured fruit per plant using lease squares regression in SAS (SAS Institute 2002).

Hernando and Lake Counties

Samples were taken from two commercial farms in Hernando Co., Florida, during early spring 2007 and one commercial farm in Hernando and another in Lake Co. in 2008. A 5-ha area on farm 1 in Hernando Co. was sampled only in 2007. The varieties on this farm are arranged in blocks of six to nine rows. A 2.5-ha area of the second farm in Hernando Co., farm 2, and of the Lake Co. farm was sampled. Farm 2 had alternating

rows of different varieties. Blueberry plants at the Hernando Co. farms were four to seven years of age, while those at the Lake Co. farm were only one year old.

On each farm, the four most popular SHB varieties: Emerald, Jewel, Millennia, and Windsor were divided into three treatments: T100, T200, and an untreated control. If the number of thrips per trap exceeded 200 in the T200 treatment or 100 in the T100 treatment, SpinTor® 2 SC (spinosad) (Dow Agrosciences, Indianapolis, IN) was applied at the label rate of 0.438 L / ha. The 100 thrips per trap threshold is only slightly higher than the economic injury level calculated by Arévalo-Rodriquez (2006) for rabbiteye blueberries when SpinTor® is applied. The treatment thresholds encompassed a row of each of the varieties. There were three replicates containing each threshold/variety combination, which encompassed all of the samples from the beginning, middle, and end of the rows. A sticky trap was placed in each threshold/variety combination. Five flowers from each of two plants closest to the trap were also sampled.

In 2007, sticky trap samples were collected for six weeks beginning on Feb. 1 and 2 on farms 1 and 2, respectively. Flower samples were collected until the majority of plants were in fruit set. On farm 1, both treatments were above threshold after the first week of sampling. Applications of SpinTor® were made on Feb. 9 and Feb. 23. Thrips numbers on farm 2 remained below threshold throughout the sampling period, so SpinTor® was not applied.

In 2008, sticky trap samples were collected for four weeks from the Lake Co. farm and for three weeks from the Hernando Co. farm (farm 2 from 2007) beginning on Feb. 14 and Feb. 21, respectively. Flower samples were collected until the majority of plants

were in fruit set. The number of thrips per trap did not exceed either of the treatment threshold levels on any date, so SpinTor® was not applied on either farm.

Sticky traps and flower samples were shipped to the Small Fruit and Vegetable IPM Laboratory at the University of Florida in Gainesville, FL. The number of thrips per trap was counted and flowers were dissected under a dissecting microscope. Adult and larval thrips were counted and stored in 1 dram vials containing 70% ethyl alcohol. Adults were identified to species using a key developed for Florida SHB blueberries by Arévalo et al. (2006). Thrips that did not match the character descriptions in the key were sent to the Division of Plant Industry in Gainesville, FL for identification.

At harvest time, 25 berries from the two previously sampled plants and from two adjacent plants were examined for thrips injury and marketability. The number of total injured and unmarketable fruit from each sample was divided by 25 to give proportion of total injured and unmarketable fruit per plant. The proportions from the four samples were then averaged. Total injured fruit included both those that were still marketable and the unmarketable fruit.

Average thrips per trap exceeded the threshold only on farm 1 in 2007. Therefore, average thrips per trap, average thrips larvae and adults per flower, and average proportion of total injured and unmarketable fruit per plant were transformed as necessary to meet the assumptions and compared among treatments and varieties using a two-way ANOVA test (SAS Institute 2002). If no interaction was present, main effects of both factors were compared using the LSD means separation test. If interaction was present, then simple effects were compared for whichever factor was

significant. Thrips per sticky trap, thrips larvae per flower, and thrips adults per flower were analyzed by week.

Numbers of thrips per trap did not reach the threshold on farm 2 in 2007 or on either farm in 2008 so SpinTor® was never applied. Therefore, the previously described data sets were transformed as needed to meet the assumptions of ANOVA and varietal differences were analyzed using a one-way ANOVA. Means were separated using the LSD means separation test. Thrips per sticky trap, thrips larvae per flower, and thrips adults per flower were analyzed by week.

Data from 2007 and 2008 were also examined for any linear relationship between numbers of thrips (larvae and adults) per flower pooled over all dates vs. total injured fruit per plant using Theil regression (Hollander and Wolfe 1999) in 2007 and least squares regression (SAS Institute, 2002) in 2008. Kendall's tau, a nonparametric correlation statistic (Hollander and Wolfe 1999) was also calculated for the 2007 data (Wessa 2008).

Results

Citra PSREU

2007

Traps

There were significantly more thrips per trap in the Emerald and Millennia varieties compared with the Star variety (F = 2.48, df = 3, 47, P = 0.052) on Feb. 5 (Fig. 4-1). On Feb. 12, there were significantly more thrips per trap in the Emerald variety compared with all of the other varieties (F = 8.33, df = 3, 47, P = 0.0003). Also, Jewel had significantly higher thrips per trap than Star.

Flowers

There were no significant differences among either thrips larvae or thrips adults per flower on any date (all $F \leq 2.47$, df = 3, 47, $P \geq 0.08$). Average thrips larvae per flower did not exceed 0.09 ± 0.07 larvae on any date. Average thrips adults per flower did not exceed 0.15 ± 0.07 adults on any date.

There was a high diversity in adults thrips sampled from the flowers. The majority of thrips were *F. bispinosa* (Table 1). Others species sampled included *F. fusca* (Hinds), *Franklinothrips* sp., *Haplothrips graminis* Hood, *Thrips hawaiiensis* (Morgan), and *T. pini* Karny.

Fruit

Emerald and Jewel had a significantly higher proportion of injured fruit than Millennia and Star ($F = 7.53$, df = 3, 47, $P = 0.0006$, Fig. 4-2). Emerald also had a significantly higher proportion of unmarketable fruit then all of the other varieties ($F = 11.31$, df = 3, 47, $P < 0.0001$).

Simple linear regression did not show any relationship between thrips per flower and proportion of total injured fruit in any of the varieties (all $R^2 \leq 0.03$, all $t \leq 1.13$, df = 11, $P_{slope} \geq 0.28$).

2008

Traps

On Feb. 14, there were significantly more thrips per trap in the Emerald and Jewel varieties than in the Millennia variety ($F = 3.9$, df = 2, 35, $P = 0.036$, Fig. 4-3).

Flowers

There were significantly more thrips larvae per flower in the Emerald variety compared with the Jewel variety on Feb. 14 ($F = 3.37$, df = 2, 35, $P = 0.053$) and

compared with both other varieties on Feb. 22 (F = 12.69, df = 2, 35, P = 0.0002) and March 8 (F = 6.81, df = 2, 35, P = 0.0050, Fig. 4-4A).

The Emerald variety also had significantly more thrips adults per flower compared with the other two varieties on Feb. 14 (F = 7.2, df = 2, 35, P = 0.0039, Fig. 4-4B). In contrast, Jewel had significantly higher numbers of thrips adults per flower compared with the other two varieties on March 14 (F = 7.99, df = 2, 35, P = 0.0025).

Percent of adult thrips species sampled from flowers was similar to 2007, with *F. bispinosa* comprising the majority (> 60%) of thrips sampled (Table 4-1). Most of the remaining adult thrips were either *T. hawaiiensis* or *T. pini*. *Frankliniella fusca*, *Franklinothrips* sp., and *H. graminis* were also found.

Fruit

There were no significant differences in either proportion of injured (F = 0.18, df = 2, 35, P = 0.83) or unmarketable (F = 0.62, df = 2, 35, P = 0.55) fruit among varieties. Emerald, Jewel, and Millennia averaged 0.14 ± 0.02, 0.16 ± 0.03, and 0.16 ± 0.02 proportions of injured fruit, respectively. All three varieties averaged a 0.01 ± 0.00 proportion of unmarketable fruit.

Simple linear regression did not show any relationship between thrips per flower and proportion of total injured fruit in any of the varieties (all $R^2 \leq 0.12$, all $t \leq 1.57$, df = 11, $P_{slope} \geq 0.15$).

Hernando and Lake Counties

2007

Traps

There were no treatment*variety interactions on any date after treatments were applied (all $F \leq 1.23$, df = 6, 35, $P \geq 0.33$). Therefore each factor was examined separately.

There were significantly fewer thrips per trap recorded from the 200 thrips per trap threshold treatment compared with the control on March 1 ($F = 4.1$, df = 2, 35, $P = 0.029$, Fig. 4-5).

On farm 1, Emerald had significantly higher numbers of thrips per trap compared with at least two of the other varieties on all sampling dates. There were significantly higher numbers of thrips per trap in the Emerald variety compared with the Jewel and Millennia varieties ($F = 7.18$, df = 3, 35, $P = 0.0013$) on Feb. 1 (Fig. 4-6). Windsor also had significantly higher numbers of thrips per trap compared with Millennia on this date. Emerald had significantly higher numbers of thrips per trap than all of the other varieties on Feb. 8 ($F = 11.27$, df = 3, 35, $P < 0.0001$), Feb. 15 ($F = 5.71$, df = 3, 35, $P < 0.0043$), Feb. 22 ($F = 22.65$, df = 3, 35, $P < 0.0001$), and March 1 ($F = 11.58$, df = 3, 35, $P < 0.0001$). Jewel and Windsor also had significantly higher numbers of thrips per trap than Millennia on Feb. 22. On March 8, Emerald had significantly higher numbers of thrips per trap than Jewel and Windsor ($F = 4.07$, df = 3, 35, $P = 0.018$).

On farm 2, Emerald had significantly higher numbers of thrips per trap than all other varieties ($F = 8.53$, df = 3, 35, $P = 0.0003$) on Feb. 9 (Fig. 4-7). On Feb. 16, Emerald had significantly higher numbers of thrips per trap compared with Jewel and Windsor. Also, Jewel had significantly more thrips per trap compared with Windsor ($F =$

16.27, df = 3, 35, $P < 0.0001$). On Feb. 23, both Emerald and Jewel had significantly more thrips per trap compared with Windsor ($F = 3.32$, df = 3, 35, $P = 0.033$).

Flowers

There were no treatment*variety interactions in thrips larvae per flower on any date after treatments were applied (both $F = 0.51$, df = 6, 35, $P = 0.79$) on farm 1.

There were no significant differences in thrips larvae per flower among treatments on any date (all $P \geq 0.11$). In the T200 treatment, thrips larvae per flower peaked at 2.2 ± 0.3 larvae on Feb. 8, the day before SpinTor® was applied. Thrips larvae per flower peaked in both the T100 and control treatments on Feb. 15 at 2.2 ± 0.4 and 2.4 ± 0.4 larvae, respectively.

However, there were significantly higher numbers of thrips larvae per flower in the Jewel variety compared with the other varieties ($F = 3.57$, df = 3, 35, $P = 0.029$) on Feb. 8 (Fig. 4-8A).

For thrips adults, there was no treatment*variety interaction on Feb. 15 ($F = 0.78$, df = 6, 35, $P = 0.59$). However, there was treatment*variety interaction on Feb. 22 ($F = 3.42$, df = 6, 35, $P = 0.014$).

There were no significant differences in thrips adults per flower among treatments on any date (all $F \leq 1.42$, df = 2, 35, $P \geq 0.26$). Average thrips adults per flower did not rise above 1.2 ± 0.3 adults on any date.

However, the varietal trends in thrips adults per flower on farm 1 were similar to thrips per trap. On Feb. 8, there were significantly higher numbers of thrips adults per flower in the Emerald variety compared with the Millennia and Windsor varieties ($F = 5.00$, df = 3, 35, $P = 0.0078$, Fig. 4-8B). Emerald had significantly higher numbers of thrips adults per flower compared with all of the other varieties on Feb. 15 ($F = 10.32$, df

= 3, 35, *P* = 0.0001). Jewel had significantly higher numbers of thrips adults per flower compared with Millennia on both of the above dates.

On Feb. 22, main effects showed that Emerald had significantly higher numbers of thrips adults per flower compared with Jewel and Millennia (*F* = 9.93, df = 3, 35, *P* = 0.0003). Jewel also had significantly higher numbers of thrips than Millennia. When simple effects are examined, Emerald has significantly higher numbers of thrips adults compared with all of the other varieties in the untreated control. There were no varietal differences in the T100 treatment. In contrast, Millennia had significantly fewer thrips adults per flower than all three of the other varieties in the T200 treatment.

On farm 2, there were significantly more thrips larvae per flower in the Emerald variety compared with the Windsor variety (*F* = 3.70, df = 3, 35, *P* = 0.022) on Feb. 9 (Fig. 4-9A). On Feb. 16, both Jewel and Emerald had significantly higher numbers of thrips larvae compared with Millennia and Windsor (*F* = 4.99, df = 3, 35, *P* = 0.0063). Emerald had significantly higher numbers of thrips larvae per flower compared with all of the other varieties on Feb. 23 (*F* = 4.76, df = 3, 35, *P* = 0.0079). In contrast, Jewel and Windsor had significantly higher numbers of thrips larvae per flower compared with Emerald and Millennia on March 2 (*F* = 4.54, df = 3, 35, *P* = 0.0097).

There were significantly more thrips adults per flower in the Emerald variety compared with the Jewel and Windsor varieties and significantly more thrips adults per flower in the Millennia variety compared with the Windsor variety (*F* = 5.35, df = 3, 35, *P* = 0.0045) on Feb. 16 (Fig. 4-9B). On Feb. 23, Jewel and Windsor had significantly higher numbers of thrips adults per flower compared with Millennia (*F* = 3.01, df = 3, 35, *P* = 0.046).

Farm 1 had an unusually high number of *T. hawaiiensis* and *T. pini* present in the Emerald and Windsor varieties (Table 4-2). *Frankliniella bispinosa* was the dominant species found in the Jewel and Millennia varieties. A single *H. graminis* was found in the Windsor variety.

In contrast, the majority of thrips adults sampled from flowers of all the varieties on farm 2 were *F. bispinosa* (Table 4-3). *Franklinothrips* sp., *H. graminis*, *T. hawaiiensis*, and *T. pini* were also present.

Fruit

There were no treatment*variety interactions in proportion of total injured (F = 0.47, df = 6, 35, P =0.82) or unmarketable (F = 0.70, df = 6, 35, P =0.66) fruit on farm 1. Therefore, main effects were analyzed.

Interestingly, there was a significantly higher proportion of injured (F = 5.72, df = 6, 35, P =0.0093) and malformed (F = 3.53, df = 6, 35, P =0.045) fruit in the untreated control compared with the T100 treatment (Fig. 4-10).

There were no significant differences in either proportion of total injured or unmarketable fruit among varieties on farm 1 (injured: F = 1.05, df = 3, 35, P = 0.39; unmarketable: F = 0.87, df = 3, 35, P = 0.57) or farm 2 (injured: F = 1.87, df = 3, 35, P = 0.16; unmarketable: F = 0.25, df = 3, 35, P = 0.86). On farm 1, there was an average proportion of total injured fruit of 0.09 ± 0.02 and an average proportion of unmarketable fruit of 0.02 ± 0.01 across varieties. On farm 2, there was an average proportion of total injured fruit of 0.05 ± 0.01 and an average proportion of unmarketable fruit of 0.02 ± 0.002 across varieties.

Nonparametric regression showed a significant positive linear relationship between thrips per flower and total injured fruit in the Emerald (τ = 0.41, C = 74, n = 18,

P_{slope} = 0.003), Jewel (τ = 0.35, *C* = 56, n = 18, P_{slope} = 0.024), Millennia (τ = 0.25, *C* = 44, n = 18, P_{slope} = 0.056), and Windsor (τ = 0.30, *C* = 56, n = 18, P_{slope} = 0.02) varieties (Fig. 4-11A-D).

2008

Traps

On the Lake Co. farm, Emerald, Windsor, and Jewel had significantly higher numbers of thrips per trap compared with Millennia (*F* = 4.52, df= 3, 34, *P* = 0.0096) on Feb. 21 (Fig. 4-12). On Feb. 28, Windsor had significantly higher numbers of thrips per trap compared with Millennia (*F* = 3.09, df = 3, 35, *P* = 0.041). Windsor had significantly higher numbers of thrips per trap compared with all of the other varieties on March 6 (*F* = 13.68, df = 3, 35, *P* < 0.0001).

On Hernando Co. farm 2, there were no significant differences in thrips per trap among varieties on any date (all *F* ≤ 2.09, df = 3, 32, *P* ≥ 0.12). There were an average of 8.3 ± 1.8, 4.2 ± 1.1, and 10.3 ± 2.2 thrips per trap over variety on Feb. 21, Feb. 28, and March 6 respectively.

Flowers

On the Lake Co. farm, there were significantly more thrips larvae per flower in the Emerald variety compared with the Millennia variety (*F* = 3.4, df = 3, 34, *P* = 0.030) on Feb. 14 (Fig. 4-13A).

There were significantly more thrips adults per flower in the Emerald variety compared with all of the other varieties (*F* = 16.41, df = 3, 34, *P* < 0.0001) on Feb. 14 (Fig. 4-13B). There were significantly more thrips adults per flower in the Windsor variety compared with the Jewel and Millennia varieties on Feb. 28 (*F* = 6.17, df = 2, 21, *P* = 0.0086).

On Hernando Co. farm 2, there were significantly higher numbers of thrips larvae per flower in the Emerald (0.8 ± 0.2 larvae) and Windsor (1.1 ± 0.2 larvae) varieties compared with the Jewel (0.3 ± 0.1 larvae) and Millennia (0.3 ± 0.2 larvae) varieties (F = 5.9, df = 3, 35, P = 0.0025) on Feb. 21. On Feb. 28, Windsor (0.05 ± 0.01 larvae) had significantly higher numbers of thrips per flower than all of the other varieties (0 larvae) (F = 6.32, df = 3, 22, P = 0.0037).

There were no significant differences in thrips adults per flower among varieties on either date (both $F \leq 1.42$, df = 3, 35, $P \geq 0.25$). There was an average of 0.2 ± 0.1 and 0.01 ± 0.008 adults per flower across varieties on Feb. 21 and 28 respectively.

All four varieties on the Lake Co. farm had high percentages of *T. hawaiiensis* and *T. pini* adults (Table 4-2). Most of the remaining adult thrips were *F. bispinosa*. *Frankliniella fusca*, *Franklinothrips* sp., and *H. graminis* were sampled occasionally.

In contrast, *F. bispinosa* was the dominant thrips species sampled from Jewel, Millennia, and Windsor flowers on Hernando Co. farm 2 (Table 4-3). Most of the thrips sampled from the Emerald flowers were either *T. hawaiiensis* or *T. pini*. A few *Franklinothrips* sp. were found in the Windsor variety.

Fruit

On the Lake Co. farm, Jewel had a significantly higher proportion of injured fruit compared with all of the other varieties and Windsor had a significantly higher proportion of injured fruit compared with Emerald and Millennia (F = 15.41, df = 3, 35, P < 0.0001, Fig. 4-14A). Jewel also had a significantly higher proportion of unmarketable fruit compared with all the other varieties (F = 13.87, df = 3, 25, P < 0.0001).

On Hernando Co. farm 2, Jewel and Windsor had a significantly higher proportion of injured fruit compared with Emerald and Millennia and Emerald had a significantly

higher proportion of injured fruit compared with Millennia (F = 18.43, df = 3, 35, P < 0.0001, Fig. 4-14B). Jewel also had a significantly higher proportion of unmarketable fruit compared with all the other varieties (F = 21.77, df = 3, 25, P < 0.0001).

Simple linear regression, combining the data from both farms, did not show any relationship between thrips per flower and proportion of total injured fruit in any of the varieties (all $R^2 \leq 0.01$, all $t \geq -1.08$, df = 17, $P_{slope} \geq 0.30$).

Discussion

The only significant difference in thrips numbers among treatment thresholds occurred with thrips per trap on March 1, 2007 on farm 1. By this date, flowers were only present on the Emerald variety. The lack of effectiveness of the thresholds may have been caused by thrips from untreated areas of the farms recolonizing the treated rows. Funderburk and Stavisky (2004) note that *F. bispinosa* adults can quickly recolonize a treated area, making the application appear to be ineffective. The proportion of injured and unmarketable fruit data suggest that 100 thrips per trap is an effective threshold, but more research is needed to confirm this fact.

Southern highbush blueberry variety does appear to influence thrips numbers. This was particularly true on the two Hernando Co. farms in 2007. Emerald frequently had significantly more thrips per trap and per flower than the other varieties. Millennia and Star tended to have the lowest numbers of thrips. This may be due to their flowering characteristics. Emerald, Jewel, and Millennia reach 50% open flowers around Feb. 16 in Gainesville, FL. Star and Windsor reach 50% open flowers about a week later (Williamson and Lyrene 2004). Unlike the other varieties, Emerald flowers uniformly. All of the varieties tested except Millennia reach petal fall around the same time. Millennia reaches petal fall 3 to 4 days earlier (Williamson and Lyrene 2004). The

combination of flowering early and uniformly, when flower thrips are abundant, may make Emerald more attractive to flower thrips.

The differences in thrips numbers among varieties were not as pronounced on the Lake and Hernando Co. farms in 2008 compared with 2007. There are several possible reasons for this difference. Firstly, sampling was initiated late and only a few weeks of data were collected. Secondly, only the week of Feb. 14 contained a complete data set for flowers from farm 1. Many plants had already reached petal fall by Feb. 21 on both farms. Therefore, there were several missing data points from Feb. 21 and 28. Thirdly, there were fewer thrips on the farms in 2008 compared with 2007.

The differences in thrips numbers among varieties were also not as pronounced on the Citra PSREU farm compared with the Hernando and Lake Co. farms. The four varieties at the Citra farm are distributed evenly among each other. This may be partially masking the effect of variety on thrips numbers. In contrast, farm 1 in Hernando Co. has large blocks of a single variety. Farm 2 has an intermediate setup, with only a few rows of the same variety adjacent to each other. Further research is needed to confirm the hypothesis that arrangement of blueberry varieties affects thrips numbers.

There were differences in fruit injury among varieties, but these did not appear to be related to differences in thrips numbers. There could be several reasons for this. The different varieties could have different levels of tolerance to flower thrips. It is also possible that some varieties are more susceptible to diseases than others. Lastly, the different species of thrips may differ greatly in their effect on the blueberry flowers and subsequent fruits. It has been shown that peppers in Florida can tolerate high numbers

of *F. bispinosa* and *F. tritici*, but only a few *F. occidentalis* will cause significant injury (Funderburk 2009).

The thrips complex in SHB blueberry flowers in Florida is dominated by *F. bispinosa* (Arévalo et al. 2006). *Frankliniella bispinosa* was the most common species sampled from all of the varieties at the Citra PSREU. A diversity of other species was also found. This diversity of species was probably due to the wide variety of crops grown at the research station.

The two Hernando and Lake Co. farms, however, differed from this norm. On farm 1 in 2007, the Millennia variety was the only one dominated by *F. bispinosa*. Jewel and Windsor had high percentages of *F. bispinosa*, *T. hawaiiensis*, and *T. pini*. Emerald was dominated by the two *Thrips* species. On the Lake Co. farm in 2008, all four varieties were dominated by the two *Thrips* species. Farm 2 was less extreme in its differences from the expected. In 2007, only the Jewel variety had high percentages of the two *Thrips* species. Even so, the majority of thrips sampled from Jewel were *F. bispinosa*. In 2008, the Emerald variety was dominated by the two *Thrips* species, while the other varieties were dominated by *F. bispinosa*. Further research is needed to determine why the two *Thrips* species occurred in such high numbers on these three farms.

Significant positive linear relationships between thrips per flower and fruit injury were found in all four varieties from the Hernando Co. farms in 2007. Neither the Hernando and Lake Co. farms in 2008 nor the Citra PSREU in either year showed a relationship between thrips per flower and fruit injury. This may be due to the low numbers of thrips present at these farms during these years.

The results from these experiments show evidence that SHB blueberry varieties may attract different numbers of thrips and may have varying tolerance to thrips injury. If this is the case, then each variety would have a different Economic Injury Level (EIL). Since multiple varieties are grown on the same farm, the lowest EIL could be used to set the threshold level for the farm.

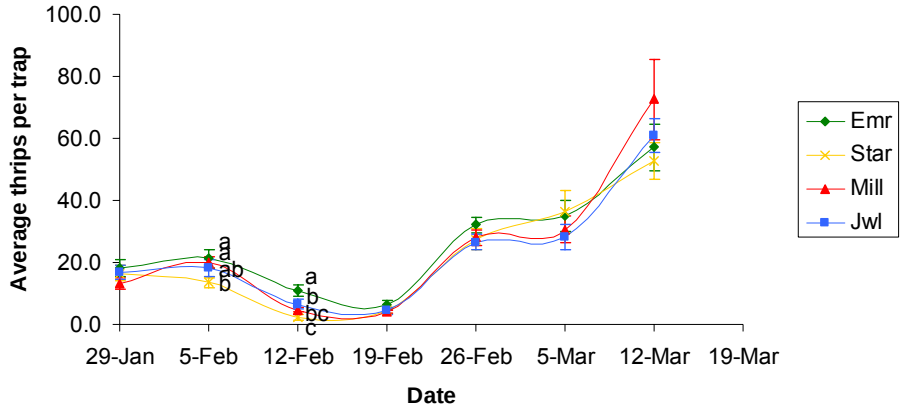


Fig. 4-1. Average thrips per sticky trap recorded from each variety per week in 2007. Error bars represent standard error of the mean. Means with the same letter are not significantly different from each other at the *P* = 0.05 level.

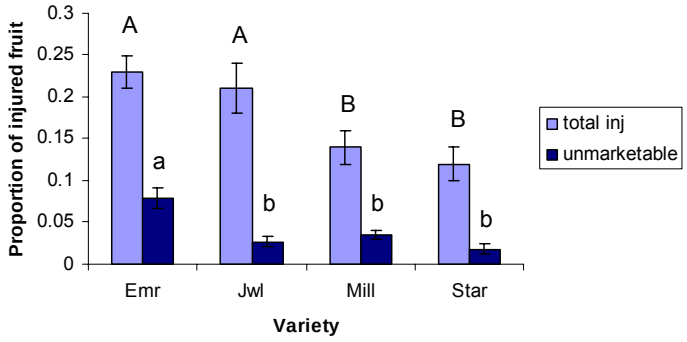


Fig. 4-2. Proportion of injured and unmarketable fruit sampled from each variety in 2007. Error bars represent standard error of the mean. Means with the same letter are not significantly different from each other at the *P* = 0.05 level.

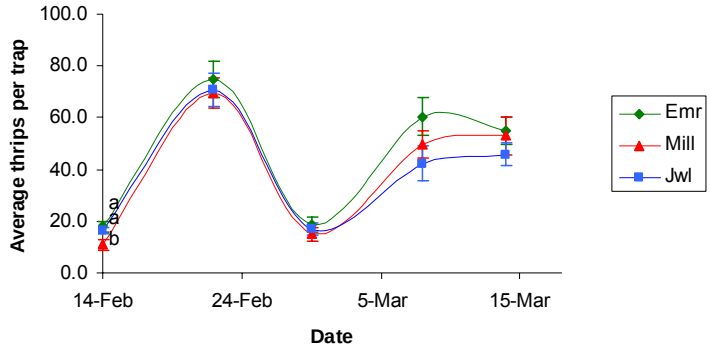
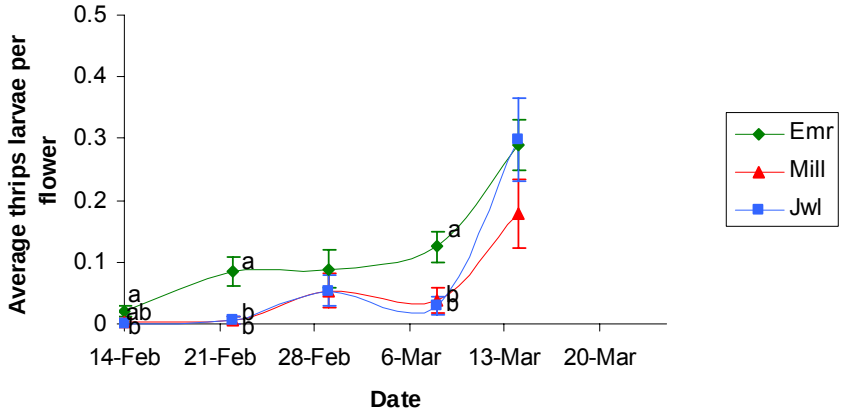
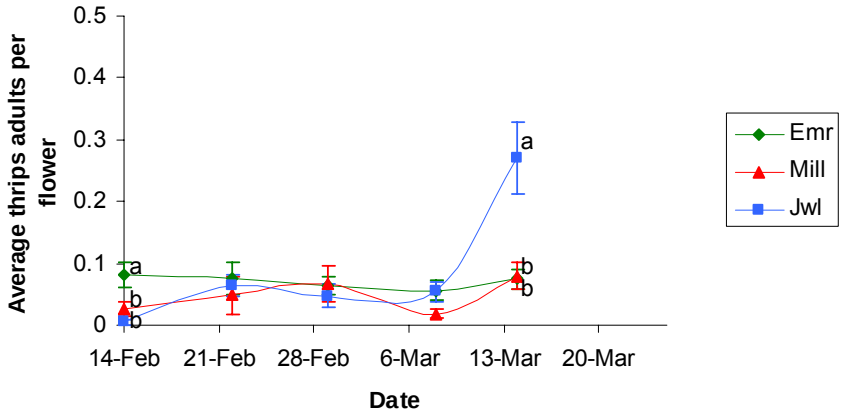


Fig. 4-3. Average thrips per sticky trap recorded from each variety per week in 2008. Error bars represent standard error of the mean. Means with the same letter are not significantly different from each other at the *P* = 0.05 level.



A



B

Fig. 4-4. Average thrips A) larvae and B) adults per flower recorded from each variety per week in 2008. Error bars represent standard error of the mean. Means with the same letter are not significantly different from each other at the *P* = 0.05 level.

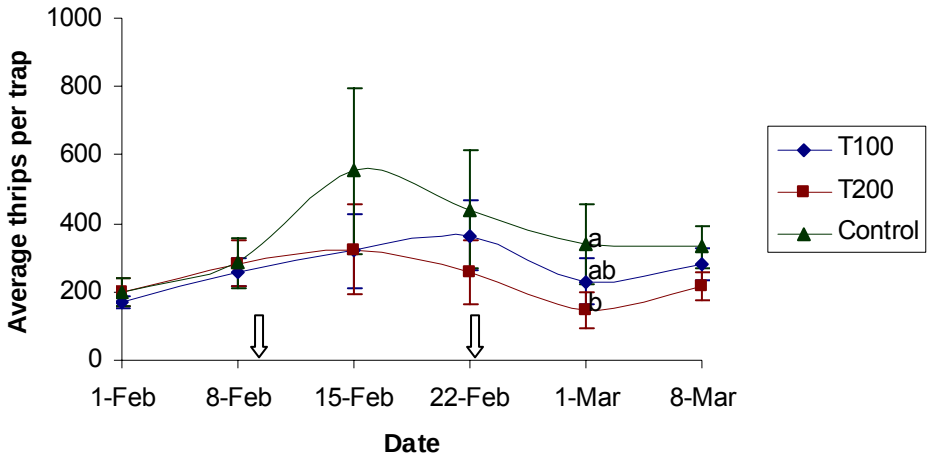


Fig. 4-5. Average thrips per trap recorded from each treatment per week on farm 1 in 2007. Error bars represent standard error of the mean. Means with the same letter are not significantly different from each other at the *P* = 0.05 level. Arrows indicate the dates when SpinTor® was applied.

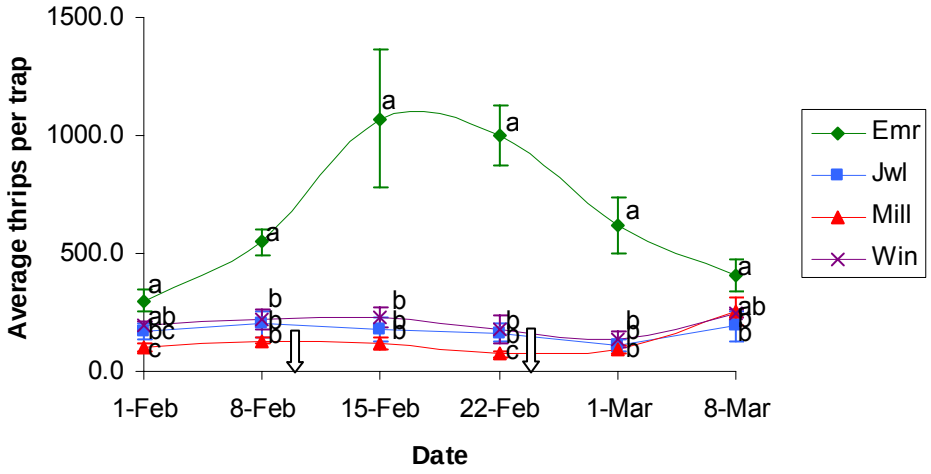


Fig. 4-6. Average thrips per trap recorded from each variety per week on farm 1 in 2007. Error bars represent standard error of the mean. Means with the same letter are not significantly different from each other at the *P* = 0.05 level. Arrows indicate the dates when SpinTor® was applied.

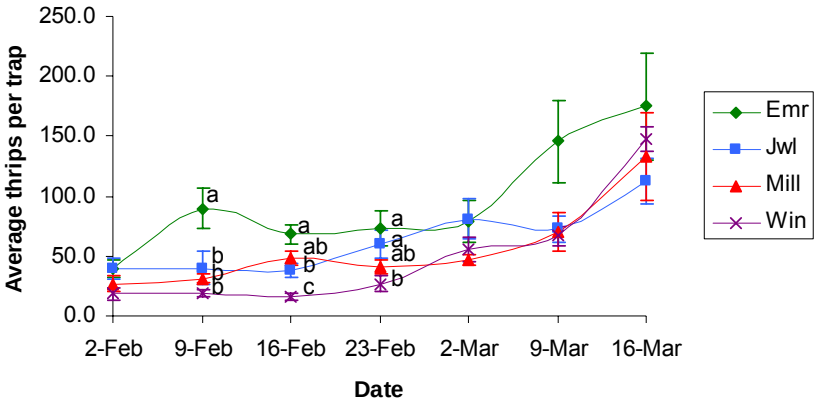
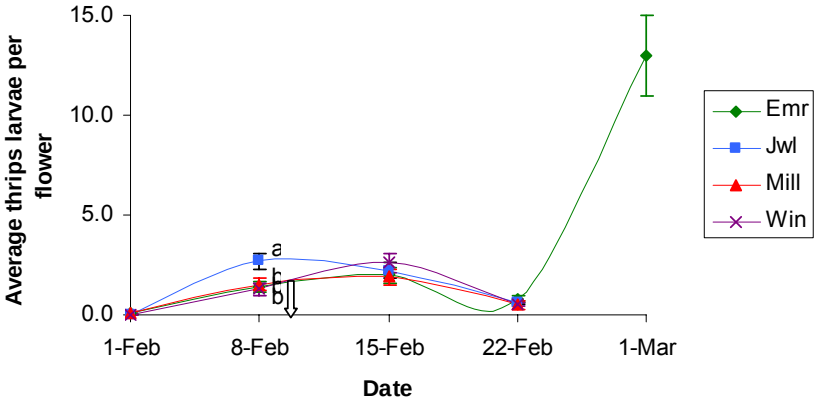
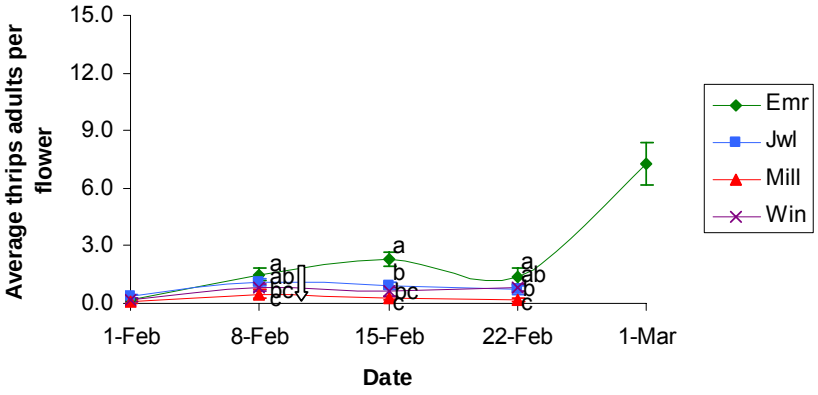


Fig. 4-7. Average thrips per trap recorded from each variety per week on farm 2 in 2007. Error bars represent standard error of the mean. Means with the same letter are not significantly different from each other at the *P* = 0.05 level.

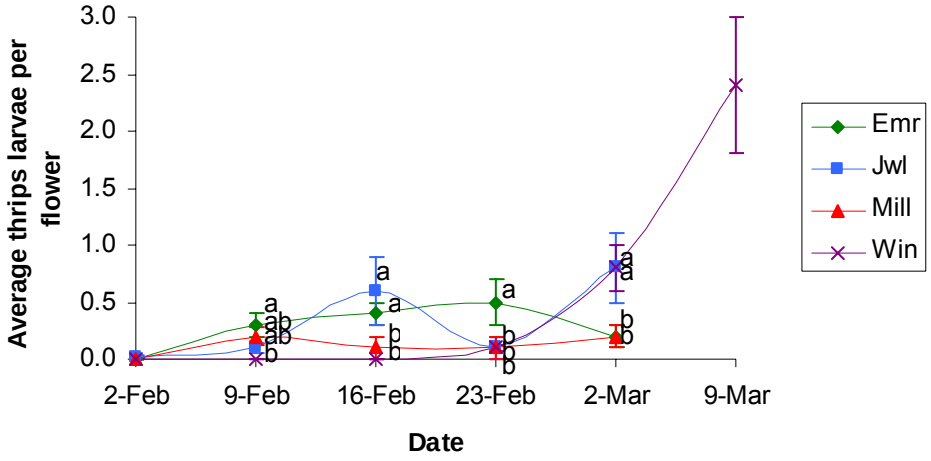


A

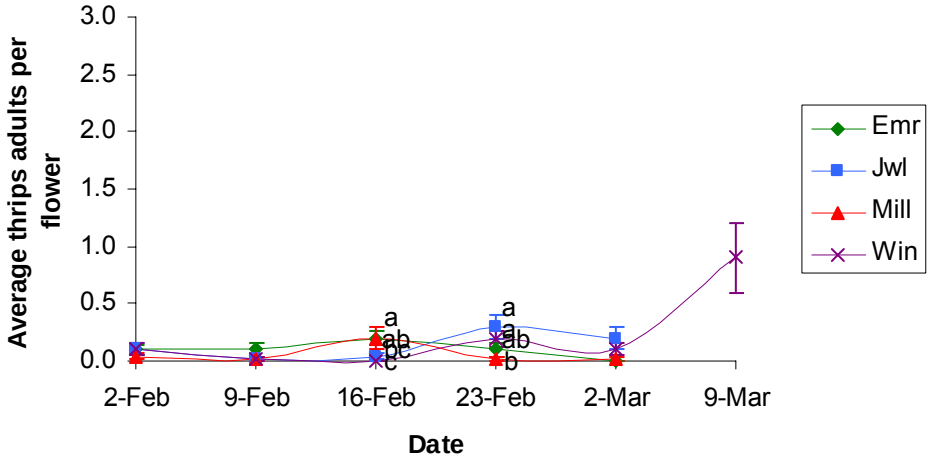


B

Fig. 4-8. Average thrips A) larvae and B) adults per flower recorded from each variety per week on farm 1 in 2007. Error bars represent standard error of the mean. Means with the same letter are not significantly different from each other at the *P* = 0.05 level. Arrows indicate the dates when SpinTor® was applied.



A



B

Fig. 4-9. Average thrips A) larvae and B) adults per flower recorded from each variety per week on farm 2 in 2007. Error bars represent standard error of the mean. Means with the same letter are not significantly different from each other at the *P* = 0.05 level.

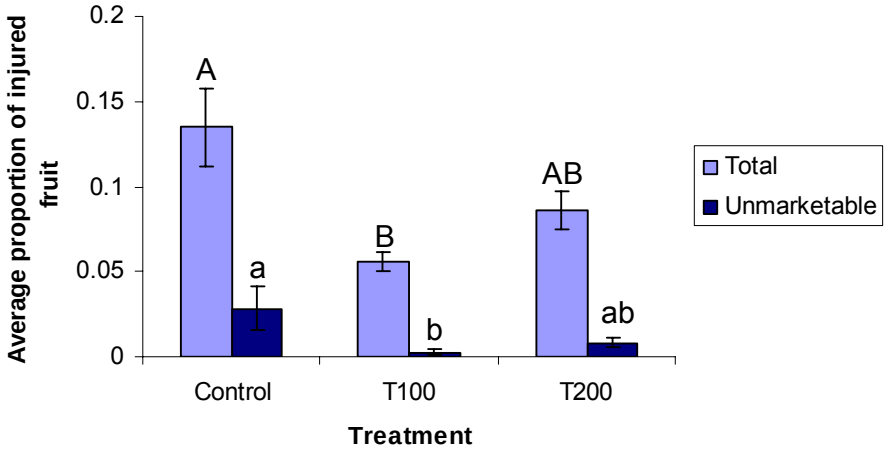
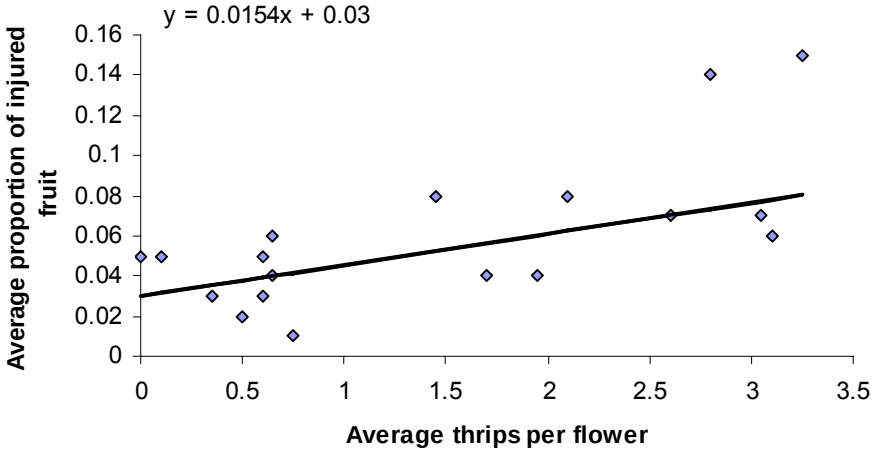
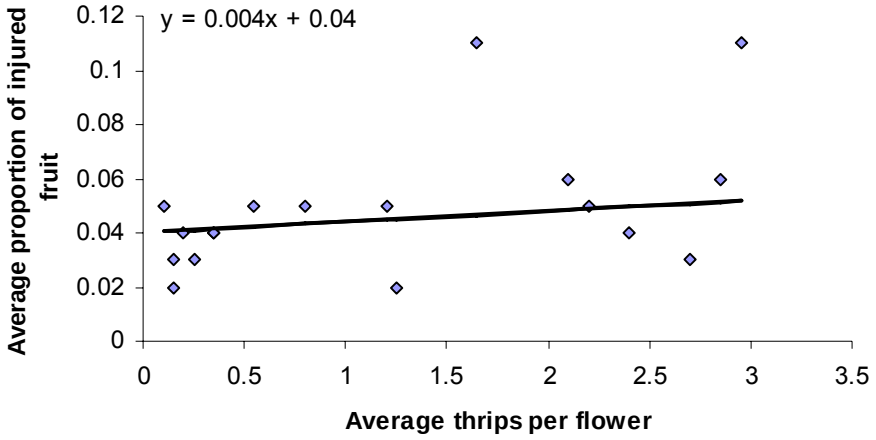


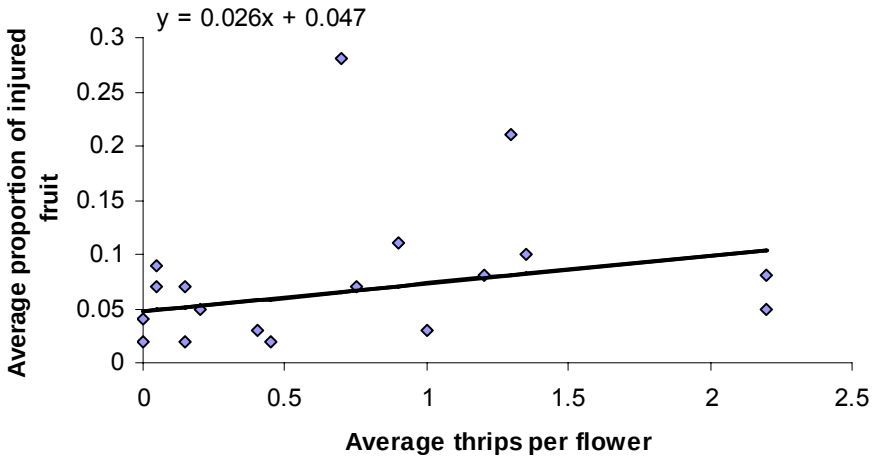
Fig. 4-10. Proportion of injured and unmarketable fruit sampled from each treatment on farm 1 in 2007. Error bars represent standard error of the mean. Means with the same letter are not significantly different from each other at the *P* = 0.05 level.



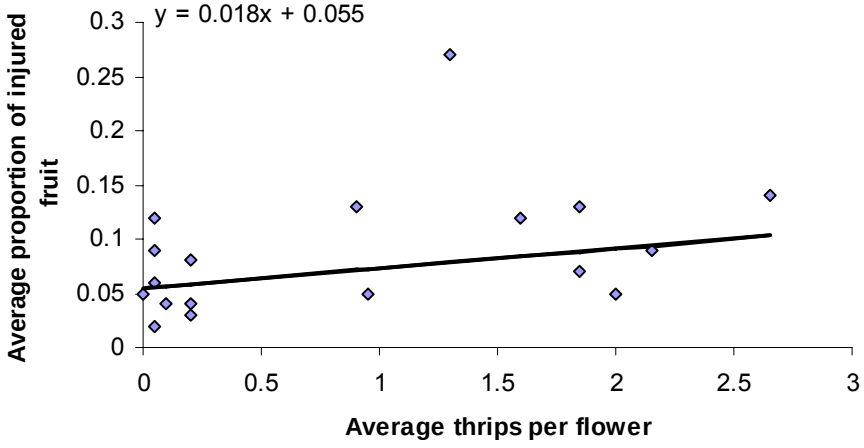
A



B



C



D

Fig. 4-11. Graphs showing average thrips per flower vs. average proportion of injured fruit, the Theil regression line, and equation for the A) Emerald, B) Jewel, C) Millennia, and D) Windsor varieties. Data from both farms were combined.

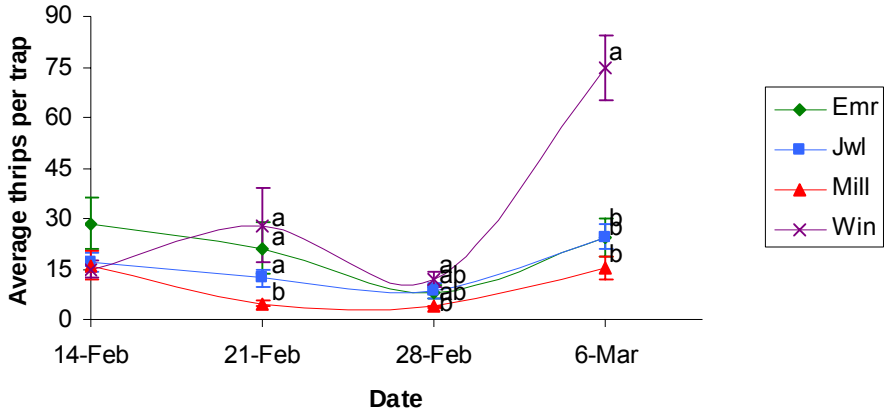
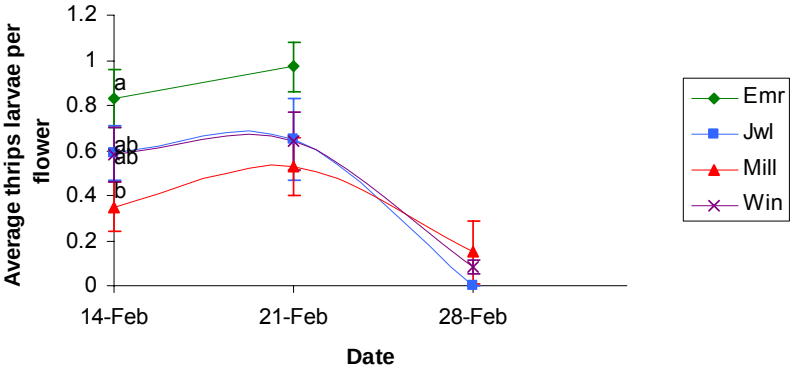
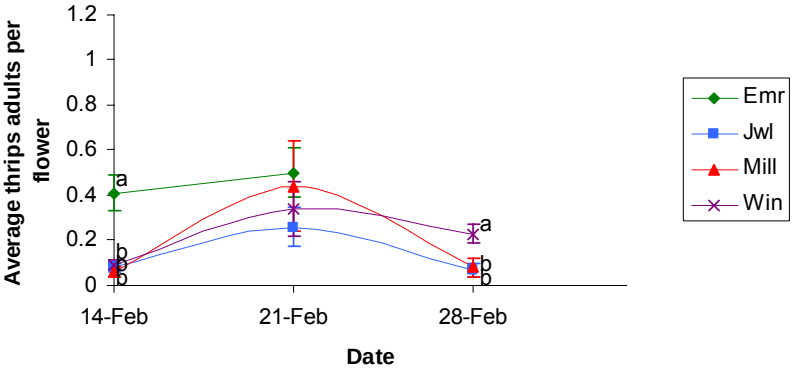


Fig. 4-12. Average thrips per trap recorded from each variety per week on farm 1 in 2008. Error bars represent standard error of the mean. Means with the same letter are not significantly different from each other at the *P* = 0.05 level.

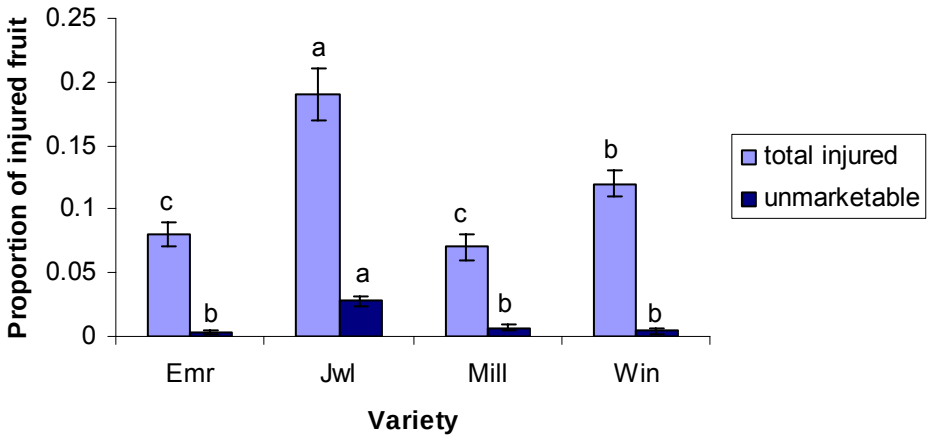


A

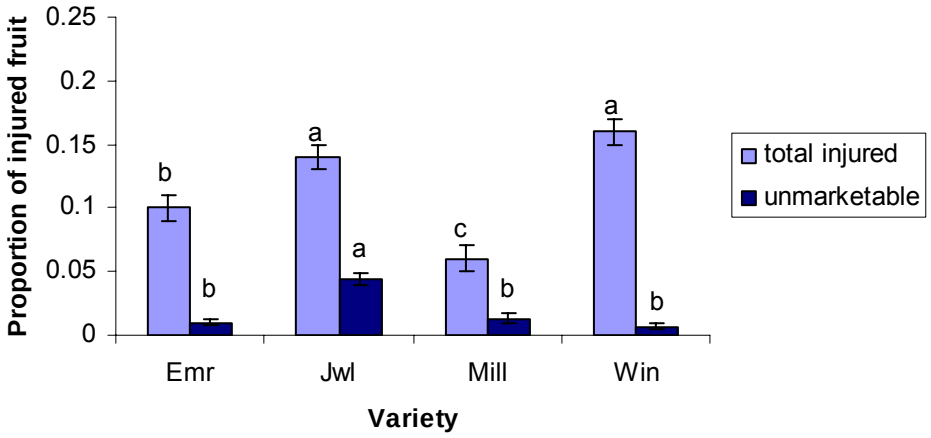


B

Fig. 4-13. Average thrips A) larvae and B) adults per flower recorded from each variety per week on farm 1 in 2008. Error bars represent standard error of the mean. Means with the same letter are not significantly different from each other at the *P* = 0.05 level.



A



B

Fig. 4-14. Proportion of injured and unmarketable fruit sampled from each variety on A) farm 1 and B) farm 2 in 2008. Error bars represent standard error of the mean. Means with the same letter are not significantly different from each other at the *P* = 0.05 level.

Table 4-1. Percent of adult thrips species sampled from flowers in each treatment at the Citra PSREU

		F. bispinosa	*F. fusca*	*F. occidentalis*	*T. hawaiiensis*	*T. pini*	*Franklinothrips* sp.	*H. graminis*
2007	Emerald	73.3	0	3.3	3.3	13.3	3.3	3.3
	Jewel	72.0	4.0	0	4.0	0	8.0	12.0
	Millenia	91.2	2.9	0	0	0	5.9	0
	Star	54.5	9.1	0	3.03	9.09	3.03	21.2
2008	Emerald	71.9	0.6	0	7.8	15.6	3.1	0
	Jewel	53.3	0.6	0	14.1	23.9	6.5	1.1
	Millenia	76.9	0	0	10.3	2.6	7.7	2.6

Table 4-2. Percent of adult thrips species sampled from flowers in each treatment on farm 1

		F. bispinosa	*F. fusca*	*T. hawaiiensis*	*T. pini*	*Franklinothrips* sp.	*H. graminis*
2007	Emerald	15.1	0	36.2	49	0	0
	Jewel	50.0	0	20.2	30	0	0
	Millennia	71.9	0	6.3	22	0	0
	Winsor	41.2	0	27.1	31	0	1.2
2008	Emerald	28.4	2.7	43.2	16.2	9.5	0
	Jewel	40.0	0	36.0	24.0	4.0	0
	Millenia	15.7	0	56.9	25.5	0	2.0
	Winsor	36.5	1.4	39.2	21.6	0	1.4

Table 4-3. Percent of adult thrips species sampled from flowers in each treatment on farm 2

		F. bispinosa	*T. hawaiiensis*	*T. pini*	*Franklinothrips* sp.	*H. graminis*
2007	Emerald	77.3	4.5	18.2	0	0
	Jewel	56.3	18.8	25.0	0	0
	Millenia	90.9	0	0	9.1	0
	Winsor	81.0	4.8	4.8	4.8	4.8
2008	Emerald	16.7	41.7	41.7	0	0
	Jewel	100.0	0	0	0	0
	Millenia	66.7	33.3	0	0	0
	Winsor	70.0	3.3	20.0	6.7	0

CHAPTER 5
EXAMINING THE SPATIAL DISTRIBUTION OF THRIPS UTILIZING GEOSTATSITICAL METHODS

Introduction

Flower thrips are the key pest of southern highbush (SHB) blueberries in Florida. The most common species is *Frankliniella bispinosa* (Morgan), the Florida flower thrips (Arévalo-Rodriguez et al. 2006). They feed on and breed in all flower tissues. Flower thrips injure the flower tissues while feeding and laying their eggs. When the ovaries of the flowers develop into fruit, this injury can become magnified and appear as scars on fruit tissue. High populations of flower thrips can cause fruit to be malformed and unmarketable (Arévalo-Rodriguez et al. 2006).

Flower thrips have a highly clumped distribution and tend to form small areas of high population termed “hot spots” (Arévalo and Liburd 2007). If these “hot spots” can be modeled and predicted, insecticide applications could specifically target these spots instead of the entire field.

With the advent of geostatistics into the world of insect ecology, the spatial relationships of insect populations can now be studied (Liebhold et al. 1993). The cornerstone of geostatistics is called the variogram or semivariogram (Webster and Oliver 2001). A semivariogram plots the semivariance, ½ of the average squared difference between data values at the same separation distance, on the y-axis and the specified distance between sample pairs, the lag, on the x-axis (Wright et al. 2002). Since it is very difficult to fit a model to a semivariogram where each individual semivariance is plotted, the semivariance is averaged for each of several lags (Webster and Oliver 2001). This is expressed mathematically as $\gamma(h) = \{1/2m(h)\} \Sigma \{z(x_i) - z(x_i + h)\}^2$, where $\gamma(h)$ is the semivariance at lag h, m(h) is the number of data point pairs

separated by lag h, and $z(x_i)$ and $z(x_i + h)$ are the data values (z) a places separated by h (Webster and Oliver 2001). The important features of semivariograms are the sill, range, lag, and nugget, which are defined as the value of the semivariance when it stops increasing, the distance at which spatial independence is reached, the distance between sample pairs, and the semivariance value when x = 0 respectively. The nugget variance is a combination of measurement error and variation over distances less than the shortest lag distance sampled for all continuous variables (Webster and Oliver 2001).

Semivariograms have been used to examine and describe the spatial relationship of several corn pests, including western corn rootworm adults on yellow sticky traps in corn (Midgarden et al. 1993), corn rootworm injury to corn (Park and Tollefson 2005), and European corn borer larvae and their damage in whorl stage corn (Wright et al. 2002). Semivariograms have also been used to examine and describe the spatial relationships of three species of *Xylella fastidiosa* (Wells) sharpshooter vectors on citrus (Paulo et al. 2003) and of *Lygus hesperus* (Knight) in lentils (Schotzko and O'Keeffe 1990). Florez and Corredor (2000) used semivariogram along with other geostatistical analyses to examine the spatial dependence of *F. occidentalis* in a covered strawberry crop at Bogota plateau. Spatial dependence was found in 3 of 12 sampling weeks. They found that although thrips colonies were aggregated at first, over time the pattern changed toward a random pattern. This change was caused by thrips movement to neighboring quadrants.

Kriging is a method that allows researchers to estimate the continuous properties of something in the environment from a finite number of sampled points (Webster and

Oliver 2001). Ordinary kriging is the most common kriging method used in most applications (Webster and Oliver 2001). In ordinary kriging, the overall mean of the population is assumed to be unknown. Like IDW, ordinary kriging uses a weighted average to estimate unknown values. However, the weights are based upon the semivariogram model.

Two other commonly used interpolation techniques are natural or nearest neighbor and inverse distance weighting (IDW). Natural neighbor is the simplest interpolation method. The value at an unknown point is set equal to the value of the nearest sample point (Ess and Morgan 2003). In IDW, a set of samples that are a given distance away from the unknown point are used to interpolate the value at that point. Sample points closer to the unknown point are given a higher weight than those farther away. IDW is, in effect, a weighted average (Ess and Morgan 2003). The estimated value for the unknown point a location j, Z_j, is calculated using the equation $\{\Sigma(z_i/d^p_{ij})\} / \{ \Sigma(1/d^p_{ij})\}$, where d_{ij} is the distance between known point i and unknown point j, z_i is the value at known point i, and p is an exponent defined by user that is commonly set equal to two (Bolstad 2006).

There were two major objectives of this study. The first was to determine the best spatial interpolation method to use to model thrips population distribution. Natural neighbor, IDW, and ordinary kriging were compared. Ordinary kriging tends to be the most accurate interpolation method. If thrips variation can be modeled with semivariograms, ordinary kriging will most likely prove the most accurate in this study as well. However, if the thrips variation cannot be modeled well with semivariograms, IDW will be as accurate as, if not more accurate than, ordinary kriging.

The second objective was to use the semivariogram models to determine optimum trap spacing. Traps spaced at or beyond the range of the semivariogram will monitor populations that are spatially independent from each other.

Materials and Methods

In 2008, 100 white sticky traps (Great Lakes IPM, Vestaburg, MI) were distributed throughout a 1.13-ha SHB blueberry planting of four to seven year old bushes in Inverness, Florida, in a regular grid at 15.24-m increments (Fig. 5-1). An additional 30 traps were placed randomly throughout the plot to collect information on distances shorter and longer than 15.24-m. Traps were changed out weekly over a three week period on Feb. 14, 21, and 28, 2008. The number of thrips per trap was counted and recorded.

Trap locations were mapped using a Trimble GeoXT GPS receiver (Trimble, Sunnyvale, CA) in the WGS84 datum. The data were then imported into ArcMap 9.1 (ESRI 2005), projected, and interpolated using several spatial interpolation methods. When the data was imported into ArcMap, the NAD 27 datum was automatically attached to it. The data was redefined into the NAD 83 datum and then projected into Albers Equal Area Conic. Natural neighbor, IDW, and Ordinary kriging (Ess and Morgan 2003) were computed in ArcMap 9.1 itself. The semivariograms for the ordinary kriging were constructed in Space Time Information System (STIS) (Terraseer, Inc. 2007) and then input into ArcMap for kriging. For IDW, p was set at the default 2 and the search area was divided into 4 quadrants from which at least 5 data points per quadrant were included. In Ordinary kriging, the search area, with a radius equal to the range of the semivariogram, was also divided into 4 quadrants from which at least 1 point per quadrant up to a total of 5 points was used in the interpolation.

In 2009, 100 white sticky traps were distributed throughout a 1-ha of the same blueberry planting used in the previous year in a regular grid at 7.61-m increments (Fig. 5-2). A smaller area was used in order to identify finer scale spatial variability. An additional 30 traps were again placed randomly throughout the plot. Traps were changed out weekly over a five-week period on Jan. 30, Feb. 5, Feb. 13, Feb. 20, and Feb. 26, 2009. The number of thrips per trap was counted and recorded.

Trap locations were mapped using a Trimble Pathfinder GPS receiver (Trimble, Sunnyvale, CA) in the WGS84 datum. The data were then imported into ArcMap 9.1 (ESRI 2005), projected into universal transverse mercator (UTM), and interpolated using several spatial interpolation methods. Again, the datum was automatically assumed to be NAD 27, so this datum was used in the UTM projection. Natural neighbor, IDW, and Ordinary kriging were computed in ArcMap 9.1 itself. The semivariograms for the ordinary kriging were constructed in SGeMS (Remy 2007) and then input into ArcMap for kriging. It was necessary to normalize the data for semivariogram analysis using a natural logarithmic transformation for all sample dates except Feb. 13. For IDW, p was set at the default 2 and the search area was divided into 4 quadrants from which at least 5 data points per quadrant were included. In ordinary kriging, the search area, with a radius equal to the range of the semivariogram, was also divided into 4 quadrants from which at least 2 points per quadrant up to a total of 5 points were used in the interpolation.

Cross-validation was used to assess the accuracy of the predictions from all three interpolation methods in both years. For IDW and kriging, this was done in ArcMap. For the natural neighbor interpolation, the cross-validation had to be done manually. Mean

prediction error (ME) was calculated using the equation ME = {Σ (predicted - measured)} / n, where n is the sample size (Webster and Oliver 2001). R^2 values were calculated using the equation R^2 = Σ (predicted - mean measured)^2 / Σ (measured - mean measured)^2. The root mean square error (RMSE) was calculated using the equation RMSE = √ {Σ (predicted - measured)^2 / n)}, where n is the sample size (Bolstad 2006). The residual prediction deviation (RPD) was calculated using the equation RPD = σ_{val} / $RMSE_v$√ {n / (n-1)}, where σ_{val} is the standard deviation of the validation set, $RMSE_v$ is the root mean square error of the validation as calculated above, and n is the sample size (Vasques et al. 2010).

Results

The summary data for thrips per trap was similar for all three weeks in 2008 (Table 5-1). On Feb. 14, high numbers of thrips per trap were located in the southeastern quadrant of the northern block of rows and throughout the southern block of rows, but more concentrated in the northern half of the southern block (Fig. 5-3A). The highest numbers of thrips per trap on Feb. 21 were located in two rows, one in the southwest quadrant of the sampling area and the other towards the east side of the northern block of rows (Fig. 5-3B). The traps with the highest numbers of thrips on Feb. 28 were located at the northern end of the southern block of rows (Fig. 5-3C).

The natural neighbor, IDW, and Ordinary kriging interpolations of thrips per trap for each sampling week from 2008 are shown in figures 5-4, 5-5, and 5-6 B, D & F respectively. Locations of areas of high thrips population, 'hot spots,' are similar in all three interpolation methods. The natural neighbor method was the least accurate for all three sample weeks (Table 5-2). IDW and ordinary kriging had very similar RMSEs, RPDs, and R^2 values on all three dates, indicating that their accuracies were similar.

However, IDW had a ME much closer to 0 than ordinary kriging on Feb. 21, indicating that IDW was more accurate on this date.

On Feb. 14, one hotspot was distinguishable in the southwest area of the field in the natural neighbor and IDW maps. The area of this ‘hot spot’ was larger in the natural neighbor map. It was also present in the ordinary kriging map, but the estimated number of thrips was much smaller.

On Feb. 21, three major “hot spots” had formed: two were very close to each other in the southwest area of the field, and one was present in the northeast area of the field. The one present on Feb. 14 was still present along with several other smaller “hot spots”. All three maps looked very similar, but the area of the “hot spots” was smaller in the IDW map.

On Feb. 28, the remnants of the “hot spots” in the southern half of the field could be seen. The kriging map showed fewer thrips in these ‘hot spot’ remnants compared with the other two methods.

The semivariograms used for the ordinary kriging varied greatly among the weeks (Fig. 5-6 A, C, & E, Table 5-3). The Feb. 14 semivariogram had a very large nugget and a large range (~ 80 m). The nugget to sill ratio was also large at 1.44. The Feb. 21 semivariogram showed a distinct spatial trend with a small nugget (0.14), a very small nugget to sill ratio (0.0000015) and a range of 11.04 m. The Feb. 28 semivariogram had a small nugget of 0.002, a very small nugget to sill ratio (0.000000071), and a very short range of 2.51 m.

The summary data of thrips per trap for all five sampling weeks is shown in Table 5-4. The Jan. 30 summary data was similar to that found for all three weeks in 2008.

Traps with high numbers of thrips per trap on Jan. 30 were concentrated in two rows, the south center row and one of the southwest rows (Fig. 5-7A). There was also a trap with high trips numbers in the southeast corner of the sampling area. All values on Feb. 5 were low because very few thrips were caught on the traps during the preceding week (Fig. 5-7B). Summary data from the remaining three sampling weeks was very similar except that the skewness coefficient and kertosis were much smaller on Feb. 13. The distribution of high and low numbers of thrips per trap on Feb. 13 appeared to be random (Fig. 5-7C), with high numbers located in several of the northern and southwestern rows and in the southeast corner of the sampling area. The furthest southwestern row had very low numbers of thrips per trap. On Feb. 20, high numbers of thrips per trap were found throughout the northern rows, particularly in the central and east rows (Fig. 5-7D). High numbers were also found in several of the southeast rows and in one row towards the southwest. The furthest southwest row again had very low numbers of thrips per trap. A similar pattern was seen on Feb. 26 (Fig. 5-7E) with even higher numbers of thrips per trap.

The natural neighbor, IDW, and Ordinary kriging interpolations for each sampling week from 2009 are shown in figures 5-8, 5-9, and 5-10 B, D, F, H, & I respectively. Locations of areas of high thrips population, ‘hot spots,’ are similar in all three interpolation methods. The natural neighbor method was the least accurate for all five sample week according to the RMSE and RPD values, and IDW and ordinary kriging had very similar accuracies (Table 5-5). The ME indicates that the natural neighbor interpolation was just as accurate as the ordinary kriging interpolation on Feb. 5 while the IDW interpolation had greater accuracy than both of them. On Jan. 30, Feb. 20, and

Feb. 26, IDW was more accurate than ordinary kriging. On Feb. 13, the reverse was true.

On Jan. 30, “hot spots” appeared to be developing in the south center and west of the field. They are visible in all three maps, but are less distinct and contain a smaller number of thrips in the ordinary kriging map. There is another developing ‘hot spot’ in the eastern corner of the IDW map. This spot is also present in the kriging map, but with fewer thrips. In the natural neighbor map, high thrips numbers are found throughout the eastern edge of the field.

On Feb. 5, the thrips population in the field had all but disappeared. The areas where the developing “hot spots” had been the previous week had less than 50 thrips per trap. The rest of the field had less than 15 thrips per trap.

On Feb. 13, “hot spots” reappeared in the same areas they were developing in on Jan. 30. Also, a new ‘hot spot’ appeared in the northeast area of the field. The “hot spots” were smaller in the IDW map compared with both other maps and contained less thrips in the ordinary kriging map.

On Feb. 20, the ‘hot spot’ in the northeast corner of the field had expanded in all three maps. The expansion was much less pronounced in the IDW map. Many other, smaller “hot spots” were present in both the natural neighbor and IDW maps, but not in the ordinary kriging map because they were smoothed out.

On Feb. 26, the ‘hot spot’ in the northeast corner on Feb. 13 had expanded to cover a large part of the northeast and center of the field. Again, the expansion was less pronounced in the IDW map and there were other, smaller “hot spots” present in both the natural neighbor and IDW maps that were not found in the ordinary kriging map.

The semivariograms used for the ordinary kriging varied greatly among the weeks (Fig. 5-10 A, C, E, G, I, Table 5-6). The Jan. 30 semivariogram had a fairly large nugget, a nugget to sill ratio of 0.38, and a range of 28.75 m. The Feb. 5 semivariogram was mostly nugget with a nugget to sill ratio of 0.71 and a range of 22.50 m. The Feb. 13 semivariogram, the only data set that could be modeled without transformation, had a small nugget, a nugget to sill ratio of 0.2, and a range of 17.50 m. The Feb. 20 semivariogram was mostly nugget with a nugget to sill ratio of 0.73 and a range of 27.50 m. The Feb. 26 semivariogram had a very large nugget with a nugget to sill ratio of 0.67 and a range of 23.75 m.

Discussion

In 2008, the differences among the three weeks could be explained by the flowering stage of the blueberry plants. Arévalo and Liburd (2007) documented the close relationship between thrips numbers and blueberry flowering stage. Plants were approaching peak flowering during the week of Feb. 7 - 14. The thrips population was also increasing and “hot spots” were beginning to form. The plants were at peak flowering during the week of Feb. 14 - 21. The thrips population also reached its peak during this week. By Feb. 21, petal fall had begun and fruits were forming on some of the varieties. By Feb. 28, most of the plants contained developing fruit and had few remaining flowers and the thrips population had greatly diminished as well.

In 2009, both stage of flowering and temperature appeared to play major roles in explaining the difference in the thrips population among the weeks. The blueberry plants had reached about 70% open flowers on Jan. 30. The thrips population was increasing and “hot spots” were beginning to form. Plants had reached peak flowering by Feb. 5 and remained at this stage until Feb. 13. In contrast, the thrips population had crashed

to very low levels on Feb. 5. This was most likely caused by an extreme cold front that blew through Florida during the preceding week (FAWN 2009). The thrips population was increasing dramatically by Feb. 13 and remained high throughout the next two weeks. In contrast, the blueberry bushes had declined to 70% open flowers on Feb. 20 and then to 20% open flowers on Feb. 26. The extreme temperature event seemed to cause the thrips population to peak well after peak flowering.

All three interpolation methods showed “hot spots” in the same areas of the blueberry field during both years. On Feb. 14 and 28, 2008 and on all dates in 2009 except Feb. 5, the ordinary kriging maps showed a much lower number of thrips in these “hot spots” than the natural neighbor and IDW maps. This is because there were only a few traps with very high numbers of thrips on these dates. The ‘hot spot’ was centered where the one trap with > 1000 thrips on it was located. This point on the map is set equal to this value in both natural neighbor and IDW interpolation, but not in ordinary kriging. This causes the kriged map to be much smoother. The combination of setting the points at data locations to the value of the data point and using a weighted average causes the ‘bulls-eye’ effect that IDW maps are known to exhibit (Bolstad 2006). This effect is not as pronounced in the natural neighbor maps, because all points closest to a sample point are set to its exact value (Ess and Morgan 2003) producing large areas of the same value.

On Feb. 21, 2008, the maps were very similar. The area of the three major “hot spots” is smaller in the IDW map. This is because IDW calculates an average that is weighted by distance whereas natural neighbor interpolation sets every unknown point equal to the closest data point. This causes all of the points near a trap with high thrips

numbers to have that high number on the natural neighbor map, which in turn creates “hot spots” with a large area. Because of the nature of the semivariogram for this week (see below), the ordinary kriging map displays the same property as the natural neighbor map.

The ordinary kriging interpolation varied among the weeks during both years because the data varied greatly and was not always modeled well using semivariograms. Wright et al. 2002 found that the spatial distribution of European corn borer larvae was modeled well by semivariograms in only four out of seven data sets. Farias et al. (2003) calculated 36 semivariograms for sharpshooters on citrus, but could fit only nine of them with mathematical models. The semivariograms from Feb. 14, 2008, Feb. 5, 2009, Feb. 20, 2009, and Feb. 26, 2009 had large nuggets. The range of the Feb. 28, 2008 semivariogram was so short that no traps were at a distance shorter than the range. This caused most of the points to be weighted the same in the interpolations for these dates. The ordinary kriging interpolation on these dates was, thus, very similar to a local average interpolation. In contrast, the semivariogram from Feb. 21, 2008 had a very small nugget, but leveled off very rapidly. Because of this, only points very close to the unknown point were given a high weight in the interpolation and the interpolation, therefore, closely resembled the natural neighbor interpolation for this date. The semivariograms from Jan. 30, 2009 and Feb. 13, 2009 had a moderate and small nugget, respectively and had ranges that encompassed many data points. The resulting maps are, therefore, the best examples of ordinary kriging.

In terms of accuracy, the natural neighbor interpolation was the least accurate. The ordinary kriging and IDW interpolations were similar in accuracy. Since natural

neighbor interpolation simply sets all unknown values to the value of the nearest sample point, it is not surprising that it is the least accurate method. Ordinary kriging is only as powerful as the semivariograms used to perform it. In 2008, the spatial trend in flower thrips populations in blueberries was localized. Because of this, the semivariograms either had a very short range (Feb. 21 and 28) or a large nugget due to a lack of sample point pairs below the actual range (Feb. 14). The result was that, in 2008, ordinary kriging interpolation was no more accurate than IDW interpolation. The reduced grid spacing in 2009 resulted in better semivariograms, suggesting that the spatial variability of thrips is high and could be better captured with the finer grid spacing used in the 2009 sampling. In both years, the shortest distance sampled was 2-m. However, in 2008, there were only two data pairs at this distance while in 2009, there were approximately ten. The data from the weeks of Jan. 30 and Feb. 13 was modeled very well by semivariograms resulting in kriged maps with a slightly higher accuracy then the IDW maps from these weeks. Therefore, both IDW and kriging are reasonable interpolation methods to use to model flower thrips distribution in blueberry fields. This is in agreement with results presented by Roberts et al. (1993) and others. The accuracy of kriging is dependent upon the accuracy of the semivariogram. Semivariogram models are sensitive to many factors, including: nonnormality, outliers, directional differences in spatial trends, inconsistency of spatial trends among different parts of the sample area, and the placement and spacing of the sample points.

The range of the semivariograms varied greatly in 2008 from 2.51 to 79.8 m. In 2009, the ranges of the semivariograms were much more consistent, varying from 17.5

to 28.8 m. Therefore, spacing white sticky traps at least 28.8 m apart should result in sampling independent populations of flower thrips.

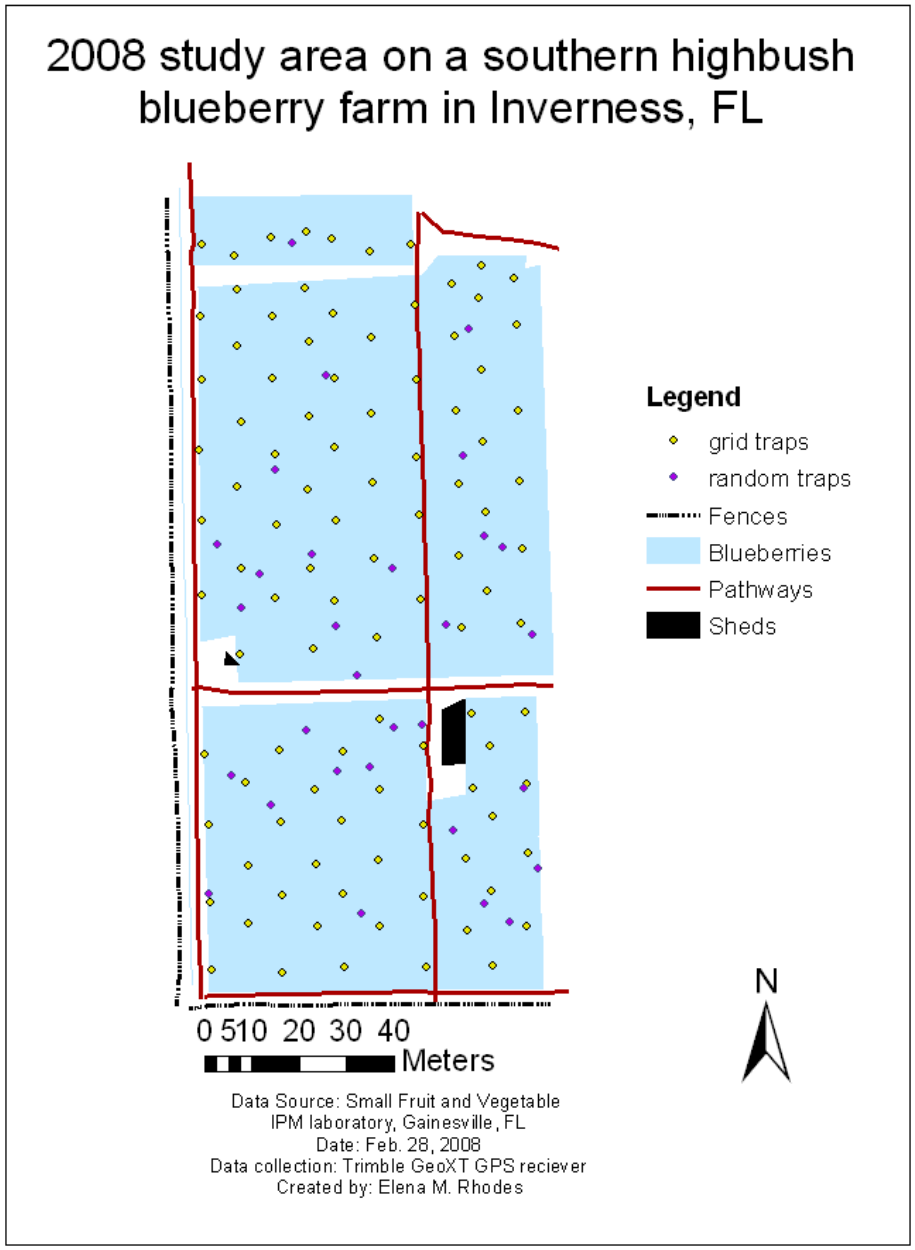


Fig. 5-1. GIS map of the study area in 2008.

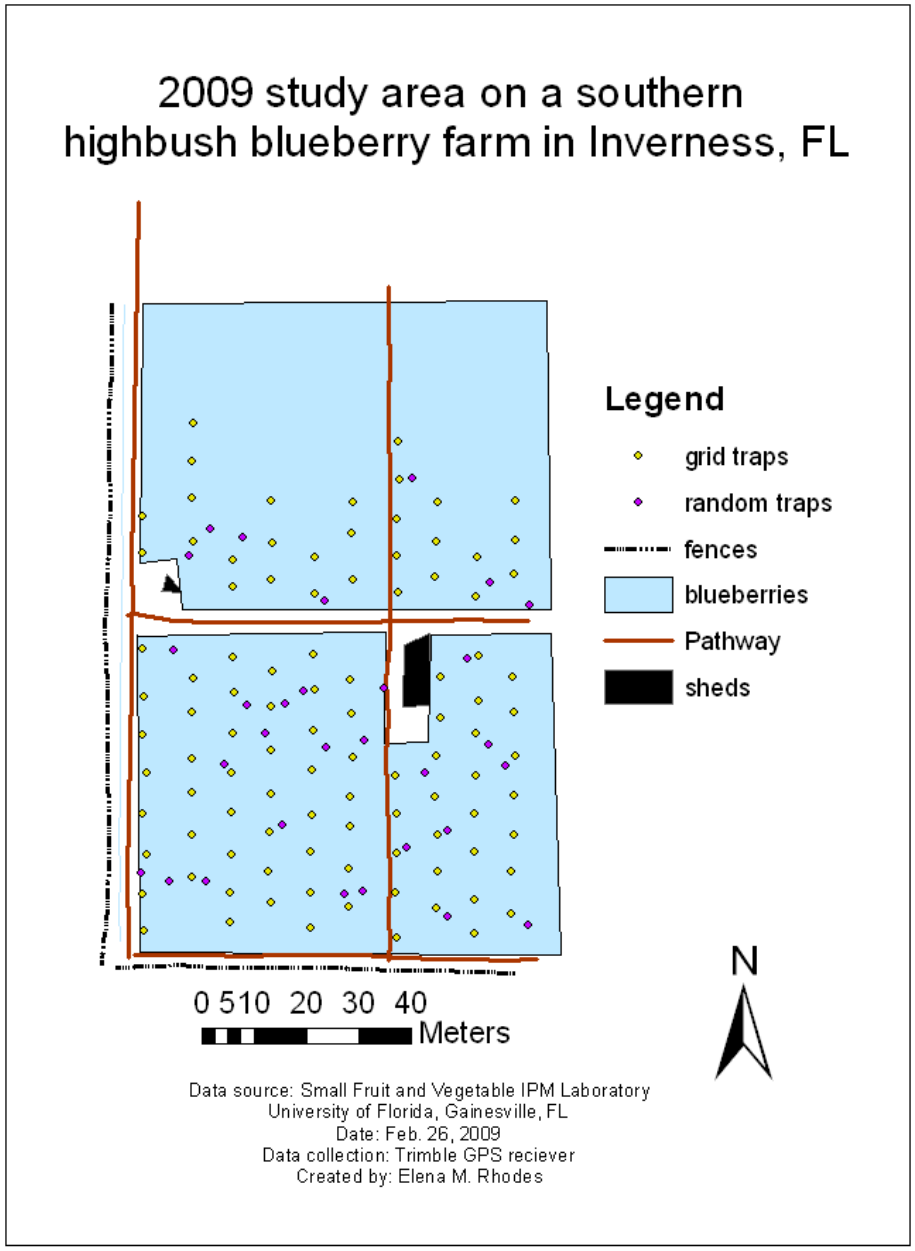
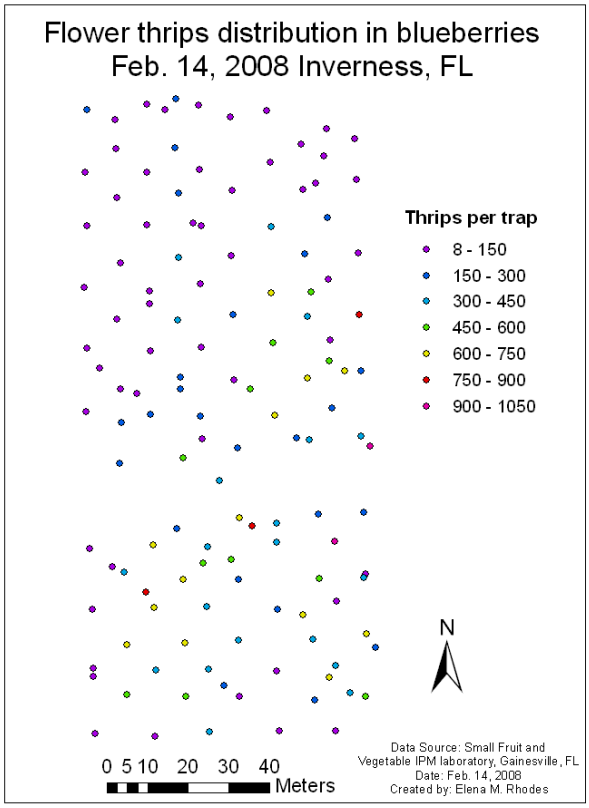
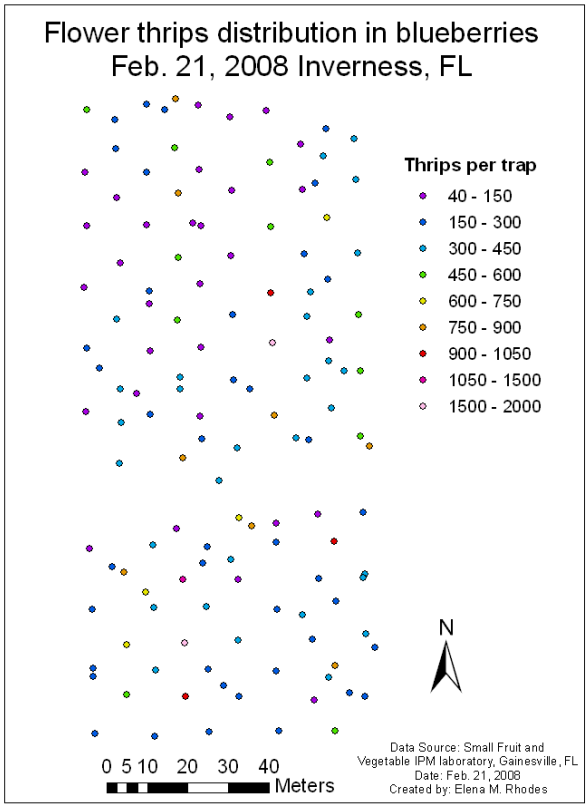


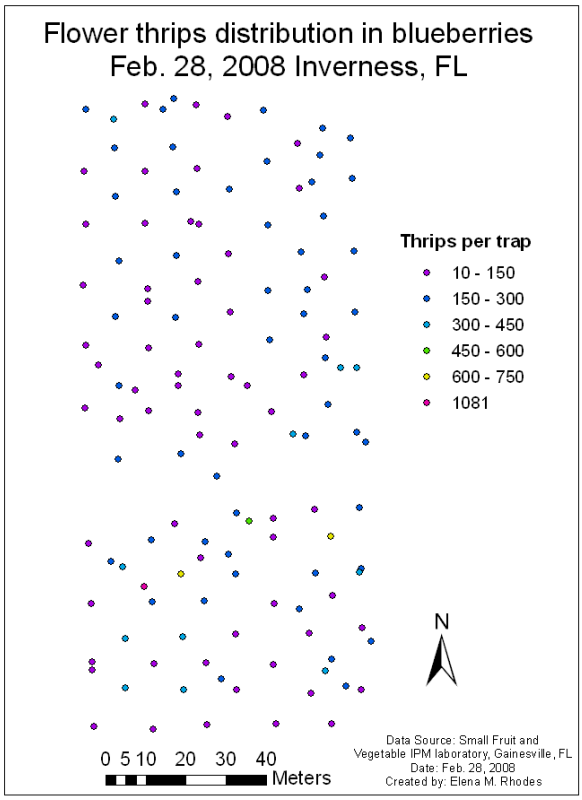
Fig. 5-2. GIS map of the study area in 2009.



A



B



C

Fig. 5-3. Point maps of thrips per trap for each sampling week in 2008.

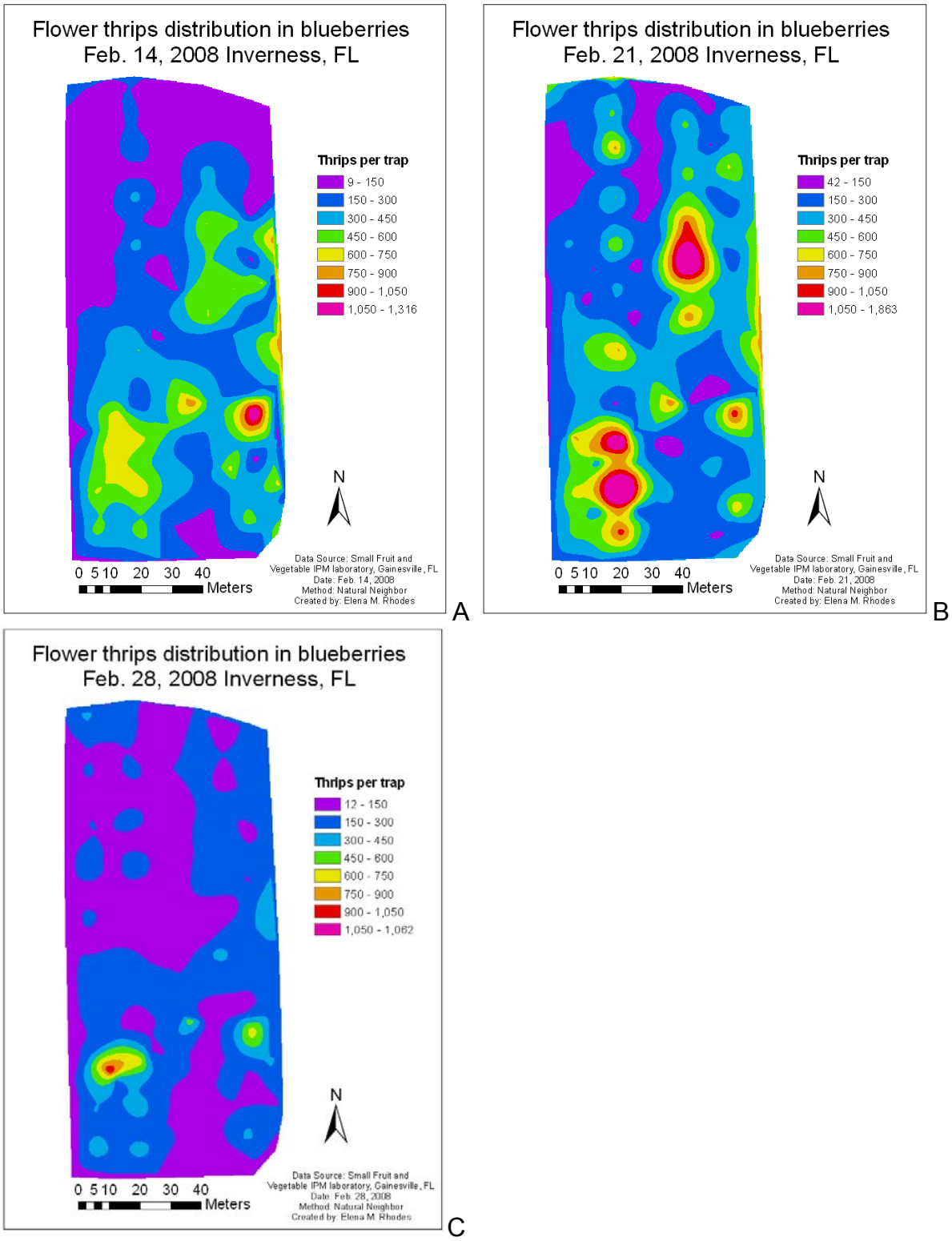


Fig. 5-4. Natural neighbor interpolation of thrips per trap from A) Feb. 14, 2008, B) Feb. 21, 2008, and C) Feb. 28, 2008.

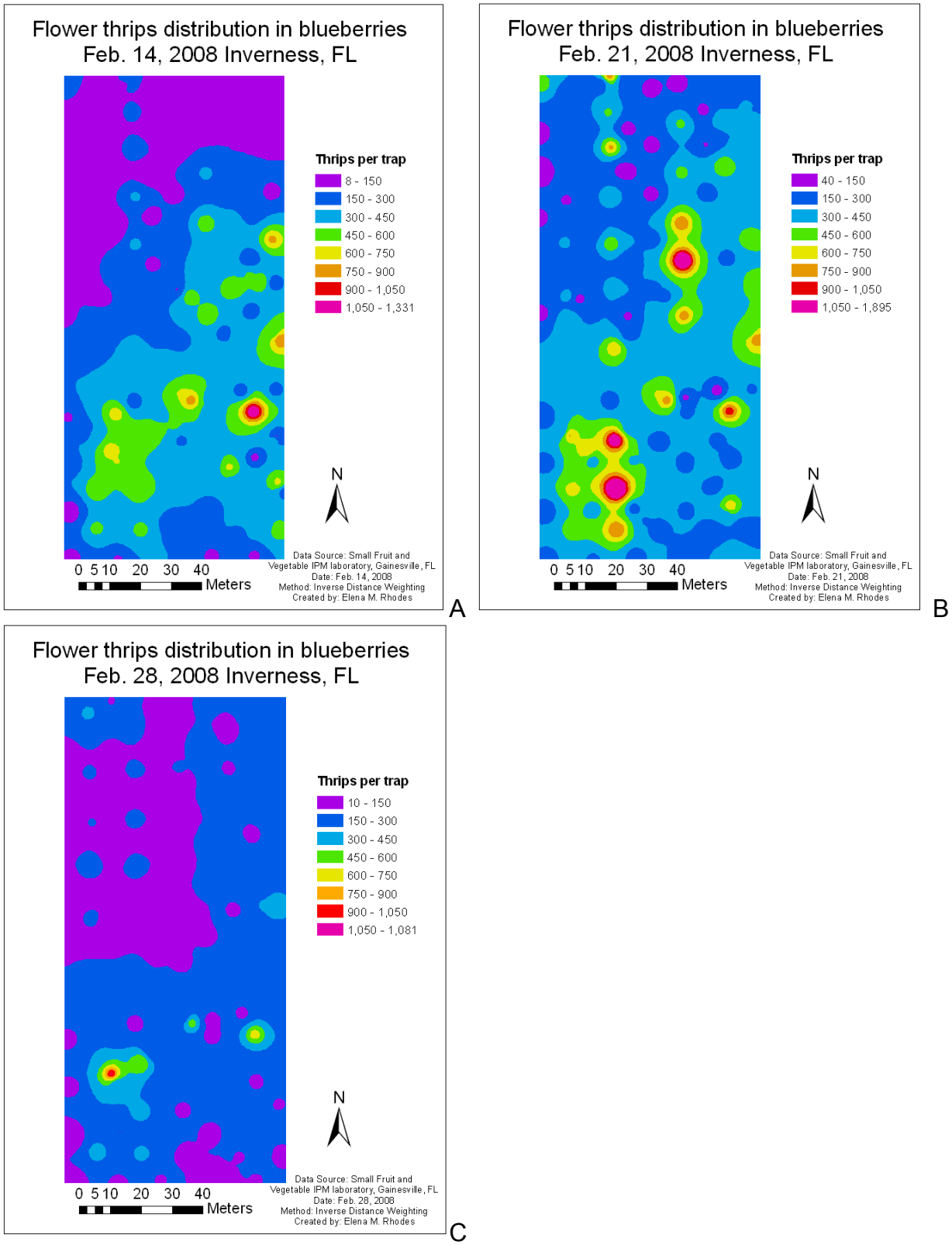
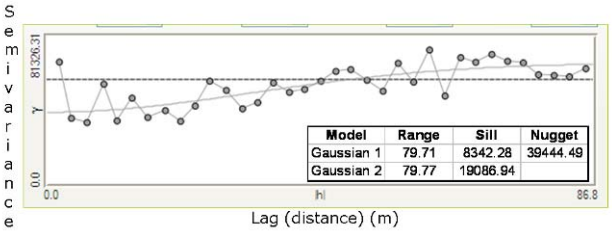
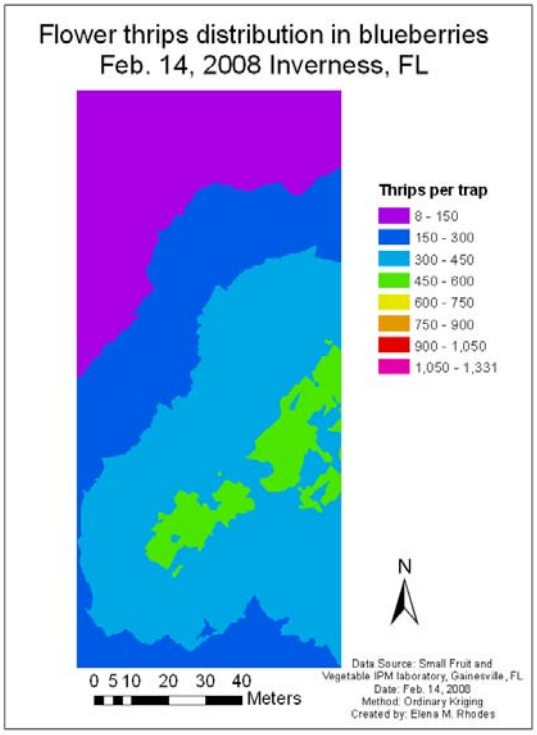


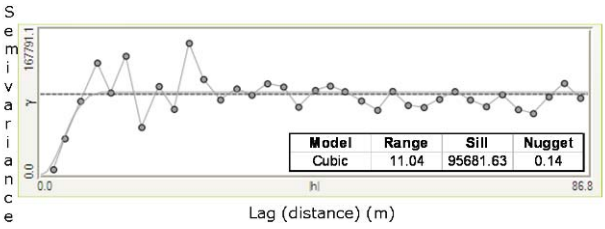
Fig. 5-5. Inverse Distance Weighting interpolation (p = 2, # points = 20) of thrips per trap from A) Feb. 14, 2008, B) Feb. 21, 2008, and C) Feb. 28, 2008.


Semivariance
81326.31
γ
0.0
0.0
|h|
86.8
Lag (distance) (m)
Model | Range | Sill | Nugget
Gaussian 1 | 79.71 | 8342.28 | 39444.49
Gaussian 2 | 79.77 | 19086.94

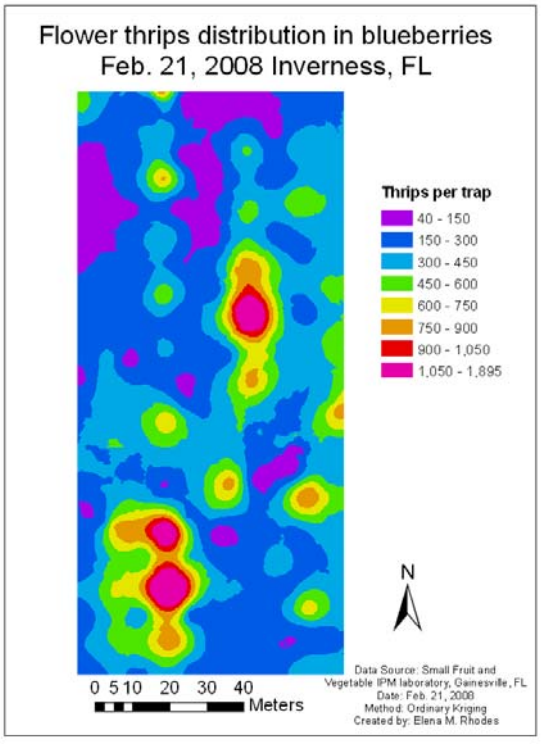
A


Flower thrips distribution in blueberries
Feb. 14, 2008 Inverness, FL
Thrips per trap
8 - 150
150 - 300
300 - 450
450 - 600
600 - 750
750 - 900
900 - 1,050
1,050 - 1,331
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM laboratory, Gainesville, FL
Date: Feb. 14, 2008
Method: Ordinary Kriging
Created by: Elena M. Rhodes

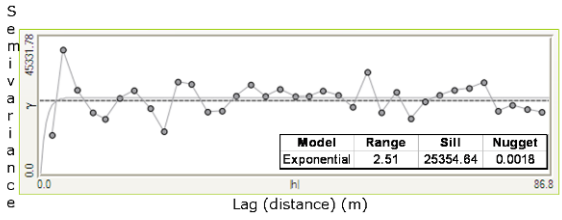
B


Semivariance
167791.1
γ
0.0
0.0
|h|
86.8
Lag (distance) (m)
Model | Range | Sill | Nugget
Cubic | 11.04 | 95681.63 | 0.14

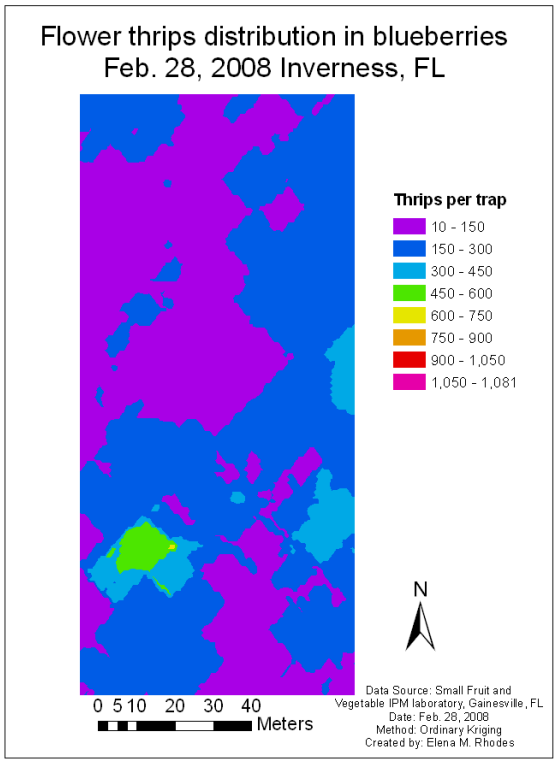
C


Flower thrips distribution in blueberries
Feb. 21, 2008 Inverness, FL
Thrips per trap
40 - 150
150 - 300
300 - 450
450 - 600
600 - 750
750 - 900
900 - 1,050
1,050 - 1,895
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM laboratory, Gainesville, FL
Date: Feb. 21, 2008
Method: Ordinary Kriging
Created by: Elena M. Rhodes

D

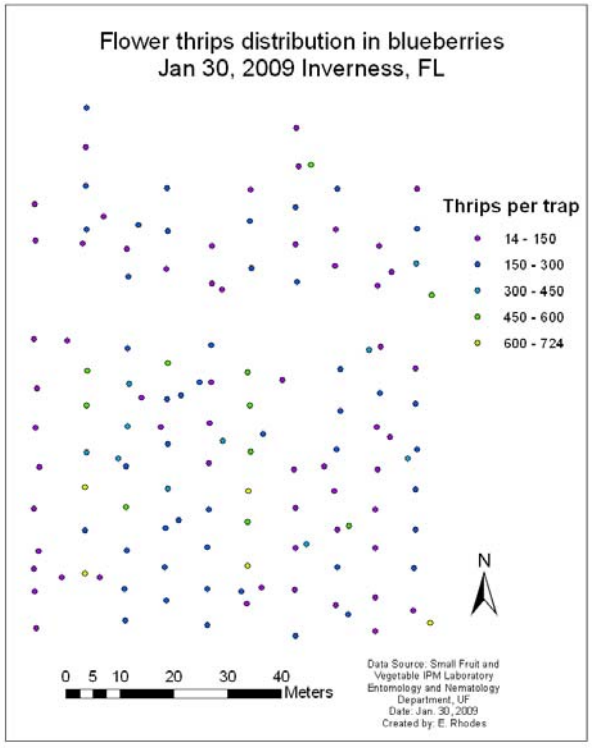


E

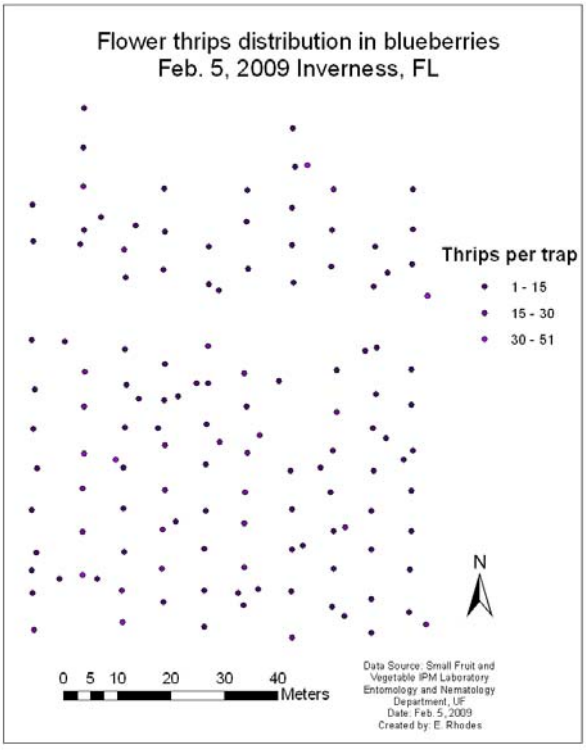


F

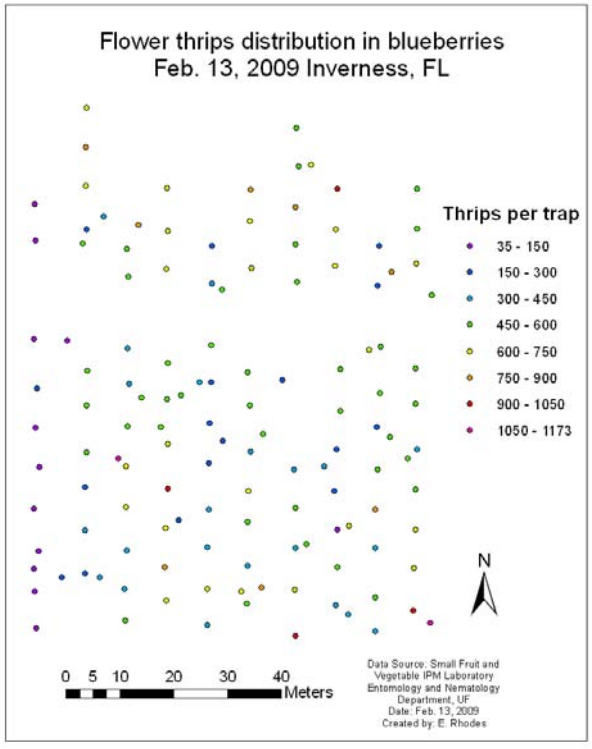
Fig. 5-6. Semivariograms (A, C, E) and Ordinary Kriging interpolation (B, D, F) of thrips per trap from A) & B) Feb. 14, 2008, C) & D) Feb. 21, 2008, and E) & F) Feb. 28, 2008.


Flower thrips distribution in blueberries
Jan 30, 2009 Inverness, FL
Thrips per trap
14 - 150
150 - 300
300 - 450
450 - 600
600 - 724
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Jan. 30, 2009
Created by: E. Rhodes

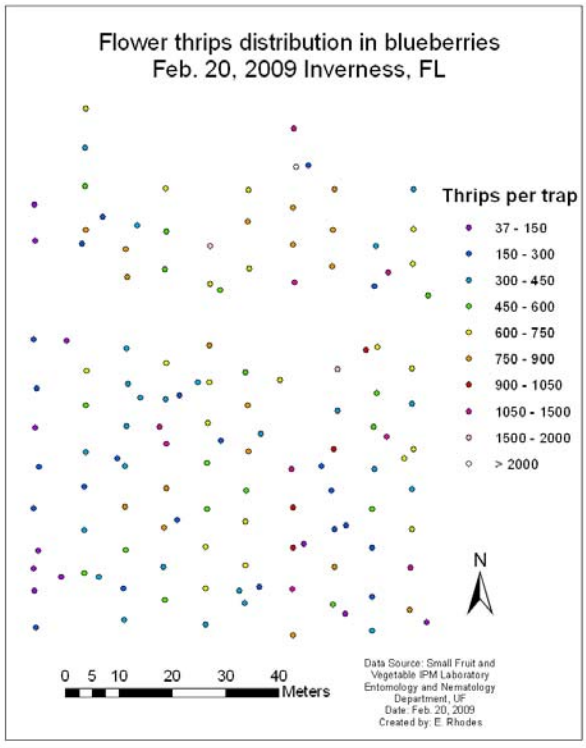
A


Flower thrips distribution in blueberries
Feb. 5, 2009 Inverness, FL
Thrips per trap
1 - 15
15 - 30
30 - 51
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Feb. 5, 2009
Created by: E. Rhodes

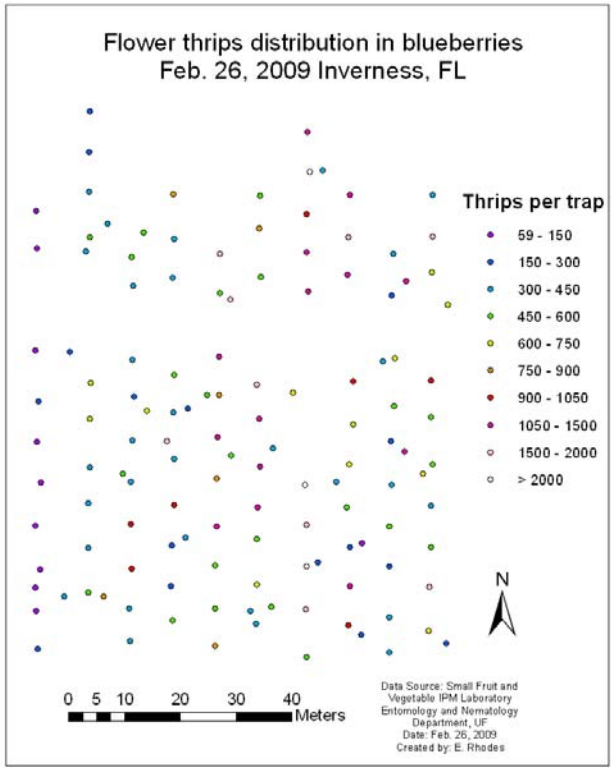
B


Flower thrips distribution in blueberries
Feb. 13, 2009 Inverness, FL
Thrips per trap
35 - 150
150 - 300
300 - 450
450 - 600
600 - 750
750 - 900
900 - 1050
1050 - 1173
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Feb. 13, 2009
Created by: E. Rhodes

C

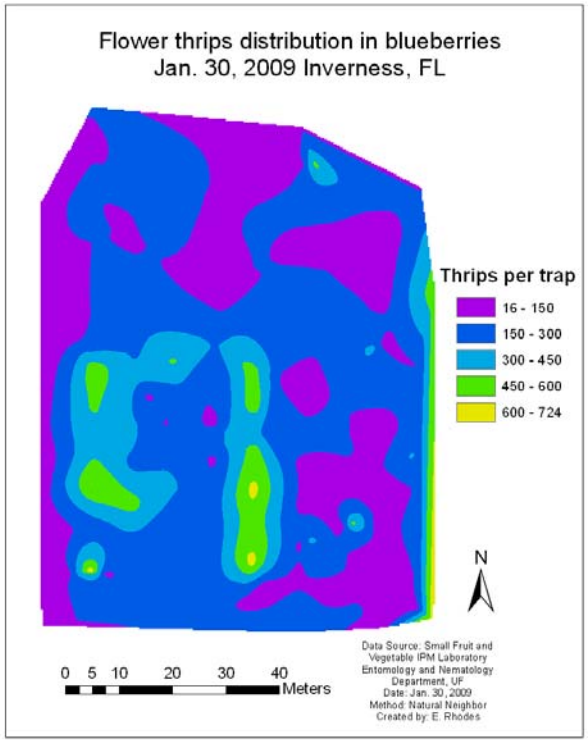

Flower thrips distribution in blueberries
Feb. 20, 2009 Inverness, FL
Thrips per trap
37 - 150
150 - 300
300 - 450
450 - 600
600 - 750
750 - 900
900 - 1050
1050 - 1500
1500 - 2000
> 2000
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Feb. 20, 2009
Created by: E. Rhodes

D

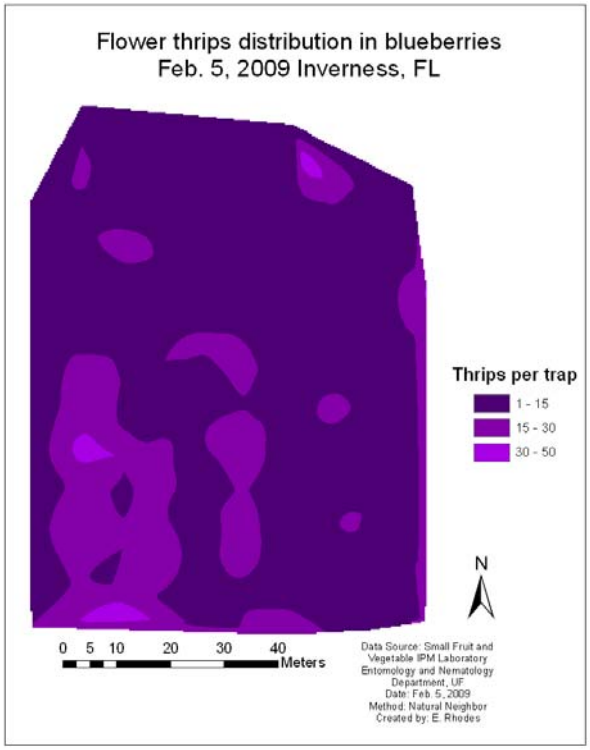


E

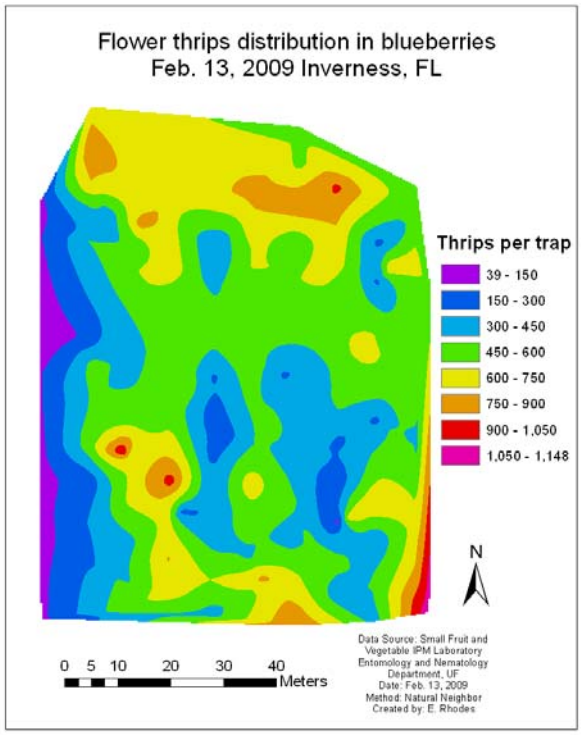
Fig. 5-7. Point maps of thrips per trap for each sampling week in 2009.


Flower thrips distribution in blueberries
Jan. 30, 2009 Inverness, FL
Thrips per trap
16 - 150
150 - 300
300 - 450
450 - 600
600 - 724
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Jan. 30, 2009
Method: Natural Neighbor
Created by: E. Rhodes

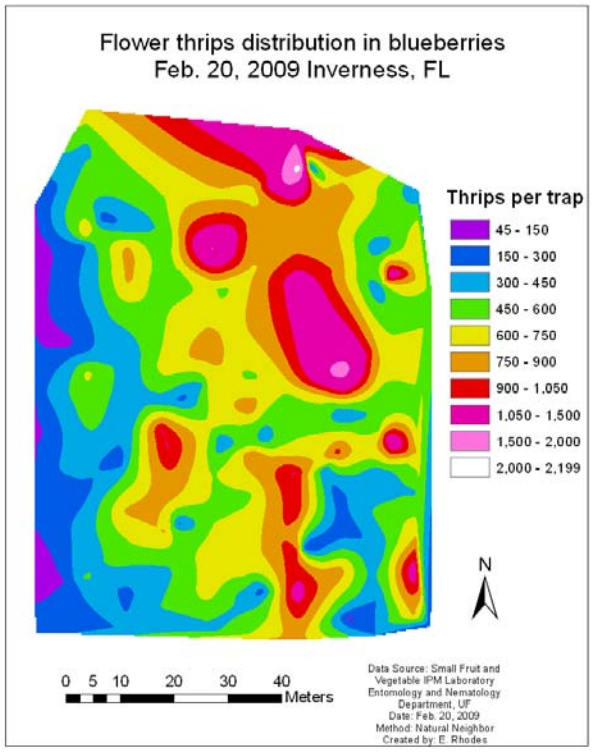
A


Flower thrips distribution in blueberries
Feb. 5, 2009 Inverness, FL
Thrips per trap
1 - 15
15 - 30
30 - 50
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Feb. 5, 2009
Method: Natural Neighbor
Created by: E. Rhodes

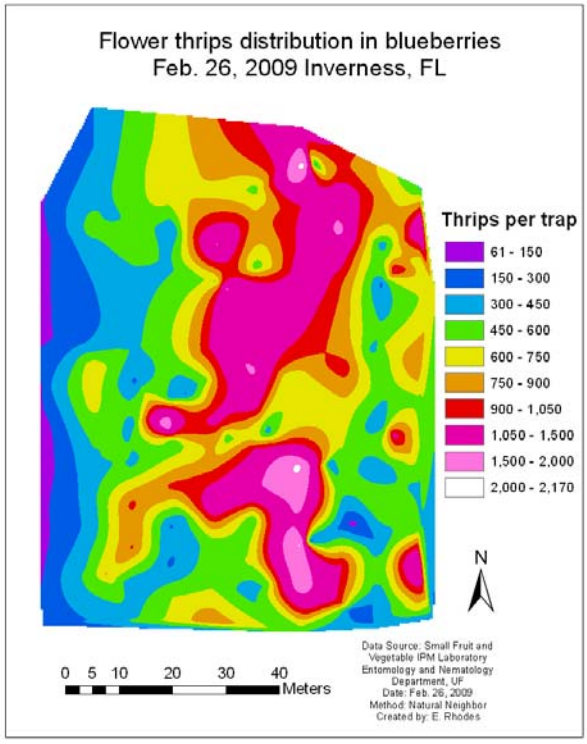
B


Flower thrips distribution in blueberries
Feb. 13, 2009 Inverness, FL
Thrips per trap
39 - 150
150 - 300
300 - 450
450 - 600
600 - 750
750 - 900
900 - 1,050
1,050 - 1,148
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Feb. 13, 2009
Method: Natural Neighbor
Created by: E. Rhodes

C

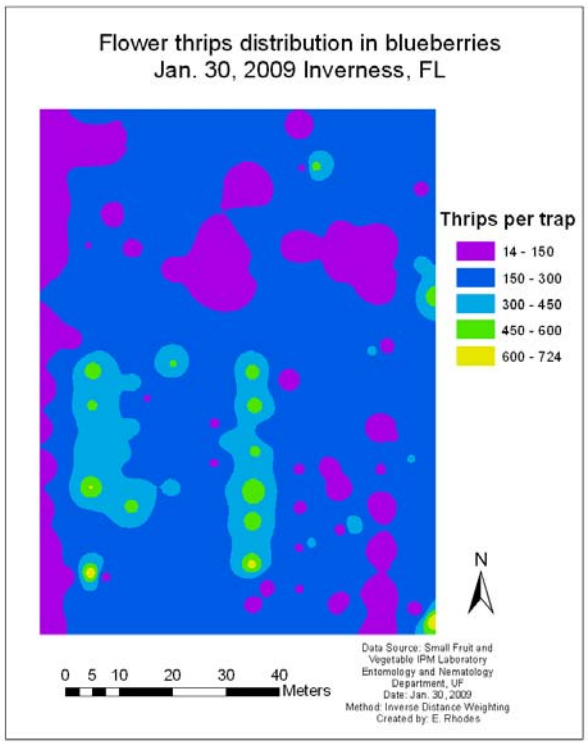

Flower thrips distribution in blueberries
Feb. 20, 2009 Inverness, FL
Thrips per trap
45 - 150
150 - 300
300 - 450
450 - 600
600 - 750
750 - 900
900 - 1,050
1,050 - 1,500
1,500 - 2,000
2,000 - 2,199
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Feb. 20, 2009
Method: Natural Neighbor
Created by: E. Rhodes

D

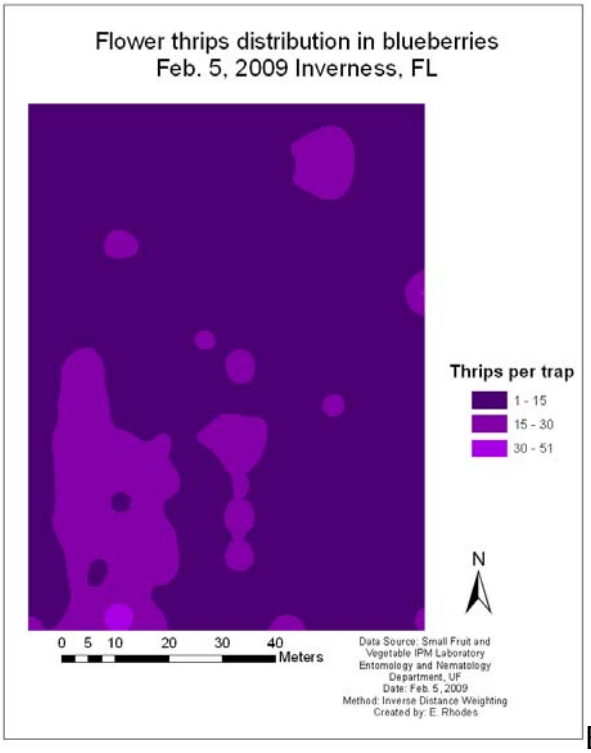


E

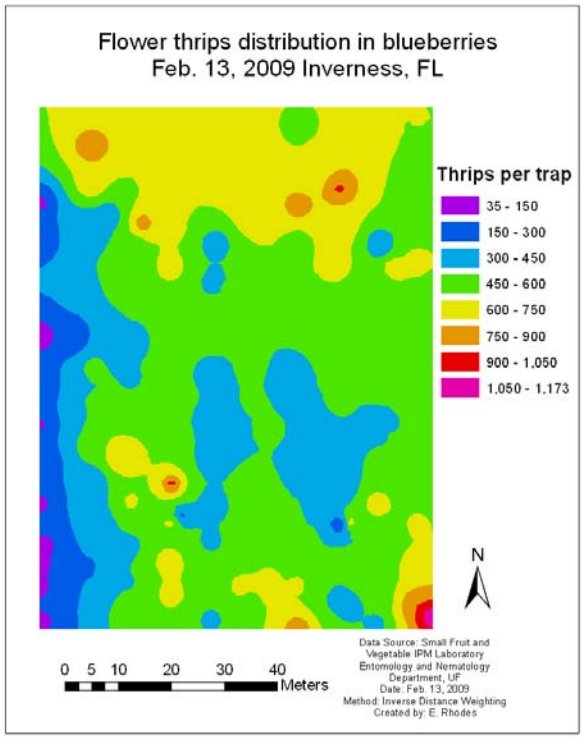
Fig. 5-8. Natural neighbor interpolation of thrips per trap from A) Jan. 30, 2009, B) Feb. 5, 2009, C) Feb. 13, 2009, D) Feb. 20, 2009, and E) Feb. 26, 2009.


Flower thrips distribution in blueberries
Jan. 30, 2009 Inverness, FL
Thrips per trap
14 - 150
150 - 300
300 - 450
450 - 600
600 - 724
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Jan. 30, 2009
Method: Inverse Distance Weighting
Created by: E. Rhodes

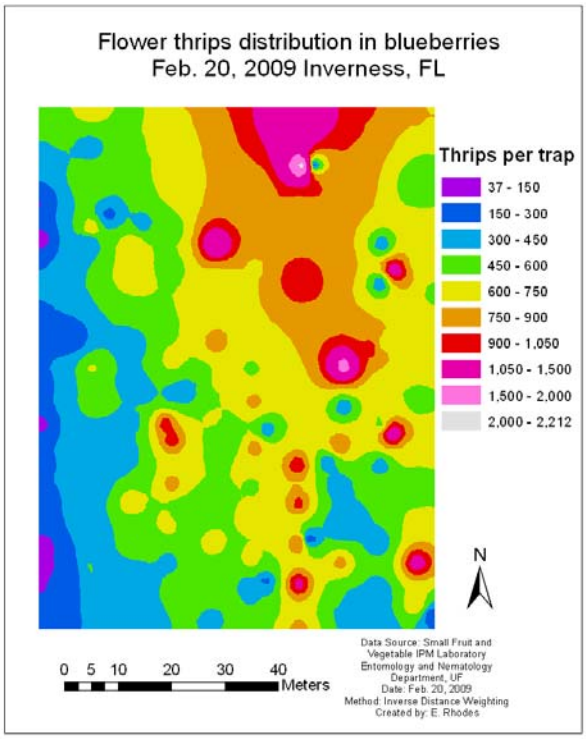
A


Flower thrips distribution in blueberries
Feb. 5, 2009 Inverness, FL
Thrips per trap
1 - 15
15 - 30
30 - 51
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Feb. 5, 2009
Method: Inverse Distance Weighting
Created by: E. Rhodes

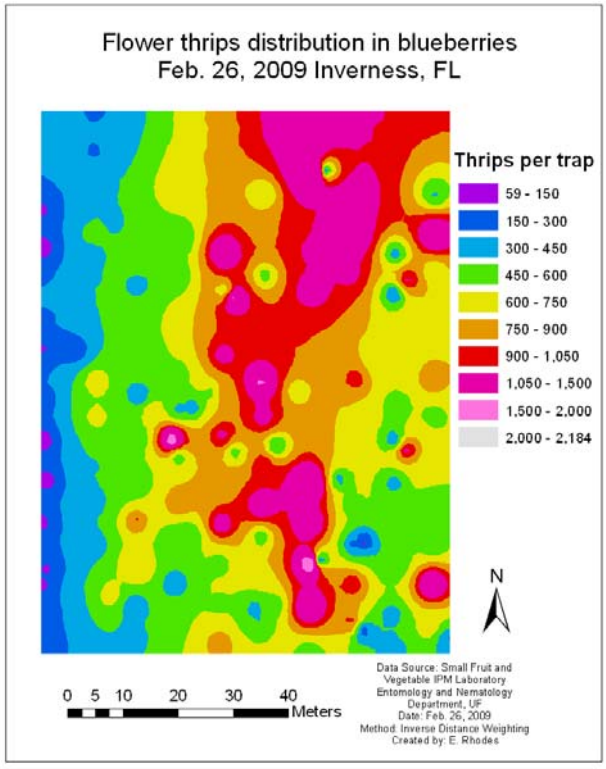
B


Flower thrips distribution in blueberries
Feb. 13, 2009 Inverness, FL
Thrips per trap
35 - 150
150 - 300
300 - 450
450 - 600
600 - 750
750 - 900
900 - 1,050
1,050 - 1,173
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Feb. 13, 2009
Method: Inverse Distance Weighting
Created by: E. Rhodes

C

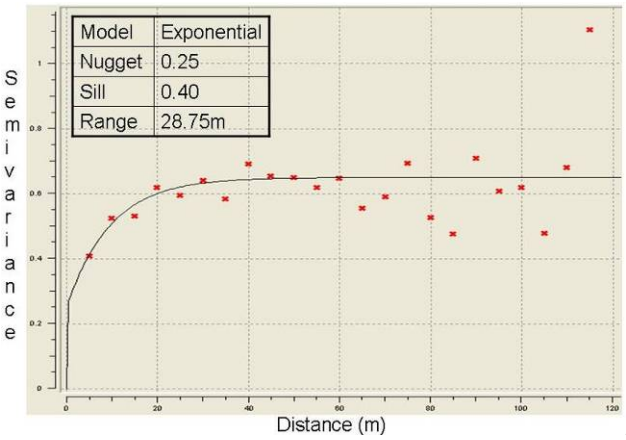

Flower thrips distribution in blueberries
Feb. 20, 2009 Inverness, FL
Thrips per trap
37 - 150
150 - 300
300 - 450
450 - 600
600 - 750
750 - 900
900 - 1,050
1,050 - 1,500
1,500 - 2,000
2,000 - 2,212
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Feb. 20, 2009
Method: Inverse Distance Weighting
Created by: E. Rhodes

D

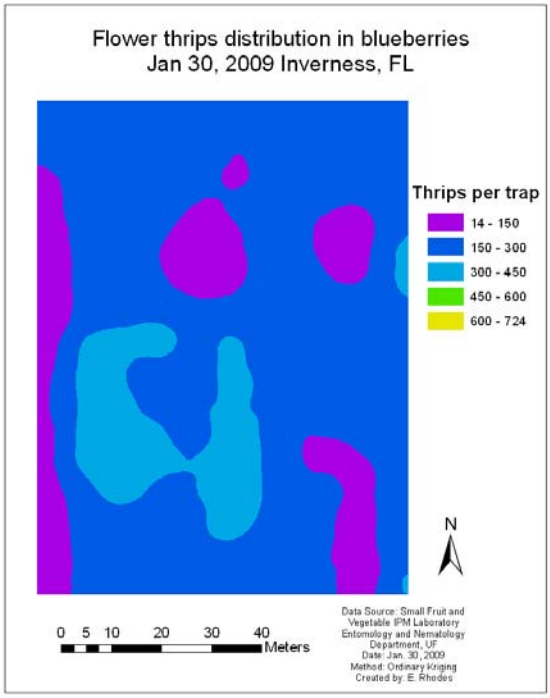


E

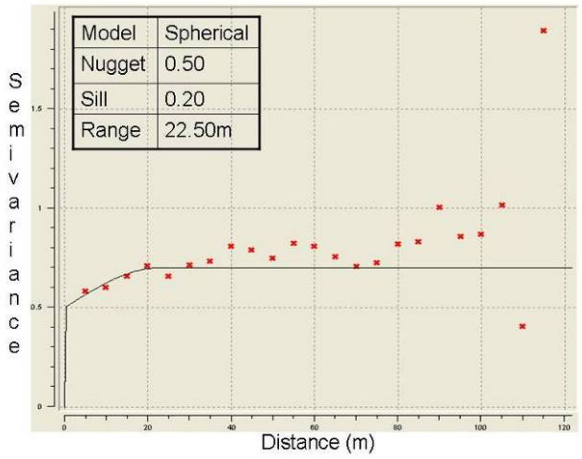
Fig. 5-9. Inverse Distance Weighting interpolation (p = 2, # points = 20) of thrips per trap from A) Jan. 30, 2009, B) Feb. 5, 2009, C) Feb. 13, 2009, D) Feb. 20, 2009, and E) Feb. 26, 2009.


Model Exponential
Nugget 0.25
Sill 0.40
Range 28.75m
Semivariance
Distance (m)

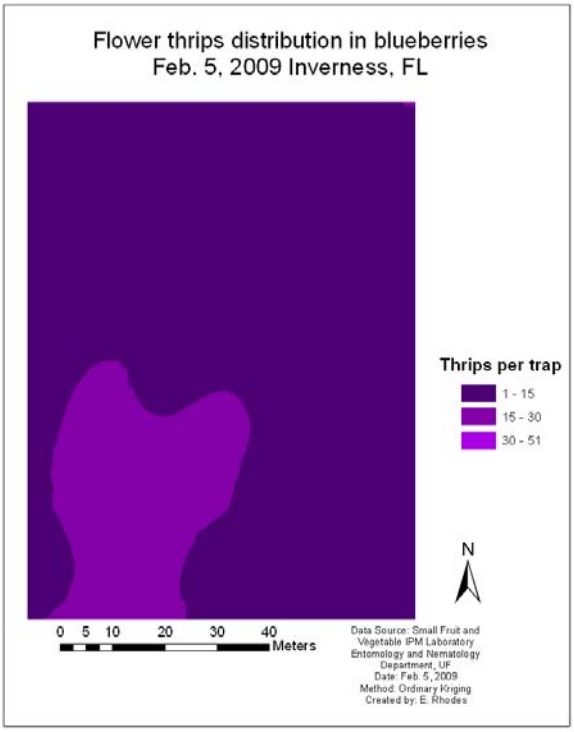
A


Flower thrips distribution in blueberries
Jan 30, 2009 Inverness, FL
Thrips per trap
14 - 150
150 - 300
300 - 450
450 - 600
600 - 724
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Jan. 30, 2009
Method: Ordinary Kriging
Created by: E. Rhodes

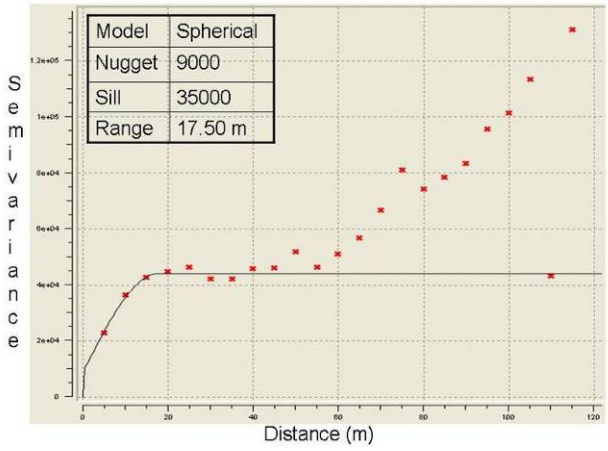
B


Model Spherical
Nugget 0.50
Sill 0.20
Range 22.50m
Semivariance
Distance (m)

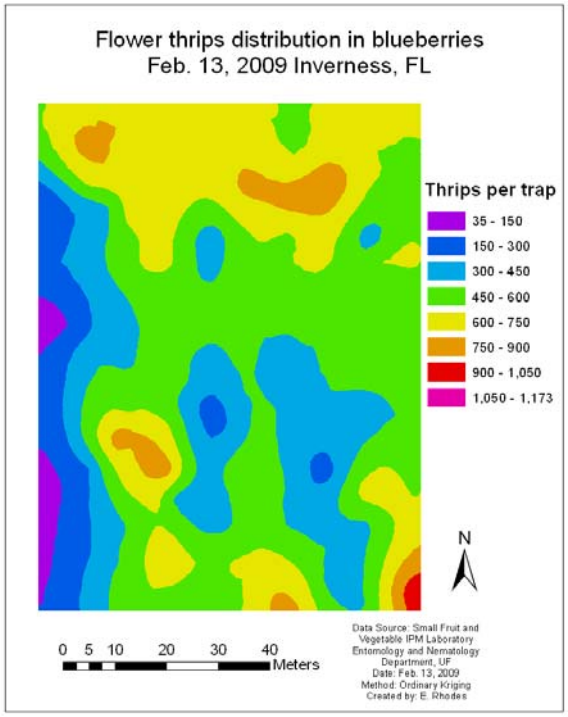
C


Flower thrips distribution in blueberries
Feb. 5, 2009 Inverness, FL
Thrips per trap
1 - 15
15 - 30
30 - 51
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Feb. 5, 2009
Method: Ordinary Kriging
Created by: E. Rhodes

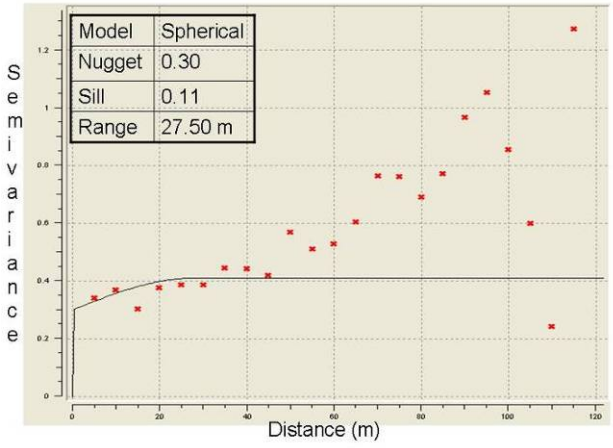
D


Model Spherical
Nugget 9000
Sill 35000
Range 17.50 m
Semivariance
Distance (m)

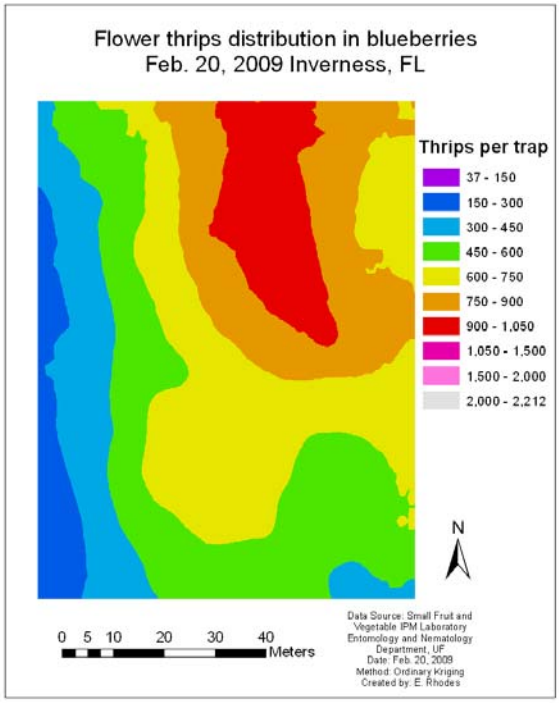
E


Flower thrips distribution in blueberries
Feb. 13, 2009 Inverness, FL
Thrips per trap
35 - 150
150 - 300
300 - 450
450 - 600
600 - 750
750 - 900
900 - 1,050
1,050 - 1,173
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Feb. 13, 2009
Method: Ordinary Kriging
Created by: E. Rhodes

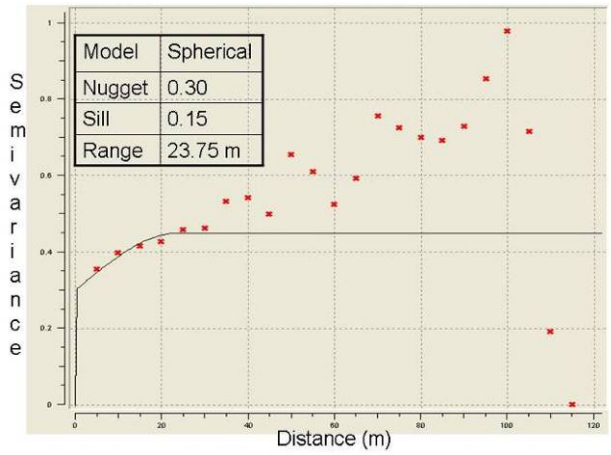
F


Model Spherical
Nugget 0.30
Sill 0.11
Range 27.50 m
Semivariance
Distance (m)

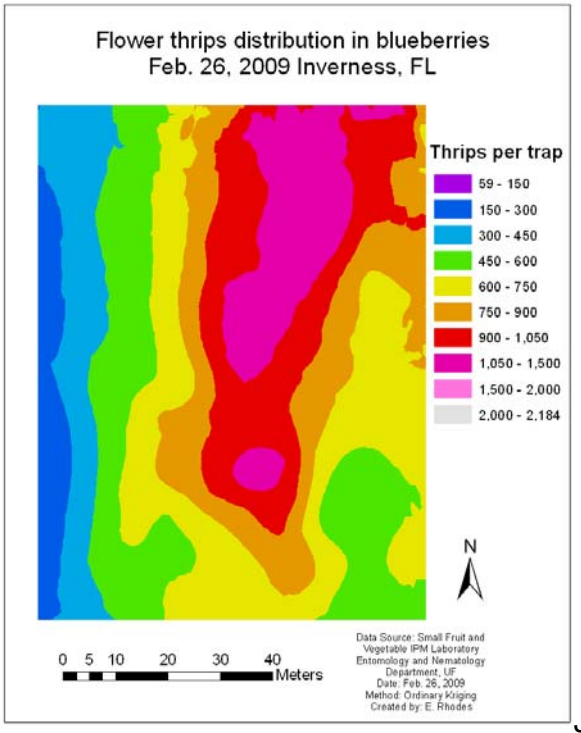
G


Flower thrips distribution in blueberries
Feb. 20, 2009 Inverness, FL
Thrips per trap
37 - 150
150 - 300
300 - 450
450 - 600
600 - 750
750 - 900
900 - 1,050
1,050 - 1,500
1,500 - 2,000
2,000 - 2,212
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: Feb. 20, 2009
Method: Ordinary Kriging
Created by: E. Rhodes

H



I



J

Fig. 5-10. Semivariograms (A, C, E, G, I) and Ordinary Kriging interpolation (B, D, F, H, J) of thrips per trap from A) & B) Jan. 30, 2009, C) & D) Feb. 5, 2009, E) & F) Feb. 13, 2009, G) & H) Feb. 20, 2009, and I) & J) Feb. 26, 2009.

Table 5-1. Summary statistics of thrips per trap for each sample date in 2008.

	Feb. 14	Feb. 21	Feb. 28
mean	277	351	179
median	195	268	158
min	8	40	10
max	1331	1895	1081
Std. Dev.	236	303	147
SEM	21	27	13
skewness coefficient	1.36	2.3	2.75
Kurtosis	5.23	10.01	14.90

Table 5-2. Several error metrics for natural neighbor (NN), inverse distance weighting (IDW), and ordinary kriging (OK) for each sample date in 2008.

		mean prediction error	root mean square error	residual prediction deviation	R^2
Feb. 14	NN	6.13	299.56	0.78	1.13
	IDW	4.78	208.80	1.13	0.34
	OK	1.61	202.90	1.16	0.29
Feb. 21	NN	-21.95	397.48	0.76	0.68
	IDW	0.10	307.80	0.98	0.11
	OK	-7.11	331.80	0.91	0.37
Feb. 28	NN	7.65	211.71	0.69	1.16
	IDW	5.13	147.20	0.99	0.20
	OK	4.49	151.60	0.97	0.26

Table 5-3. Summary of the semivariogram analysis for each sampling week in 2008.

	Feb. 14	Feb. 21	Feb. 29
model	Gaussian (1 & 2)	Cubic	Exponential
lags	23	23	23
nugget	39444.49	0.14	0.0018
sill	8342.28, 19086.94	95681.63	25354.64
nugget/sill ratio	1.44	0.0000015	0.000000071
range	79.71 m, 79.77 m	11.04 m	2.51 m
root mean square error	202.9	331.8	151.6
residual prediction deviation	1.16	0.91	0.97
mean prediction error	1.61	-7.11	4.49
R^2	0.29	0.37	0.26

Table 5-4. Summary statistics of thrips per trap for each sample date in 2009.

	Jan. 30	Feb. 5	Feb. 13	Feb. 20	Feb. 26
mean	213	11	490	571	660
median	164	8	499	512	506
min	14	1	35	37	59
max	724	51	1173	2212	2184
Std. Dev.	160	9	225	361	469
SEM	14	1	20	32	41
skewness coefficient	1.35	1.53	0.22	1.33	1.27
Kurtosis	4.29	5.61	2.97	5.92	4.11

Table 5-5. Several error metrics for natural neighbor (NN), inverse distance weighting (IDW), and ordinary kriging (OK) for each sample date in 2009.

		mean prediction error	root mean square error	residual prediction deviation	R^2
Jan. 30	NN	7.95	211.20	0.75	1.01
	IDW	1.17	164.70	0.97	0.13
	OK	3.28	157.90	1.01	0.18
Feb. 5	NN	0.38	12.40	0.768115571	1.05
	IDW	-0.02	9.93	0.959177552	0.20
	OK	0.41	9.43	1.010035322	0.20
Feb. 13	NN	8.25	212.08	1.121206761	1.13
	IDW	1.15	184.00	1.292312663	0.22
	OK	0.54	180.90	1.31445843	0.45
Feb. 20	NN	-35.59	455.18	0.809245866	1.06
	IDW	-2.69	367.50	1.002319818	0.30
	OK	20.16	342.10	1.076739355	0.28
Feb. 26	NN	-39.65	634.05	0.756782043	1.06
	IDW	0.30	476.40	1.0072159	0.24
	OK	16.61	442.80	1.083644206	0.26

Table 5-6. Summary of the semivariogram analysis for each sampling week in 2009.

	Jan. 30	Feb. 5	Feb. 13	Feb. 20	Feb. 26
model	Exponential	Spherical	Spherical	Spherical	Spherical
lags	23	23	23	23	23
nugget	0.25	0.50	9000	0.30	0.30
sill	0.40	0.20	35000	0.11	0.15
nugget/sill ratio	0.38	0.71	0.2	0.73	0.67
range	28.75 m	22.50 m	17.50 m	27.50 m	23.75 m
root mean square error	157.90	9.43	180.90	342.10	442.80
residual prediction deviation	1.01	1.01	1.31	1.08	1.08
mean prediction error	3.28	0.41	0.54	20.16	16.16
R^2	0.18	0.2	0.45	0.28	0.26

CHAPTER 6
EXAMINING THE RELATIONSHIP BETWEEN THRIPS SPATIAL DISTRIBUTION AND FLOWER DENSITY

Introduction

Southern highbush blueberries are an important crop in Florida that is grown for a highly profitable early-season fresh market (USDA 2010). Flower thrips are one of the key pests of these blueberries. Flower thrips injure blueberry flowers both when they feed on the flowers and when they lay their eggs in them. This injury can cause scaring on developing fruit, which makes the fruit unsalable on the fresh market (Arévalo-Rodriguez 2006).

Thrips populations tend to form one or a few “hot-spots” on blueberry farms, which are small areas of comparatively high thrips numbers (Arévalo and Liburd 2007). These “hot-spots” begin forming about 7-10 days after bloom initiation, peak between 12 and 15 days after initiation when the majority of the flowers are open, and decline until about 22 days after bloom initiation when most of the flowers have become fruit and the thrips population all but disappears (Arévalo and Liburd 2007). The “hot-spots” often form in different areas each year.

The objective of this study was to determine if “hot spots” of thrips are correlated with flower density. The hypothesis of this study was that thrips population density in space has a positive linear relationship with flower density.

Materials and Methods

Inverness Farm

In 2009, 100 white sticky traps (Great Lakes IPM, Vestaburg, MI) were distributed throughout a 1-ha SHB blueberry planting containing four to seven year old bushes in Inverness, FL, in a regular grid at 7.61-m increments. An additional 30 traps were again

placed randomly throughout the plot. Traps were changed out weekly over a five-week period on Jan. 30, Feb. 5, Feb. 13, Feb. 20, and Feb. 26. Traps were taken to the Small Fruit and Vegetable laboratory in Gainesville, FL, where the number of thrips per trap was counted and recorded.

Along with the thrips data, the percent of open flowers present in each blueberry row in the study was recorded each week. The sampling area was divided into 38 rows by a dirt road in the northern part of the study area. Each row contained blueberry plants of the same variety and age. Data were collected on Jan. 30 and Feb. 5, 13, 20, and 26.

Linear regression analysis was used to determine if the number of thrips (dependent variable) was related to the percent of open flowers (independent variable). All 130 sample points were input into the analysis by assigning to each trap the percentage of open flowers recorded from the row it was hung in. Since some of the assumptions of least squares regression could not be met even after transformation on several sampling dates, Theil regression (Hollander and Wolfe 1999) was used for all sampling dates. Kendall's tau, a nonparametric correlation statistic (Hollander and Wolfe 1999), was also calculated (Wessa 2008) for all sampling dates.

In addition, GIS layers of thrips numbers and percent of open flowers for each sampling date were created in ArcGIS (ESRI 2005). Trap locations were mapped using a Trimble Pathfinder GPS receiver (Trimble, Sunnyvale, CA) in the WGS 84 datum. The data were then imported into ArcMap 9.1 (ESRI 2005), projected into universal transverse mercator (UTM), and interpolated using inverse distance weighting (IDW). The NAD 27 datum was automatically assigned to the data when it was imported into

ArcMap, so this datum was used to project the data. For IDW, p was set at the default 2 and the search area was divided into 4 quadrants from which at least 5 data points per quadrant were included.

For the percent of open flowers, a point dataset was created by assigning the percent of open flowers recorded from each row to all of the sample points in that row. Inverse distance weighting (IDW), with p set at the default 2 and the search area divided into 4 quadrants from which at least 5 data points per quadrant were included, was used to create the percent of open flowers layers. Each layer was then saved as a raster with a cell size of 1.

Each raster layer was then classified. The thrips layers were classified into groups separated at 150 thrips per trap intervals up to 1,050 thrips. The final classification was > 1,050 because there were only a small number of traps with thrips exceeding this number. The one exception was week 2, which was separated at 15 thrips per trap intervals due to the extremely low numbers that week. One hundred and fifty thrips per trap is a commonly used action threshold. This produced five (week 1), three (week 2), and eight (weeks 3 through 5) categories respectively. The percent of open flower data were separated into the same number of categories as the thrips per trap data from the same sampling week using equal interval classification.

All of the layers were then reclassified so that each category was represented by a number from 1 to 3, 5, or 8 with 1 representing the lowest category and 3, 5, or 8 representing the highest. For each week, the reclassified percent of open flowers layer was subtracted from the reclassified thrips per trap layer. This produced a layer showing the qualitative relationship of the variables in space. The resulting layers were classified

as follows: 0 = high numbers of thrips per trap paired with high percentages of open flowers or low paired with low, 1 = high thrips numbers paired with moderately low percentages of open flowers, 2 -5 = high thrips numbers paired with low percentages of open flowers, > 5 = high thrips numbers paired with very low percentages of open flowers, -1 = low thrips numbers paired with moderately high percentages of open flowers, -2 - -5 = low thrips numbers paired with high percentages of open flowers, < -5 = low thrips numbers paired with very high percentages of open flowers.

Windsor Farm

This study was conducted on a farm in Windsor, FL, in Feb. and March of 2010. Twenty white sticky traps were placed in a 2464-m^2 area of a SHB blueberry planting. The blueberry plants were approximately seven years old. Traps were spaced 15-m apart in each of five blueberry rows. The rows were 10-m apart. Traps were replaced weekly and 4 - 5 flower clusters (20 - 25 flowers) were collected and placed into 50-ml vials containing 20 ml of 70% ethanol. Traps and flower samples were taken to the Small Fruit and Vegetable laboratory in Gainesville, FL, where the number of thrips per trap was counted and recorded. Thrips adults and larvae were extracted from the flowers using the “shake and rinse” method developed by Arévalo and Liburd (2007) and counted. Percent of open flowers was also recorded from each sampled plant on the Windsor farm in 2010. Traps, flower samples, and percent of open flower data were collected for 6 weeks from Feb. 18 to March 25.

Least squares regression analysis was used to determine if the number of thrips per trap (dependent variable) was related to the percent of open flowers (independent variable). The thrips per trap (x) data had to be $\log_{10}(x + 1)$ transformed so that all of the least squares regression analysis assumptions could be met.

Very few thrips were collected from the flowers until March 18. Therefore, only the March 18 and 25 data sets were analyzed for a relationship between thrips larvae and adults per flower (dependent variables) and percent of open flowers (independent variable). Since some of the assumptions of least square regression could not be met even after transformation for the thrips per flower data, Theil regression (Hollander and Wolfe 1999) was used. Kendall's tau, a nonparametric correlation statistic (Hollander and Wolfe 1999), was also calculated (Wessa 2008) for the thrips per flower data sets.

Results

Inverness Farm

A significant positive linear relationship between percent of open flowers and thrips per trap occurred on Jan. 30 ($\tau = 0.36$, $C > 1988$, $n = 130$, $P_{slope} < 0.0001$, Fig. 6.1A). There was a significant positive linear relationship between percent of open flowers and thrips per trap on Feb. 5 ($\tau = 0.24$, $C = 1734$, $n = 130$, $P_{slope} = 0.0002$) and Feb. 20 ($\tau = 0.21$, $C = 1555$, $n = 130$, $P_{slope} = 0.0012$, Fig. 6-1B & D). No relationship was found between percent of open flowers and thrips per trap on Feb. 13 ($\tau = 0.07$, $C = 273$, $n = 130$, $P_{slope} = 0.29$, Fig. 6-1C) or between percent of open flowers and thrips per trap on Feb. 26 ($\tau = 0.08$, $C = 581$, $n = 130$, $P_{slope} = 0.12$, Fig. 6-1E).

Summary data for the thrips per trap and percent of open flowers data are shown in Tables 6-1 and 6-2 respectively. On Jan. 30, 17% of the area was covered by pairings where either high thrips numbers were paired with high percentages of open flowers or low numbers were paired with low percentages (Fig. 6-2A). Pairings with a small degree of dissimilarity covered another 25% of the area. A similar pattern was seen on Feb. 5 (Fig. 6-2B), where 4% of the pairings were the same and 36% were only slightly dissimilar.

On Feb. 13, 68% of the sampling area was dominated by low thrips numbers paired with high percentages of open flowers (Fig. 6-2C). The degree of dissimilarity was much greater than that seen in the two previous weeks. Only 6% of the pairings were the same and 25% were slightly dissimilar. A similar pattern was seen on Feb. 20 (Fig. 6-2D), with 59% of the area covered by low thrips numbers paired with high percentages of open flowers. However, 11% of the area was covered by similar pairings and 27% by slightly dissimilar pairings.

Feb. 26 (Fig. 6-2E) was dominated by high thrips numbers paired with low percentages of open flowers (48%). Similar pairings encompassed 13% of the area and slightly dissimilar pairings 32%.

Windsor Farm

There was a significant negative linear relationship between percent of open flowers and $\log_{10}$thrips per trap on March 18 ($R^2 = 0.24$, $t = -2.67$, df = 19, $P_{slope} = 0.0156$, Fig. 6-3E). No relationship was found between percent of open flowers and $\log_{10}$thrips per trap on any of the other dates (all $R^2 < 0.03$, all $|t| \leq 1.23$, df = 19, $P_{slope} > 0.23$, Fig. 6-3A-D & F).

No relationship was found between percent of open flowers and thrips adults (both $\tau \leq 0.19$, $C \leq 14$, n = 20, $P_{slope} \geq 0.33$, Fig. 6-4) or larvae (both $\tau \leq 0.02$, $C = 0$, n = 20, $P_{slope} > 0.86$, Fig. 6-5) per flower on either date.

Discussion

According to Arévalo-Rodriguez (2006), flower thrips population density is strongly correlated with the percent of open flowers over time. The results from the Inverness 2009 study indicate that this relationship may exist in space as well. The differences in percent of open flowers in space most likely exist because multiple varieties are grown

on the same farm to maximize cross pollination (Childers and Lyrene 2006). Different varieties begin to flower at different times and flower for different periods of time.

However, there appeared to be no relationship between flower thrips density and percent of open flowers on the Windsor farm in 2010, except on March 18 where a relationship opposite to what was expected occurred. This may have been a result of the unusually cold winter weather that occurred throughout January and February (FAWN 2010). Further research is needed to determine if there are some cases where flower thrips density decreases with increasing percentages of open flowers.

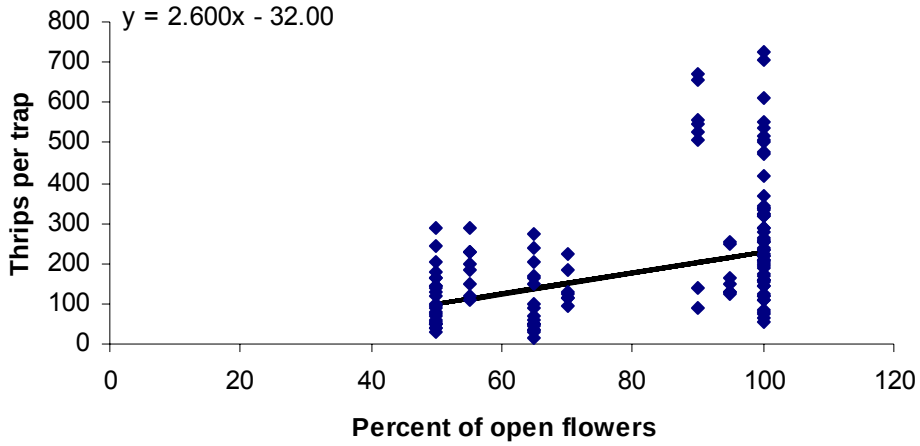
An intense cold snap that occurred from Feb. 4 - Feb. 6, 2009 (FAWN 2009) may explain some of the anomalies in the Inverness study. The extremely low thrips numbers found on Feb. 6 are likely a direct result of this cold snap. Tsai et al. (1995) found a 56% mortality rate when *Thrips palmi* Karny was held for 15h at 0°C. Development was also reduced at 26°C compared with 32°C.

The lack of any relationship between flower thrips numbers and percent of open flowers on Feb. 26 may have been indirectly related to the cold snap. After the cold snap, the thrips population began increasing and continued to do so throughout the sampling period. In contrast, peak flowering, averaged over the whole sampling area, occurred during the Feb. 13 sampling week. By Feb. 26, only a few rows, most likely containing later or longer flowering varieties, had more than 20% open flowers. This resulted in a large number of samples where high thrips numbers occurred with bushes having a low percent of open flowers as seen in Fig. 6-2E.

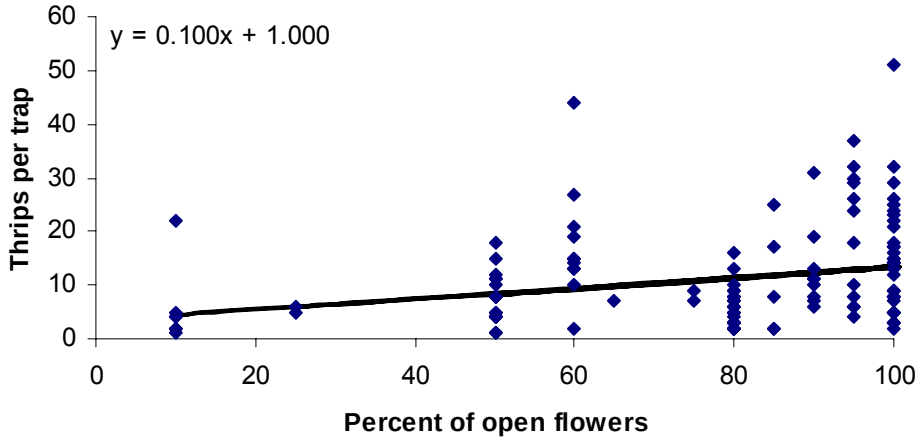
The opposite trend occurred on Feb. 13, when most of the rows were at 80 - 100% open flowers, while only a few rows, which probably contained later flowering varieties,

had just reached 50 - 65% open flowers. This resulted in a large number of samples where low thrips numbers occurred with bushes having a high percent of open flowers as seen in Fig. 6-2C.

The results from the Inverness study indicate that “hot spots” of flower thrips population may be related to flower density. Further research utilizing more accurate measures of flower density is needed.



A



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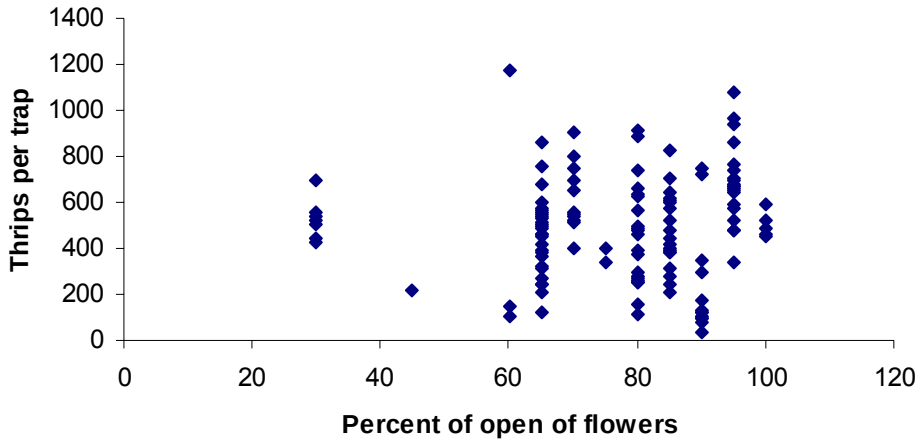

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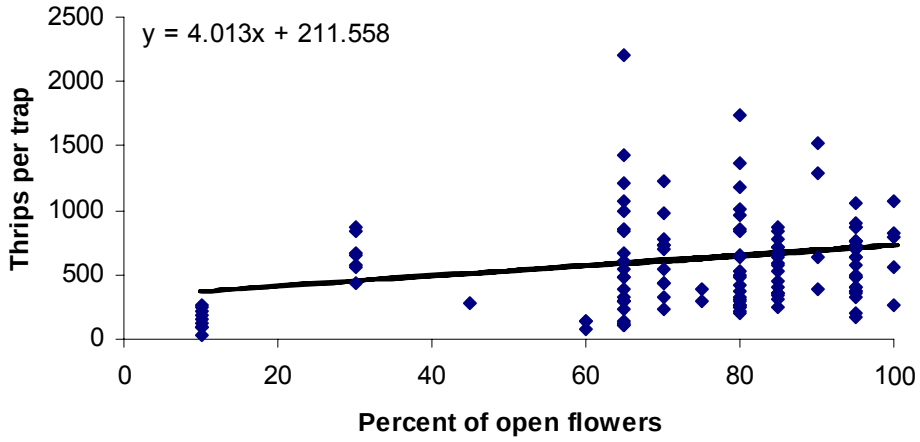
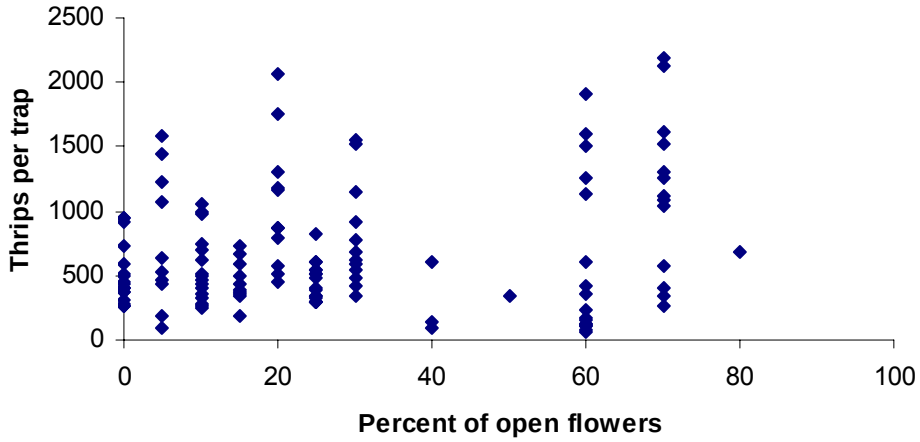
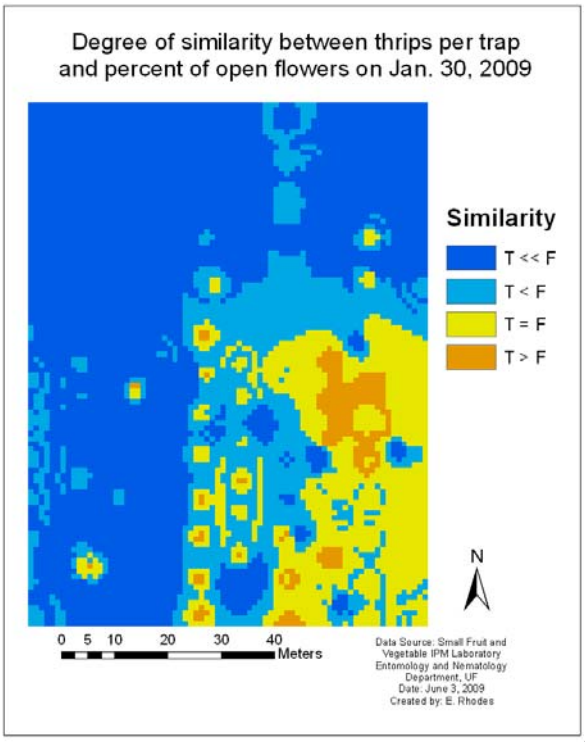


D

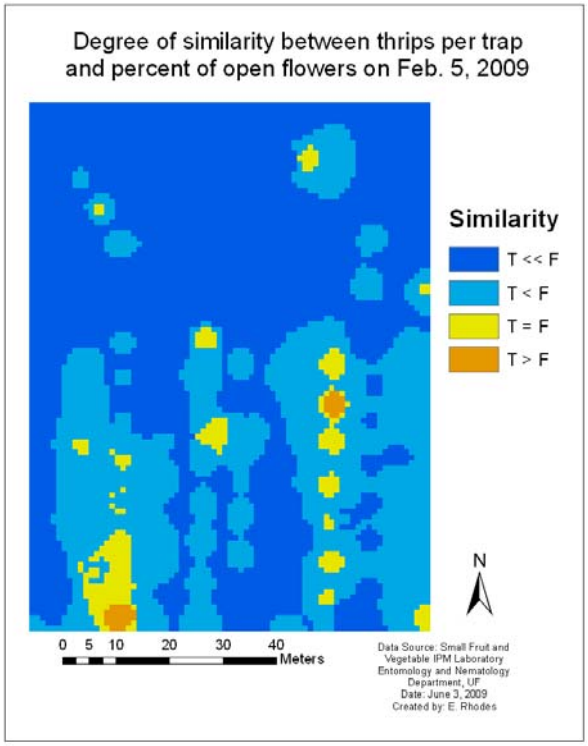


E

Fig. 6-1. Graphs showing percent open flowers vs. thrips per trap on A) Jan. 30, B) Feb. 5, C) Feb. 13, D) Feb. 20, and E) Feb. 26. The black lines represent regression lines fitted by Theil regression.


Degree of similarity between thrips per trap and percent of open flowers on Jan. 30, 2009
Similarity
T << F
T < F
T = F
T > F
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: June 3, 2009
Created by: E. Rhodes

A


Degree of similarity between thrips per trap and percent of open flowers on Feb. 5, 2009
Similarity
T << F
T < F
T = F
T > F
N
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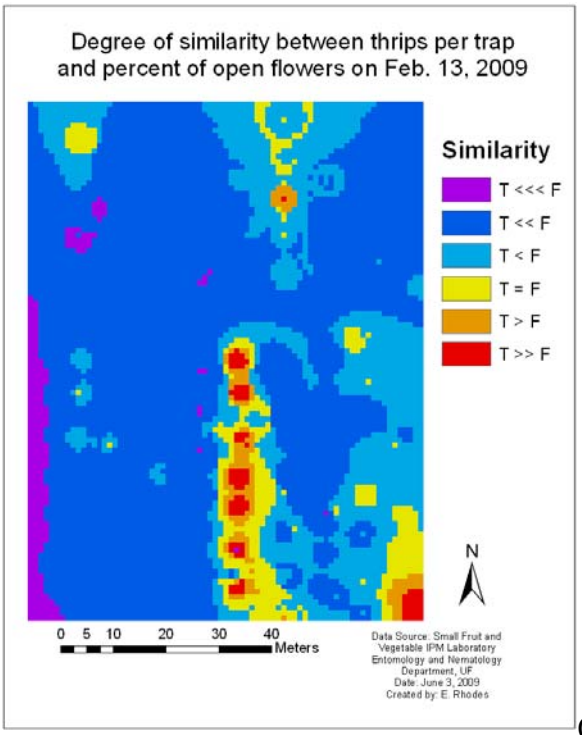
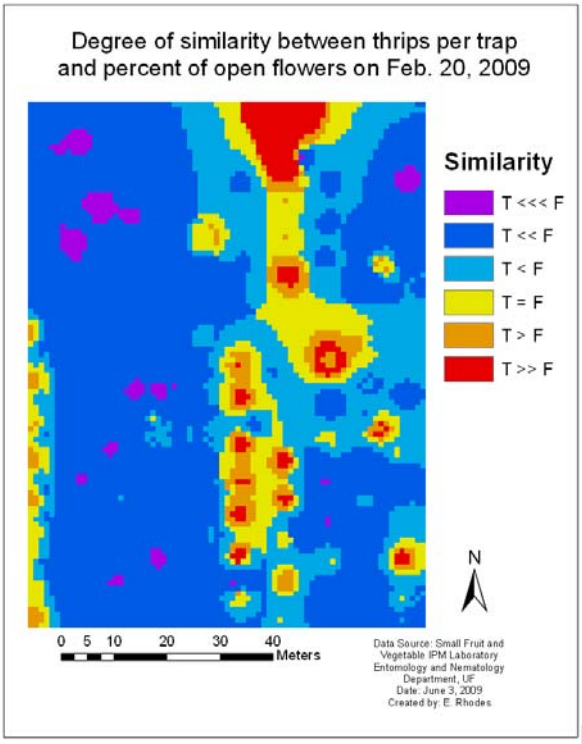
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: June 3, 2009
Created by: E. Rhodes

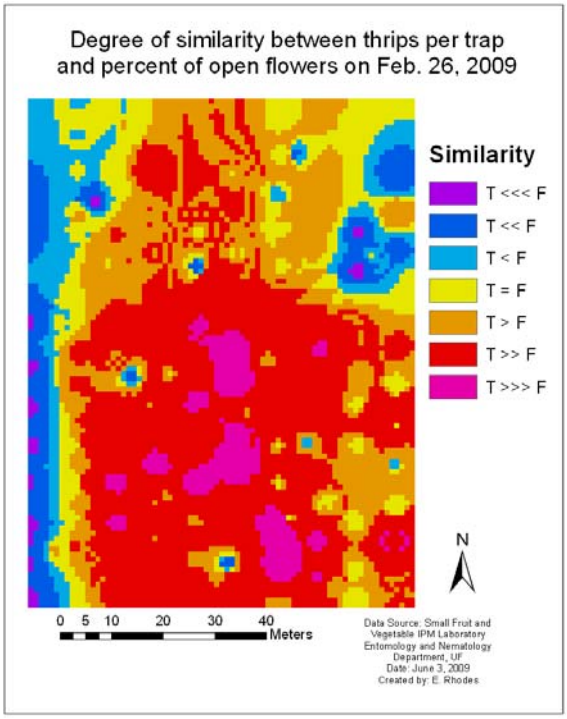
B


Degree of similarity between thrips per trap and percent of open flowers on Feb. 13, 2009
Similarity
T <<< F
T << F
T < F
T = F
T > F
T >> F
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: June 3, 2009
Created by: E. Rhodes

C

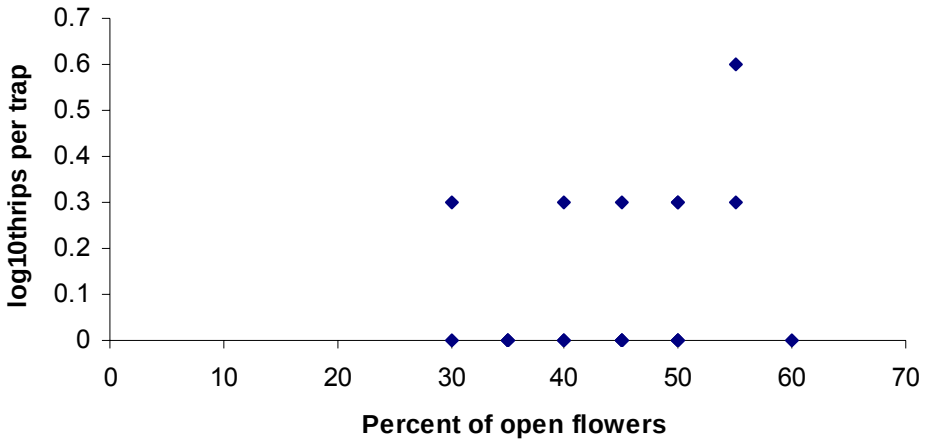

Degree of similarity between thrips per trap and percent of open flowers on Feb. 20, 2009
Similarity
T <<< F
T << F
T < F
T = F
T > F
T >> F
N
0 5 10 20 30 40
Meters
Data Source: Small Fruit and Vegetable IPM Laboratory Entomology and Nematology Department, UF
Date: June 3, 2009
Created by: E. Rhodes

D

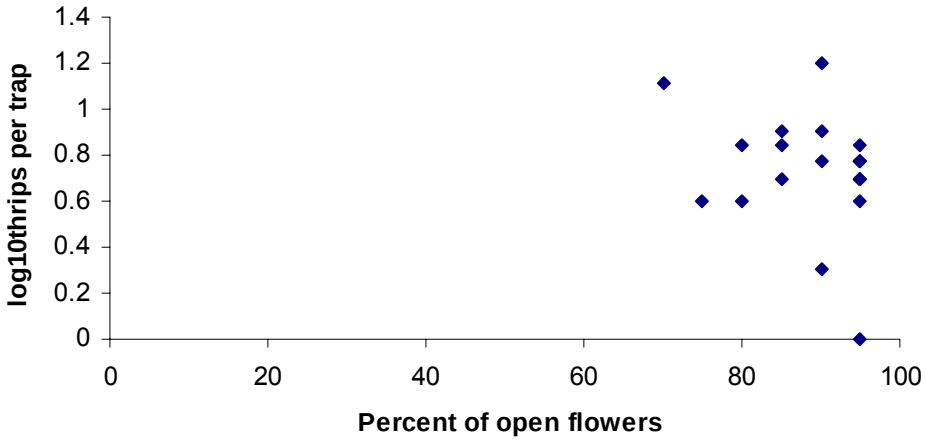


E

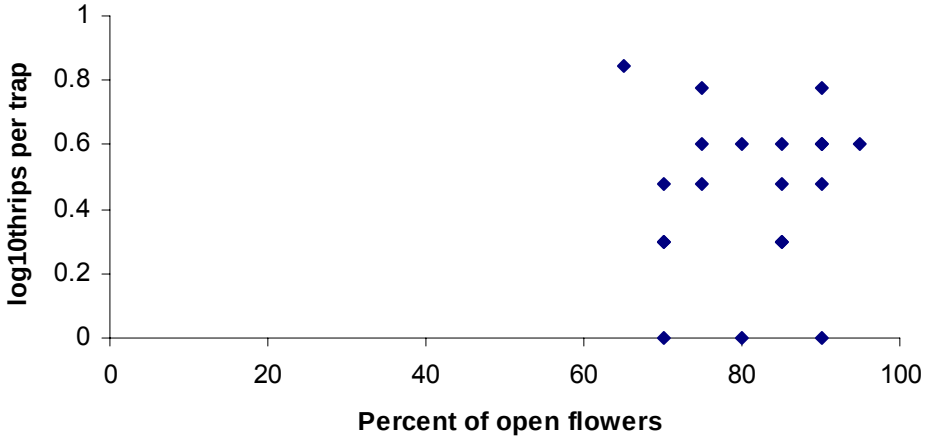
Fig. 6-2. Maps showing the spatial similarity of number of thrips per trap (T) with percent of open flowers (F) on A) Jan. 30, B) Feb. 5, C) Feb. 13, D) Feb. 20, and E) Feb. 26, 2009.


log10thrips per trap
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
Percent of open flowers

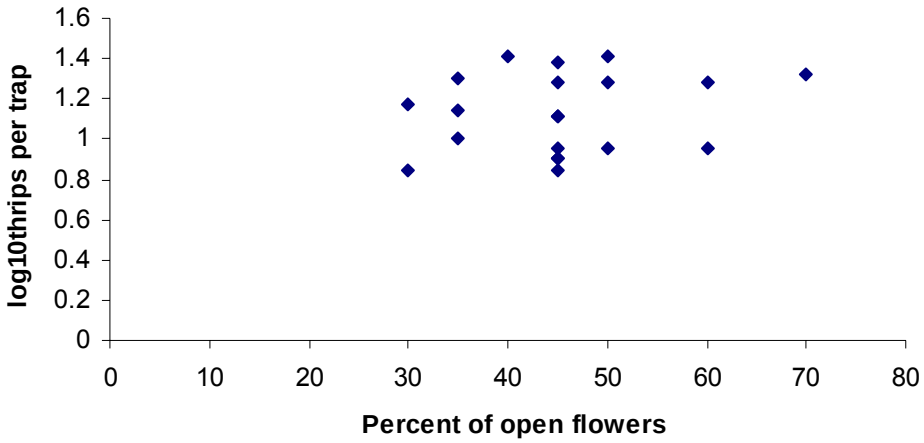
A


log10thrips per trap
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Percent of open flowers

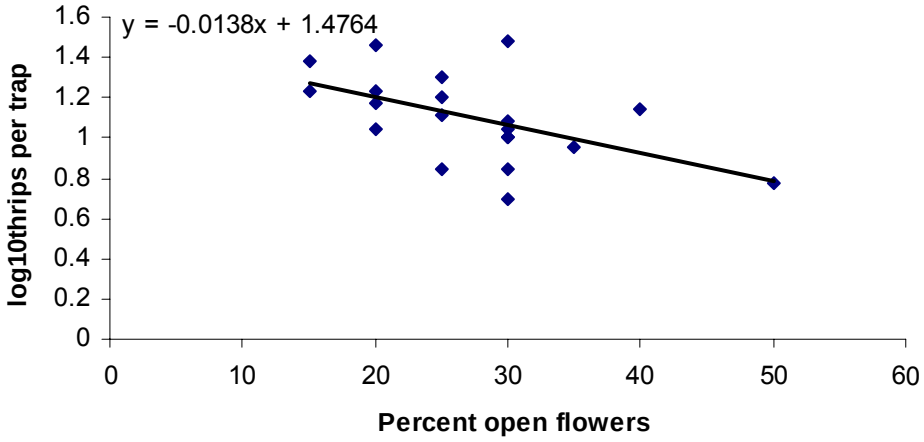
B


log10thrips per trap
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Percent of open flowers

C



D



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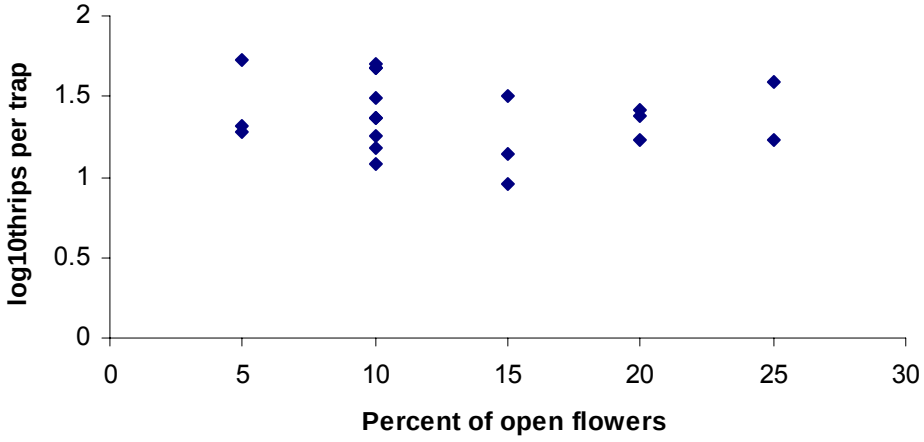
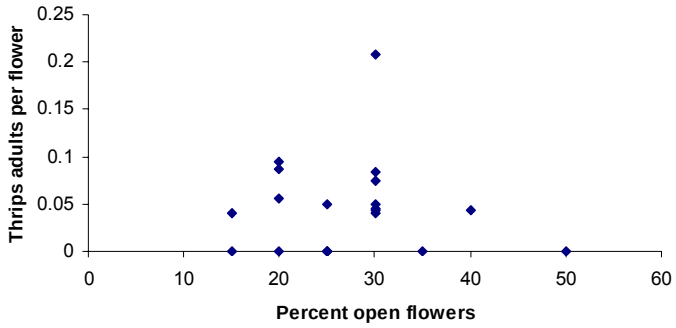
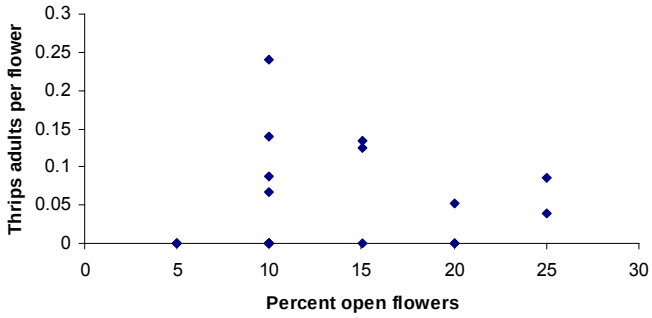


F

Fig. 6-3. Graphs showing percent open flowers vs. $\log_{10}$ thrips per trap on A) Feb. 18, B) Feb. 25, C) March 4, D) March 11, E) March 18, and F) March 25. The black lines represent regression lines fitted by least squares regression.

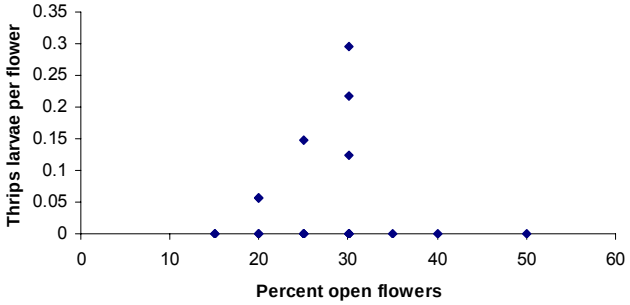


a

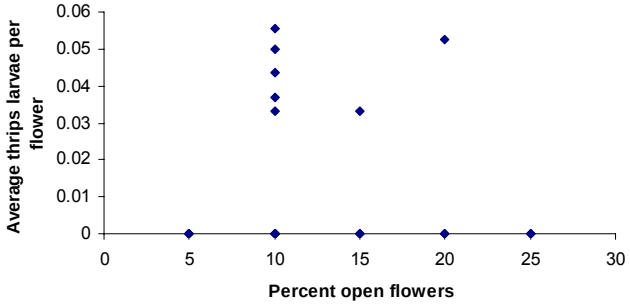


b

Fig. 6-4. Graphs showing percent open flowers vs. thrips adults per flower on a) March 18 and b) March 25.



a



b

Fig. 6-5. Graphs showing percent open flowers vs. thrips larvae per flower on a) March 18 and b) March 25.

Table 6-1. Summary statistics for the thrips per trap data from each sampling week.

	30-Jan	5-Feb	13-Feb	20-Feb	26-Feb
mean	213.0538	11.26923	489.9692	570.5923	660.4154
median	164	8	498.5	511.5	505.5
min	14	1	35	37	59
max	724	51	1173	2212	2184
Std. Dev.	160.0633	9.35086	224.6699	360.9792	469.2586
SEM	14.03848	0.820125	19.70486	31.65997	41.1567
skewness coefficient	1.35	1.53	0.22	1.33	1.27
Kurtosis	4.29	5.61	2.97	5.92	4.11

Table 6-2. Summary statistics for the percentage of open flower data from each sampling week.

	30-Jan	5-Feb	13-Feb	20-Feb	26-Feb
mean	80.26923	76.76923	77.23077	72.84615	27.26923
median	90	80	80	80	20
min	50	10	30	10	0
max	100	100	100	100	80
Std. Dev.	21.09697	24.66725	16.38989	23.58342	23.60127
SEM	1.850326	2.163461	1.437488	2.068403	2.069968
skewness coefficient	-0.35	-1.16	-1.12	-1.42	0.70
Kurtosis	1.35	3.71	4.39	4.40	2.15

CHAPTER 7
THE EFFECT OF SEVERAL REDUCED RISK INSECTICIDES ON FLOWER THRIPS POPULATIONS IN SOUTHERN HIGHBUSH BLUEBERRIES

Introduction

Flower thrips in blueberries are typically managed with applications of insecticides. The two most commonly used insecticides are malathion (Micro Flo Company LLC, Memphis, TN) and SpinTor® (spinosad) (Dow Agrosciences, Indianapolis, IN) (Arévalo-Rodriguez 2006). The recently registered Delegate™ (spinetoram) (Dow Agrosciences, Indianapolis, IN) is beginning to be used more frequently (O. E. Liburd personal communication). Malathion is a conventional, organophosphate insecticide with broad spectrum activity. SpinTor® is a reduced-risk insecticide. Its active ingredient, spinosad (spinosyn), is derived from the fermentation of the soil bacterium *Saccharopolyspora spinosa* Mertz and Yao. It must be ingested and kills insects via rapid excitation of the nervous system (IPM of Alaska 2003). Delegate™ was registered for use on flower thrips in blueberries during the course of the work presented in this chapter. Spinetoram, the active ingredient of Delegate™, is also a fermentation product of the soil bacterium *S. spinosa* (Srivastava et al. 2008).

Toxicity to bees and other pollinators is a major concern of blueberry growers. Therefore, insecticides are usually applied early in the morning or at night to minimize the impact on pollinating bees (Arévalo-Rodriguez 2006). Even with this practice, malathion still causes some pollinator mortality (O. E. Liburd personal communication).

With such a limited number of compounds, the development of resistance is also a concern. Resistance has been reported in *Frankliniella occidentalis* (Pergande) from various parts of the world to many insecticides including spinosad (Herron and James 2005, Dağh and Tunc 2007, Bielza et al. 2007). *Frankliniella occidentalis* can rapidly

develop resistance because it has a short generation time, high fecundity, and a haplodiploid breeding system (Jensen 2000). *Frankliniella bispinosa* (Morgan) share these traits.

The objective of this study was to determine the potential of using several reduced-risk insecticides to manage flower thrips in Florida blueberries. Compounds tested included spinetoram, which was registered on blueberries as Delegate™ (Dow Agrosciences, Indianapolis, IN) during the course of this study, rynaxypyr (DuPont, Wilmington, DE), and QRD 452 (AgraQuest, Davis, CA). Rynaxypyr is a ryanidine receptor agonist, causing the release of Ca^{2+} from muscle cells, which is a novel mode of action. The insects lose the ability to regulate muscle function and die via muscle paralysis (Ribbeck 2007). QRD 452 is an extract of Mexican Tea, *Chenopodium ambrosioides* L. (AgraQuest 2008). These compounds were compared with malathion, SpinTor®, and an untreated control to determine their efficacy. The hypothesis is that they will be at least as effective as malathion and SpinTor®.

Materials and Methods

This experiment was conducted on a commercial blueberry farm in Windsor, FL, in 2007 and 2008. In 2009, it was conducted at the University of Florida Plant Science Research and Education Unit (PSREU) near Citra, FL. The experiment was a randomized complete block design with four replicates of six treatments in 2007 and 2009 and five replicates of five treatments in 2008.

At the Windsor farm, treatments encompassed three rows of blueberries containing plants of approximately seven years of age. The middle row was sprayed on both sides and the two adjacent rows were sprayed on only one side, the side facing the middle row. Treatments were 12.2-m. long with a 3-m. buffer between them. There was

an unsprayed buffer row between each replicate. In 2007, the study area encompassed 0.78 ha and in 2008 it encompassed 0.83 ha.

There were four 0.13 ha plots of six year old southern highbush (SHB) blueberries at the Citra PSREU and these served as blocks. The variety Jewel was used throughout the two SHB applications. However, there were only two 0.12 ha plots of six year old rabbiteye (RE) blueberries at the research station. Therefore, two varieties, Premier and Brightwell, were included so that the experiment could be replicated four times. Each treatment group consisted of a row of five plants.

Treatments for 2007 included: 1) Malathion 5 EC at a rate of 1.75 L / ha, 2) SpinTor® 2 SC at a rate of 0.438 L / ha, 3) Rynaxypyr at a rate of 89.7 g / ha, 4) XDE-175 (spinetoram) at 131 g a. i. / ha, 5) XDE-175 (spinetoram) at 173 g a. i. / ha, and 6) untreated control. They were applied using a CO_2 sprayer three times during the flowering season 14 days apart.

Treatments for 2008 included Malathion, SpinTor® 2 SC, and Rynaxypyr at the same rates as the previous year, spinetoram at 131 g a. i. / ha, and an untreated control. They were applied using a CO_2 sprayer twice during the flowering season 14 days apart.

In 2007 and 2008, five flower clusters (~25 flowers) were collected from the blueberry bushes in the center of each treatment. They were collected the day of treatment, two days post treatment, and six days post treatment except during the second application in 2008. On this date, flowers were collected the day of treatment and five days post treatment due to inclement weather two days post treatment. The flower samples were brought back to the Small Fruit and Vegetable IPM laboratory in

Gainesville where the number of thrips and other arthropods per flower was counted utilizing the “shake and rinse” method (Arévalo and Liburd 2007). Adult thrips were identified to species using a key developed by Arévalo et al. (2006). Any thrips not matching the characters in the key were sent to the Division of Plant Industry in Gainesville, Florida for identification.

Treatments in 2009 included: 1) Malathion 5 EC, 2) SpinTor® 2 SC, and 3) Delegate™ (spinetoram) at the rates used in the previous years, and 4) QRD 452 at 4.68 L / ha, 5) QRD 452 at 9.35 L / ha and 6) water treated control. They were applied using a CO_2 sprayer twice in the SHB blueberries, 14 days apart and once in the RE blueberries during the flowering season.

Four flower clusters were collected from the three blueberry bushes in the center of each treatment. In the SHB, they were collected the day of treatment, two days post treatment, seven days post treatment, and fourteen days post treatment. In the RE, they were collected the day of treatment, two days post treatment, and seven days post treatment.

The flower samples were brought back to the Small Fruit and Vegetable IPM laboratory and sampled as in 2007 and 2008. Because a large number of adult thrips were present in the RE flowers, a sub-sample of 60 adult thrips per treatment each week was identified to species as described for 2007 and 2008.

Yield data were collected for both SHB and RE blueberries. In the SHB plots, blueberries were harvested from the two largest plants in the treatment group once a week for four weeks beginning on April 27. The yield from each week was summed and then divided by two to give an estimate of yield per plant for each treatment group. Yield

was collected from the RE treatment groups in the same way except that it was collected once a week for five weeks beginning on May 27.

Thrips per flower data from 2007, 2008, and the SHB blueberries in 2009 did not meet the assumptions of a one-way analysis of variance (ANOVA) and were therefore analyzed using the Friedman, Kendall-Babington Smith nonparametric test for a randomized complete block design and the Wilcoxon, Nemenyi, Mcdonald-Thompson multiple comparisons test (Hollander and Wolfe 1999). The 2009 RE blueberry thrips per trap data and both sets of yield data were analyzed with a one-way ANOVA in SAS and means were separated using the least significant difference (LSD) test if the ANOVA was significant ($P < 0.05$).

Results

2007

Two days after the third treatment was applied, there were significantly less thrips larvae per flower in the Rynaxypyr, SpinTor®, and XDE-175 low rate treatments compared with the control (S' = 12.36, k, n = 6, 4, $P < 0.02$, Fig. 7-1A). There were no significant differences in thrips adults per flower among treatments on any date (all $S' \leq$ 8.05, k, n = 6, 4, $P > 0.1$, Fig. 7-1B).

The percent of each species that was present in each treatment is shown in Table 7-1. *Frankliniella bispinosa* was the dominant species. Other species present included *F. fusca* (Hinds), *F. occidentalis*, *Thrips hawaiiensis* (Morgan), and *T. pini* Karny.

Very few other arthropods were recorded from the flowers (Table 7-2). Three predatory mites and three small spiders were the main predators sampled. Four Coleopterans were also collected and some of these may also have been predators.

2008

There were no significant differences among average thrips larvae per flower on any date (all $S' \leq 4.73$, k, n = 5, 5, $P > 0.1$, Fig. 7-2A).

However, two days after the first application, there were significantly more thrips adults per flower in the Rynaxypyr treatment compared with the spinetoram treatment ($S' = 9.08$, k, n = 6, 4, $P = 0.048$, Fig. 7-2B & C). Six days after the first application, the control had significantly higher numbers of thrips adults per flower than the spinetoram treatment ($S' = 9.66$, k, n = 6, 4, $P = 0.036$).

The percent of each species that was present in each treatment is shown in Table 7-3. *Frankliniella bispinosa* was the dominant species. *Thrips hawaiiensis* and *T. pini* were the second most numerous species present in the flowers. Other species present included *F. fusca*, *F. occidentalis*, and *Franklinothrips* sp.

Very few other arthropods were recorded from the flowers (Table 7-4). Eighteen predatory mites spread among the Rynaxypyr, SpinTor® and spinetoram treatments and a small spider found in the control were the main predators sampled. The wasp that was also recorded from the control may be a parasitoid.

2009

SHB thrips per flower

There were no significant differences in thrips larvae or adults per flower among treatments on any date (all $S' \leq 9.39$, k, n = 6, 4, $P \geq 0.08$, Fig. 7-3).

The percent of each species that was present in each treatment is shown in Table 7-5. *Frankliniella bispinosa* was the dominant species. *Thrips pini* was the second most numerous species. Many other thrips species were also encountered occasionally,

including *F. fusca*, *F. occidentalis*, *Franklinothrips* sp., *Haplothrips graminis* Hood, and *T. hawaiiensis*.

A number of other arthropods were found in the flower samples (Table 7-6). The only predators found were spiders, one each in the SpinTor® and QRD 452 high rate treatments. Ants, which are sometimes predatory, were found in the control, SpinTor®, and QRD 452 high rate treatments. A wasp was found in the Delegate™ treatment.

RE thrips per flower

There were no significant differences in average thrips larvae per flower among any of the treatments on any date (all $F \leq 1.99$, df = 5, 23, $P \geq 0.13$, Fig.7-4A).

However, 2 days post treatment there were significantly fewer adult thrips in the Delegate™ treatment compared with the control and both rates of the QRD 452 (F = 8.52, df = 5, 23, P = 0.0004, Fig. 7-4B). Interestingly, the high rate of the QRD 452 had significantly more thrips adults per flower than the control.

The percent of each species that was present in each treatment is shown in Table 7-7. Nearly all of the thrips sampled were *F. bispinosa*. A single *T. pini* and *H. graminis* were also sampled.

Other arthropods found in the flower samples included mostly aphids and ants (Table 7-8). A predatory mite was found in the control treatment.

Yield

There were no significant differences in SHB (F = 0.34, df = 5, 23, P = 0.88) or RE (F = 1.47, df = 5, 23, P = 0.25) yield among any of the treatments. The average yields across treatments in the SHB and RE blueberries were 1.03 ± 0.19 and 2.14 ± 0.68 kg per plant respectively.

Discussion

Spinetoram reduced either thrips larvae or adults below levels found in the control after one application each year. At all other times, it was as effective as SpinTor®. Srivastava et al. (2008) found that spinetoram was effective against *F. bispinosa*, *F. occidentalis*, and *F. tritici* (Fitch) in pepper at a rate of 151 g a. i. per acre. This rate is only slightly higher than the lower rate of 131 g a. i. per ha used in this study.

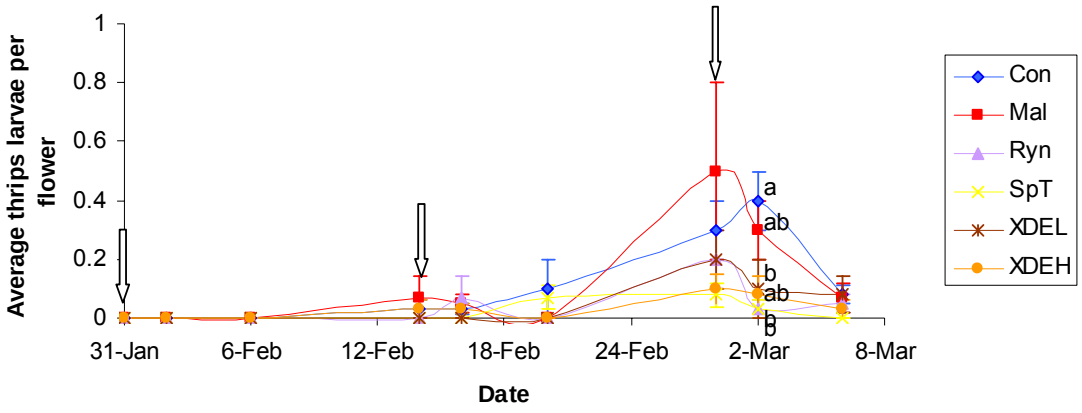
Rynaxypyr reduced numbers of thrips larvae below the control in 2007, but not in 2008. It did not reduce adult numbers in either year. Rynaxypyr has been shown to be effective against various Lepidopterous pests (Ribbeck 2007), leaf rollers in apples (Puciennik and Olszak 2009), and several sugar cane pests including termites and early shoot borer (Rajavel et al. 2009, Singh et al. 2009). It may prove useful against thrips, but further research is necessary.

The QRD 452 high rate treatment had significantly higher numbers of thrips adults than the control 2 days post treatment. QRD 452 is an extract of *C. ambrosioides*, commonly called Mexican Tea. It produces an odor that is pleasing to the human nose (E. Rhodes personal observation). It is possible that QRD 452 may contain a volatile that is attractive to *F. bispinosa*. There are a number of floral volatiles that are attractive to various species of flower thrips (Lewis 1997). However, further research is needed to substantiate this hypothesis.

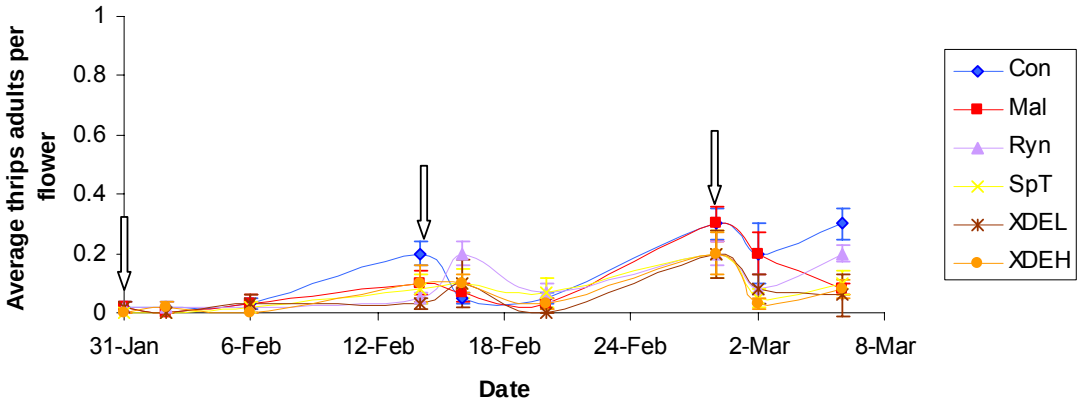
The main reason for the presence of only a few significant results is the very low numbers of both thrips adults and larvae that were present in the SHB blueberry flowers during all three years. Neither numbers of thrips larvae nor adults exceeded an average of 0.5 thrips per flower in 2007 or 2009. Thrips numbers were higher before the second application of insecticides in 2008, but a violent storm that blew through the area on

March 7 prevented sampling on that date and most likely washed the treatments off of the blueberry plants. Numbers of thrips larvae per flower were also low in the RE blueberries.

Overall, both spinetoram and Rynaxypyr performed as well as malathion and SpinTor® while QRD 452 appeared to cause an increase thrips numbers. Spinetoram, now registered in blueberries as Delegate™, has become another tool for thrips control in blueberries. Further trials must be done before any firm conclusions on the effectiveness of Rynaxypyr and QRD 452 against thrips in blueberries can be drawn.

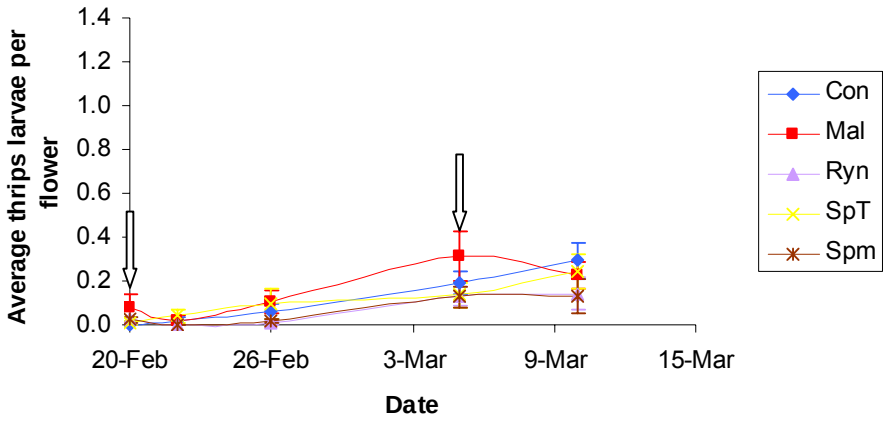


A



B

Fig. 7-1. Average thrips A) larvae and B) adults per flower in each treatment on each sampling date. Arrows indicate dates when treatments were applied. Error bars indicate standard error of the mean. Means with the same letter are not significantly different from each other at $P = 0.05$.



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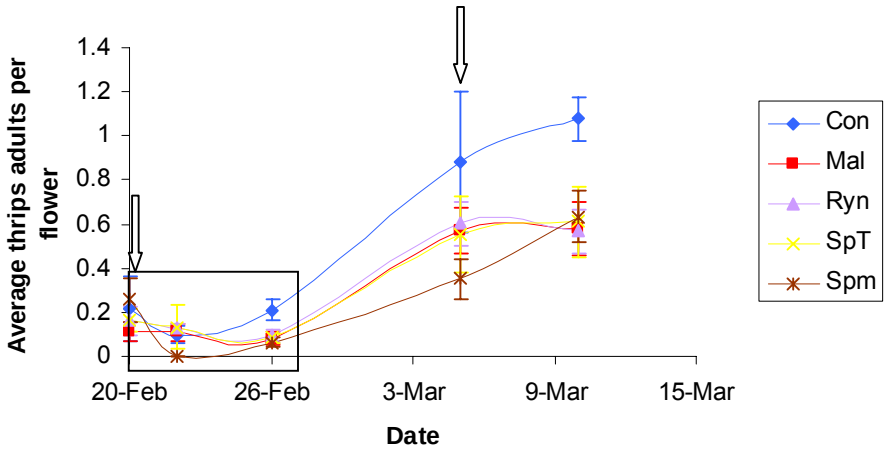

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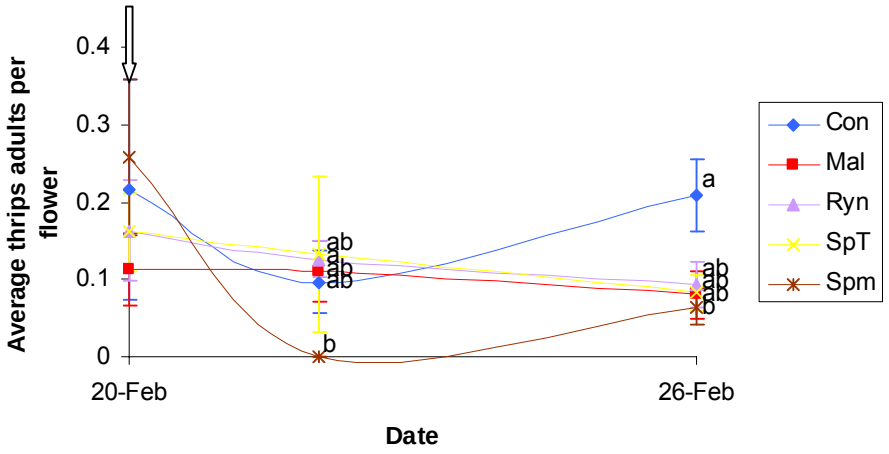
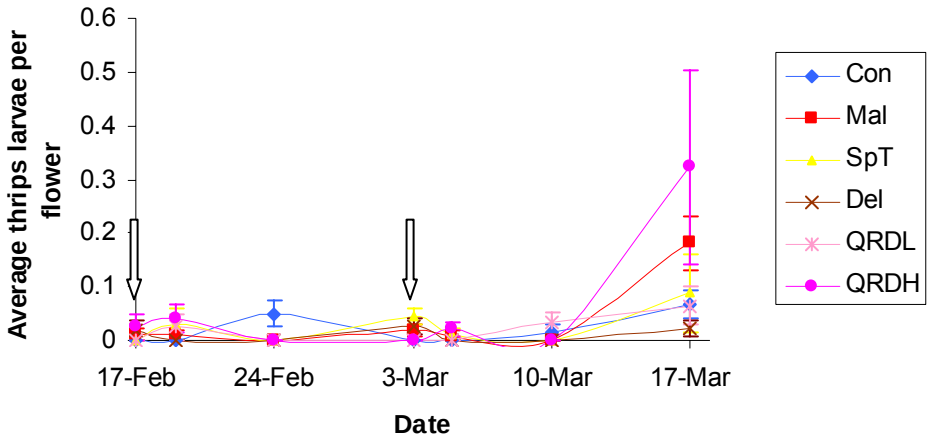
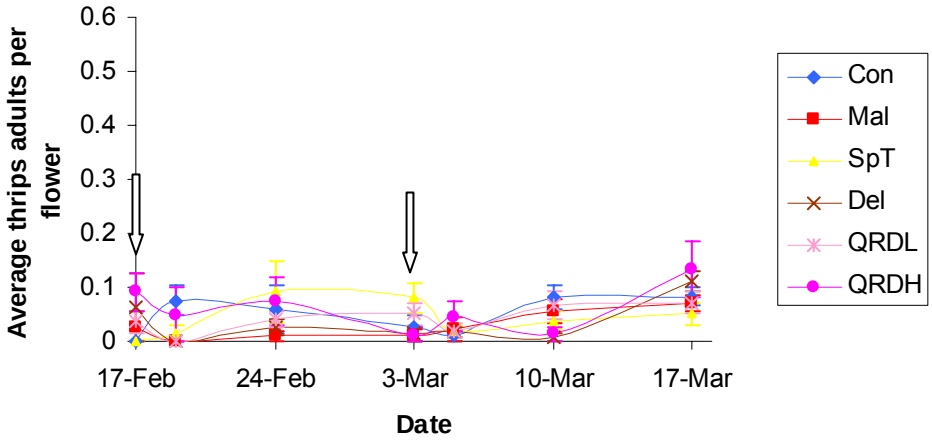


C

Fig. 7-2. Average thrips A) larvae and B) adults per flower in each treatment on each sampling date and C) adults per flower during the first three sampling weeks as indicated by the box in B). Arrows indicate dates when treatments were applied. Error bars indicate standard error of the mean. Means with the same letter are not significantly different from each other at $P = 0.05$.

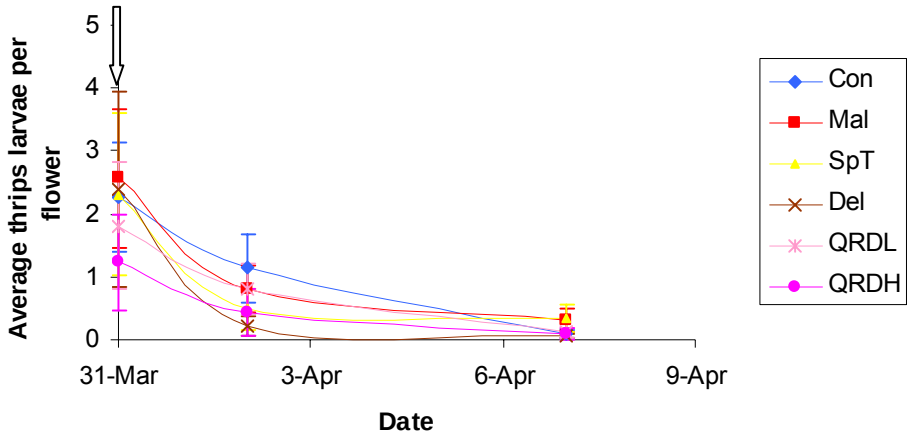


A

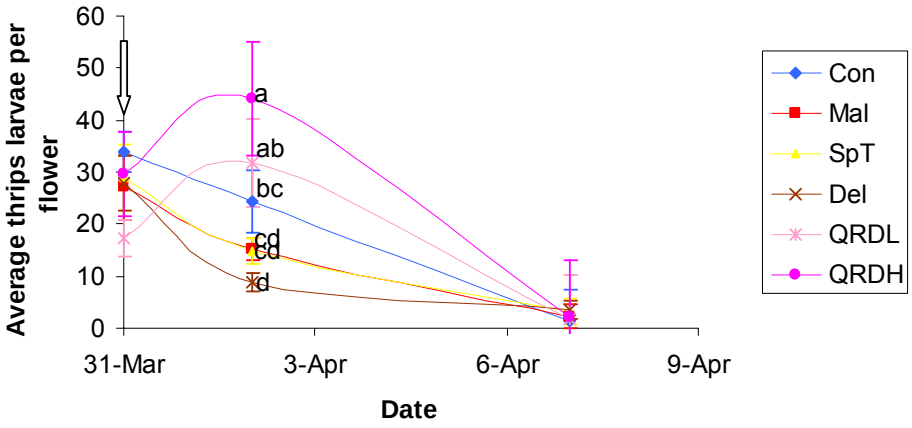


B

Fig. 7-3. Average thrips A) larvae and B) adults per flower in each treatment on each sampling date. Arrows indicate dates pesticides were applied. Error bars indicate standard error of the mean. Means with the same letter are not significantly different from each other at $P = 0.05$.



A



B

Fig. 7-4. Average thrips A) larvae and B) adults per flower in each treatment on each sampling date. The Arrow indicates the date the pesticides were applied. Error bars represent standard error of the mean. Means with the same letter are not significantly different from each other at $P \leq 0.05$.

Table 7-1. Percent of each thrips species per treatment in 2007

	F. bispinosa	*F. fusca*	*F. occidentalis*	*T. hawaiiensis*	*T. pini*
Con	78.0	12.2	2.4	4.9	2.4
Mal	74.5	4.3	2.1	19.1	0
Ryn	70.0	10.0	6.7	10	3.3
SpT	80.6	5.6	2.8	5.6	5.6
XDEL	73.9	4.3	13.0	0	8.7
XDEH	64.3	0	3.6	7.1	25.0

The total thrips sampled from each treatment were: control (Con) 41, malathion (Mal) 47, Rynaxypyr (Ryn) 30, SpinTor® (SpT) 36, XDE-175 low rate (XDEL) 23, XDE-175 high rate (XDEH) 28.

Table 7-2. Average number of other arthropods per flower in each treatment for the season in 2007

	Acari:: Phytoseiidae	Araneae	Coleoptera	Diptera	Hemiptera: Aphidae	other Hemiptera	Lepidoptera larvae
Con	0.002	0.002	0.002	0.080	0	0	0.002
Mal	0	0.002	0	0.135	0.006	0	0
Ryn	0	0	0.004	0.117	0	0	0.002
Sp	0.002	0	0	0.191	0.057	0	0
XDEL	0	0	0	0.135	0.002	0.002	0
XDEH	0.002	0.002	0.002	0.178	0.013	0	0

Table 7-3. Percent of each thrips species per treatment in 2008

	F. bispinosa	*F. fusca*	*F. occidentalis*	*T. hawaiiensis*	*T. pini*	*Franklinothrips* sp.
Con	65.8	0.7	0	15.4	14.8	3.4
Mal	64.9	1.5	0.7	6.0	26.9	0
Ryn	66.9	0	0	7.0	24.2	1.9
SpT	69.5	0	0	15.6	14.3	0.6
Spm	68.3	1.6	0	12.2	17.9	0

The total thrips sampled from each treatment were: control (Con) 149, malathion (Mal) 134, Rynaxypyr (Ryn) 157, SpinTor® (SpT) 154, spinetoram (Spm) 123.

Table 7-4. Average number of other arthropods per flower in each treatment for the season in 2008

	Acari: Phytoseiidae	Araneae	Hymenoptera	Diptera	Hemiptera: Aphidae	other Hemiptera	Lepidoptera larvae	Coleoptera: Curculionidae
Con	0	0.0019	0.0018	0.0983	0	0	0.0019	0.0019
Mal	0	0	0	0.0624	0	0	0	0
Ryn	0.0052	0	0	0.1138	0	0.0018	0	0
SpT	0.0067	0	0	0.0871	0.0047	0	0.0027	0
Spm	0.0204	0	0	0.1722	0	0	0	0

Table 7-5. Percent of each thrips species per treatment in the SHB blueberries in 2009

	F. bispinosa	*F. fusca*	*F. occidentalis*	*T. hawaiiensis*	*T. pini*	*Franklinothrips* sp.	*H. graminis*
Con	79.2	0	4.2	0	0	16.7	0
Mal	80.0	0	0	0	13.3	0	6.7
SpT	90.0	0	0	0	5.0	0	5
Del	78.6	7.1	0	0	14.3	0	0
QRDL	78.3	4.3	0	4.3	4.3	8.7	0
QRDH	85.7	4.8	0	0	9.5	0	0

The total thrips sampled from each treatment were: control (Con) 24, malathion (Mal) 15, SpinTor® (SpT) 20, Delegate™ (Del) 14, QRD-452 low rate (QRDL) 23, QRD-452 high rate (QRDH) 21.

Table 7-6. Average number of other arthropods per flower in each treatment for the season in the SHB blueberries in 2009

	Araneae	Hymenoptera	Hymenoptera: Formicidae	Diptera	Hemiptera: Aphidae	other Hemiptera
Con	0	0	0.4241	0	4.2633	0.0588
Mal	0	0	0	0.1566	1.0122	0
SpT	0.0385	0	0.05	0	1.8689	0
Del	0	0.0333	0	0.0357	7.2433	0
RqL	0	0	0	0	1.3130	0
RqH	0.0345	0	0.1934	0.0476	1.3707	0

Table 7-7. Percent of each thrips species per treatment in the RE blueberries in 2009

	F. bispinosa	*T. pini*	*H. graminis*
Con	100	0	0
Mal	100	0	0
SpT	100	0	0.6
Del	99.4	0	0
QRDL	100	0	0
QRDH	100	0	0

A total of 180 thrips were sampled from each treatment.

Table 7-8. Average number of other arthropods per flower in each treatment for the season

	Acari: Phytoseiidae	Hymenoptera: Formicidae	Diptera	Hemiptera: Aphidae	other Hemiptera
Con	0.0588	0.5278	0.0625	0.25	0.0625
Mal	0	0.0625	0	0.4	0
SpT	0	0.0546	0	0.203219	0
Del	0	0	0.5	0.2223	0
RqL	0	0.6	0	0.2889	0.0556
RqH	0	0	0	0.1111	0

CHAPTER 8
CONCLUSIONS

Results related to 5 objectives were presented in this dissertation. The objective were: 1) to examine southern highbush blueberry plantings and adjacent fields for alternate hosts of flower thrips and thrips dispersal from these host plants into blueberry plantings, 2) to determine the relationship between populations of thrips and yield in southern highbush blueberries and to determine an action threshold for thrips in southern highbush blueberries, 3) to model the spatial distribution of flower thrips in a blueberry planting utilizing geostatistical methods and to determine optimum trap spacing, 4) to determine if “hot spots” are correlated with flower density, and 5) to determine the potential of using several experimental reduced-risk insecticides to manage flower thrips in Florida blueberries.

In the preliminary plant surveys, several reproductive hosts of *Frankliniella bispinosa* were found. However, *F. bispinosa* developed in a white clover field and blueberry planting simultaneously. Also, the highest numbers of thrips were often found in the center of the blueberry planting. Other reproductive hosts still need to be examined as sources of flower thrips in blueberry plantings, but results suggest that thrips persist and overwinter in blueberry plantings.

The studies performed to examine objective 2 revealed that different varieties will attract significantly different numbers of thrips. Varieties like Emerald, which flower early and uniformly, appear to attract high numbers of thrips. However, this does not necessarily lead to a significant difference in yield among varieties. Because of these differences, economic injury levels may have to be developed for individual varieties or for groups of varieties with similar flowering characteristics. Observations indicate that

varietal differences are minimized when different varieties are interplanted evenly among each other, but further research is needed to substantiate this hypothesis.

The spatial distribution study conducted for objective 3 revealed that both inverse distance weighting and kriging can be used to model flower thrips spatial distribution in blueberries. The choice between the two would depend upon the objectives of a particular study and the number of sample points to be taken. Semivariogram analysis showed that white sticky traps should be spaced at least 28.8 m apart to ensure that all samples are spatially independent from each other.

The correlation study, objective 4, conducted on the Inverness farm provided evidence that “hot spots” may be correlated with flower density. Further research incorporating more accurate measures of flower density is needed to confirm these findings. Further research is also needed to determine if Incorporating temperature and other environmental factors would prove beneficial.

In the efficacy trials conducted for objective 5, spinetoram was the most effective of the reduced-risk compounds tested in reducing flower thrips numbers. In 2008, it was registered for use in southern highbush blueberries as Delegate™. Rynaxypyr showed some promise and should be tested further. Trials examining the efficacy of QRD-452 are ongoing.

The overall goal of this project was to improve monitoring and management of flower thrips in southern highbush blueberries in Florida. Awareness of the potential effects of variety, flower density, and temperature on thrips density and spacing traps at least 28.8 m apart should improve monitoring. Management can be improved by planting no more than two consecutive rows of the same variety and by making proper

use of Delegate™. Further research into the various topics addressed in this dissertation will bring more improvement to flower thrips management in Florida blueberries.

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BIOGRAPHICAL SKETCH

Born and raised in Miami, Elena Marion Rhodes has lived all of her 29 years in Florida. She earned her bachelor's degree in biology at New College of Florida in Sarasota in May of 2003. During her seventh semester, she interned in the Invertebrate Laboratory of Archbold Biological Station in Lake Placid, Florida. While there, she completed a project on backswimmer population ecology, which became her senior thesis project. She graduated with a master’s degree in entomology from the University of Florida in 2005. Her thesis investigated predator-prey relationships in an attempt to control twospotted spider mites in strawberries. With the completion of this dissertation, she received her Ph.D. from the University of Florida in August of 2010. This dissertation is the culmination of her work on the ecology and management of flower thrips in Florida blueberries. She is a member of the Gamma Sigma Delta honors society of agriculture and the Talking Gators Toastmasters club.