

HOST SUSCEPTIBILITY AND POPULATION DYNAMICS OF *Scirtothrips dorsalis* HOOD
(THYSANOPTERA: THIRIPIDAE) ON SELECT ORNAMENTAL HOSTS IN SOUTHERN
FLORIDA

By

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Humility before nature

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Abstract of Thesis Presented to the Graduate School
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Scirtothrips dorsalis Hood (1919) is an invasive pest thrips that recently arrived in Florida. The growth and dispersal of *S. dorsalis* populations are influenced by environmental factors. Populations show a positive relationship with increasing temperature, and months with greater accumulated degree-days show larger thrips populations on all hosts tested. Increasing humidity and rainfall are associated with negative population growth. Periods of peak population growth also appear to be periods of peak population dispersal. Temperature and humidity are also important to dispersal, with higher temperatures increasing thrips flights throughout the day, and higher humidity reducing the number of flying thrips. Dispersal of *S. dorsalis* is heavily influenced by the direction of the wind.

This thrips appears capable of choosing between hosts, appearing in greater density on schefflera than buttonwood, but this may be an effect of the denser foliage of the schefflera trapping more thrips in the wind. It was the predominant thrips detected on all hosts year round, but while all life stages were detected on hosts such as schefflera and buttonwood, populations were significantly larger on rose. Population demographics of rose also suggested a growing population.

When comparing different cultivars of rose, all tested appear to be exploited in a similar fashion and suffer similar damage from the thrips. Larger populations of *S. dorsalis* resulted in greater damage to host plants, with a reduction in blossom size by almost half. Thrips were more abundant in flowers than on leaves, but the density of thrips per square centimeter was similar between the two parts. Thrips density was fairly even between plants within a plot, suggesting that the thrips has density dependent distribution. The nutrient quality of plants also impacted thrips populations. While higher rates of fertilization did not result in significantly larger numbers or sizes of flowers, there were trends suggesting that over time it would result in significantly larger populations of thrips.

CHAPTER 1 LITERATURE REVIEW

Expansion and Economic Impact

Scirtothrips dorsalis Hood (1919) is a remarkably successful invasive thrips whose range has expanded rapidly from Asia over the last twenty years. It is a polyphagous insect with a broad host range and a rapid rate of development and reproduction. Its small size permits wind dispersal and makes it difficult to detect during agricultural inspection. Together, these traits contribute to its pest status on many crops of economic significance, and have led to its recent arrival in Florida.

Nomenclatural and Biogeographic History

The characteristic feeding damage of *S. dorsalis* was known and recognized as “Murda disease” (Kulkarni 1922, Ramakrishna Ayyar 1932) on chili long before the thrips was associated with and then determined to be the cause of the blight. The insect was first described in India by J. Douglas Hood of Cornell University (1919b) and then by subsequent authors (Table 1-1) as a pest common to *Ricinus communis* L. (castor bean) and *Capsicum annuum* L. (chili pepper) (1919a). Synonymy probably occurred due to the global distribution and broad host range of this thrips, its small size and difficulty to characterize, as well as the limited access that earlier authors had to type material (Mound and Palmer 1981).

While it is currently believed that the point of biogeographical origin for the thrips is in Southeast Asia or on the Indian subcontinent, the original hosts are unknown. As chili peppers did not arrive in India until the sixteenth and seventeenth centuries with Portuguese traders (Collingham 2006), and given *S. dorsalis*' broad host profile, it is unlikely that the initial host of description is also the point of origin. It has been speculated that a weed such as *Ricinus communis* L., later adopted for agriculture, may have been one of several hosts of origin. As

agriculture developed in its native range, the thrips may have adapted to opportunity, and began to exploit other hosts as they became available – a pattern observed as this insect expands its range.

Biological Invasion

The success of an invasive species depends on its ability to find and exploit a sustainable ecological niche. The organisms most likely to establish a foothold in a new environment are generalist herbivores. As a group, they are more likely to find sufficient substrate at lower trophic levels to meet their basic nutrient needs. This allows their population to subsist until they have the opportunity to disperse into more ideal environments (Crawley 1986).

Thrips are inadvertently well adapted to a lifestyle as an invasive species (Morse and Hoddle 2006), and have shown themselves to be remarkably effective at human-aided dispersal. When transported by humans, some species ranges have advanced by almost two hundred kilometers in a year (Kirk and Terry 2003). As a small cryptophilic organism that prefers to feed in the tightly packed meristem of growing plants, they may successfully avoid many control measures. Inspectors may not observe individuals hiding within the blooms, and topical pesticides or vigorous washes may not penetrate the tight folds of buds to remove or exterminate the thrips. Thrips rely upon their host plant for a controlled environment providing moisture and nutrients, remaining insulated against even some extremes of temperature. More severe mechanisms to kill the thrips might also damage or destroy the host, thereby reducing its economic value.

The mechanisms by which an organism achieves dispersal are important to the evolutionary success of any species (Nathan 2001, Nathan et al. 2003), but are particularly important to an invasive species seeking to establish itself in a new environment. Thrips are capable fliers (Ellington 1980), but usually rely on their wings to carry them in directed flight

only over short distances. More recent research has suggested that their wings play a stronger role in local dispersal than in long-distance dispersal (Rhainds et al. 2005).

Thrips' low mass and the high surface area created by their fringed wings allows them to be caught and carried by the wind over great distances through the upper atmosphere by the rise and fall of daily convection currents (Lewis 1973). Collection experiments conducted during the 1930s using sticky-traps mounted on airplanes found that thrips occupied a significant proportion of the "aeroplankton" (Glick 1939). It is believed that this is the normal mechanism by which thrips achieve long-distance dispersal without human intermediaries, and populations of *S. dorsalis* found in St. Vincent (Seal et al. 2006a) appear to support this model. Within a large plot, Seal et al. observed aggregated population clusters randomly distributed through the field, suggesting an initially random colonization event within the crop followed by gradual growth and expansion to proximate hosts. Within-plot dispersal presents an interesting avenue of research, for the mechanisms which drive dispersal may provide either mechanisms for control or the ability to anticipate the direction or rate at which the invasion will proceed.

Outbreak and Establishment

Thrips populations will occasionally explode into outbreak status, increasing their potential for economic damage. The causes driving these outbreaks are unknown, but they follow an established pattern for phytophagous insects (Mattson and Haack 1987b, a). Thrips outbreaks are usually reported in conjunction with a season of drought (Schultz 1989, Wheatley et al. 1989, Irwin 1991), or recognized with the observation of tospovirus symptoms in a crop. Sensitivity to population density (Rhainds et al. 2005) and intraspecific competition may be increased by conditions affecting host quality, resulting in mass-dispersal to relieve population pressures.

It may be that lowered host-quality triggers conditions for dispersal and outbreak in thrips. There is some evidence supporting this hypothesis in *S. dorsalis*. When Shibao et al. (1993)

physically removed the apical buds of grape plants; they observed increased flight and dispersal of thrips as well as a reduced density of those thrips still feeding on plants within the plot.

Invasive organisms may also only achieve outbreak status outside of their native range. In moving to a new environment, they may no longer be restricted or restrained by their competitors or predators, and may no longer be facing hosts which have evolved defenses specific to their feeding (Hoddle et al. 2002).

As thrips are parthenogenetic insects with a high generation rate, even individuals can potentially establish a successful colony. While it is highly unlikely that a large number of thrips would successfully avoid inspection and control measures at ports, there is experimental evidence demonstrating that a self-sustaining population of thrips can be established with only a few individuals. When *Sericothrips staphylinus* was intentionally released to control *Ulex europaeus* L. (gorse) in New Zealand, it was observed that many small releases of less than a hundred thrips were more likely to establish a stable breeding population than single large releases of a thousand or more thrips (Memmott et al. 1997).

This repetitive release of small populations simulated regular commerce with an infected area, and implies that unless an invasive population is controlled and eliminated at the source, a foothold will eventually be established in any favorable environment (Zaman and Maiti 1994). Additionally, while parthenogenesis might limit the initial genetic diversity of any invading population and retard that population's ability to develop resistance to novel control measures, repeated infection from a source population will provide some form of gene flow and increase the potential to establish resistance (Morse and Hoddle 2006).

History of Expansion

The expansion of *S. dorsalis* has been fairly typical for an invasive thrips. It spread rapidly throughout the contiguous region of southeastern Asia fairly early, and there are many historical

instances of this thrips attacking key crops on a regular basis. In India, it has been described as a pest of *Ricinus communis* L. (castor) (Raizada 1965), *Capsicum* spp. L. (pepper) (Varadharajan and Veeravel 1995), *Gossypium* spp. L. (cotton) (Panickar and Patel 2001), *Camellia* spp. L. (tea) (Dev 1964, Mukhopadhyay et al. 1997), *Mangifera* spp. L. (mango), and *Arachis hypogaea* L. (peanut) (Wheatley et al. 1989). Outside of India, it has been reported as a pest in China on tea and *Litchi chinensis* Sonn. (litchi) (Li et al. 2004), in Taiwan on citrus and vegetable (Chang 1995), on citrus and tea in Japan (Okada and Kudo 1982b, Tataru and Furuhashi 1992), many vegetable and fruit crops in Thailand (Bansiddhi and Poonchaisri 1995), peppers and mango in Vietnam, and even seasonally on the Korean peninsula (Lee et al. 2001).

Under the pressures of globalization and trade, this thrips has expanded its range greatly, and EPPO (1997) recognized this pest as one with significant potential for global expansion. By that point it had already become fairly established beyond its precinctive range, had been intercepted at South African ports in 1986 (Gilbert), noted as a pest in Kenya by 1997 (Lewis), and infesting cotton in Côte d'Ivoire by 1999 (Bournier). It was described as a pest in Australia on *Anacardium occidentale* L. (cashew) in 1998 (Peng et al. 2004), and on *Fragaria x annanasa* Duchesne (strawberry) and tea only a few years later (Hoddle and Mound 2003, Chin et al. 2007). By 2001, it had been detected in Egypt, and in 2003 it was found in Israel (EPPO 2003).

It was only a matter of time before *S. dorsalis* was intercepted in the United States and the Caribbean region. While the thrips had been reported from port interceptions in Florida in 1995 and in Texas in 2000, surveys failed to detect any established populations or other sightings of the thrips (Skarlinsky 2003, Silagyi and Dixon 2006). However, interceptions of this insect at a Miami port under the calyces of pepper from St. Vincent in 2003 (Skarlinsky) inspired the USDA to act in order to predict and prevent the pest's arrival (Meissner et al. 2005). The USDA

APHIS and the University of Florida responded with investigations of Caribbean islands (Seal and Ciomperlik 2004, Seal et al. 2006a). They found the pest already distributed throughout the Caribbean, and speculated that it had almost certainly already spread throughout South and Central America (Klassen et al. 2008).

In late 2005, *S. dorsalis* was reported as a significant pest on Palm Beach County ornamental roses in Florida, and reports from other counties of the thrips infesting the Knock Out® cultivar of rose and pepper rapidly followed thereafter (Silagyi and Dixon 2006). By January of 2007, the thrips had been found in more than thirty counties from Alachua to Monroe, and has been detected in southern Georgia (Diffie et al. 2008). It has been spotted several times on retail roses in south Texas, and anecdotal evidence suggests that the expansion into Texas counties is probably greatly underreported (Ludwig 2008). Models of climatological and host potential suggest that this thrips has the potential to expand its range to cover much of the southeast, the Gulf coast region, and the western coast of the United States (Venette and Davis 2004, Nietschke et al. 2008).

Economic Impact

Nationally, horticulture is a \$16.5 billion industry, and Florida is the nation's second largest contributor, adding \$1.6 billion to the national economy last year (Jerado 2006). Among the largest of Florida's contributions are the ornamental and cut-flower industries, which provided nearly a billion dollars in sales during 2006. This industry has grown and slowed in step with the housing and development boom, following trends in disposable household income (Jerado 2006). Peppers, strawberries, cucumbers, cotton, and peanuts add another \$483.5 million in vegetable crops to Florida's economy. All of these crops have the potential to serve as hosts to *S. dorsalis*, and losing even ten percent of these industries would prove catastrophic to the national economy, as well as open the market to foreign competition.

Prolonged feeding by thrips curls tender leaves and buds, and will turn fruits and flowers from bronze to black in color, rendering the plant material unmarketable. Feeding on young tissue stunts further growth, and may induce abortion of fruit (Lewis 1997). Even damaged or scarred vegetables or inflorescences are viewed as unmarketable. When thrips feed in high densities, or in sufficiently dry climates, this process can result in the eventual desiccation and death of their host plant. Even low densities of thrips can contribute to the decline in fruit production and plant health, especially during times of drought (Kolb et al. 1991, Fournier et al. 1995).

At least ten species of thrips belonging to family Thripidae including *S. dorsalis* have been confirmed as vectors for the transmission of thirteen or more tospoviruses (Jones 2005), further emphasizing the value of studying this group (Mound 2002, Sakurai et al. 2002). Tospoviruses are negative RNA viruses in the family *Bunyaviridae*. Infection with the virus results in spotting and wilting of the plant, reduced output, and occasionally death. Even at a low density, thrips can transmit the virus and cause mortality out of proportion to their actual feeding damage. They may infect a broad spectrum of plants with thrips as a common vector, leaping from vegetable to ornamental crops (Chatzivassiliou et al. 2000). The thrips vectors are not closely related, implying an independent origin of infection for each thrips (Mound 2002), possibly transmitted horizontally through shared hosts. There may be other species of thrips competent to transmit similar viruses, but they have not been observed on crops of economic significance.

S. dorsalis has been implicated in the transmission of several separate tospovirus (Whitfield et al. 2005), as seen in (Table 1-2). However, recent experiments have cast some doubt on the efficiency at which *S. dorsalis* actually transmits the virus to its hosts. It may be a

member of a class that Nagata et al. (2002) described in a near relative, *Thrips palmi* Karny: an infected non-transmitter with detectable levels of virus.

Morphology and Classification

The Thysanoptera were first described in 1744 as a genus *Physapus* by DeGreer, and then renamed *Thrips* by Linnaeus in 1758. In 1836, Haliday promoted the genus to the rank of order, and named them Thysanoptera after their distinct ciliated wings. The order is currently divided into two suborders: the Terebrantia, and the Tubulifera. Tubulifera can be identified by their characteristic tube-shaped apical abdominal segment, whereas females of the eight families of the Terebrantia all possess the eponymous saw-like ovipositor on the antepical abdominal segment. Of the eight families of Terebrantia, family Thripidae is the most species-rich, with over 290 genera representing just over two thousand species (Mound 2002). Thripidae are considered to be among the more derived of thrips, having evolved many traits key to specializing as cryptophilous phytovores, living in the narrow spaces at the bases of leaves and within florescences (Gentile and Bailey 1968, Lewis 1973, Mound 1998).

Adult *S. dorsalis* can usually be distinguished from other thrips collected in a South Florida sample by its small size, yellow coloration, and a dark transverse ridge on the lower abdominal tergites (Seal et al. 2006a). It can be specifically identified and confirmed through the presence of forked sense cones on antennal segments III and IV, antennomeres I-II are pale and III to IX are dark; there are three discal setae on the lateral margins of abdominal tergites, with pronotal posteromarginal seta II nearly one and a half times the length of I or III, a complete posteromarginal comb on tergite VII; and three ocellar setae with III between posterior ocelli (Mound and Palmer 1981, Hoddle and Mound 2003, Skarlinsky 2004). Thus far, all observed populations within Florida meet this description (GB Edwards, personal communication).

Ecology and Behavior

Thrips are believed to have descended from a mycetophilic ancestor during the Mesozoic (Grimaldi et al. 2004), and many groups still feed upon and inadvertently redistribute fungal spores, but most research has focused on those species feeding on or in association with economically significant crops. Some thrips are predatory, but the majority are phytophagous insects feeding on pollen and the chloroplasts harvested from the outer layer of plant epidermal and mesophyll cells (Heming 1993, Kirk 1995). These species are small cryptophilic organisms that prefer to feed within the tightly packed apical buds of new growth.

Flower-feeding thrips may be responsible for pollination while feeding (Sakai 2001), and *S. dorsalis* has been documented as a pollination vector encouraging gene flow for pepper plants in the field (Saxena et al. 1996), but their most significant contribution remains the defoliation they can cause during years of outbreak. Feeding usually occurs along the main vein or ribs of leaves and petals (Lewis 1973, 1997). The feeding damage of *S. dorsalis* is distinctive, and in some cases may be considered diagnostic of the pest (EPPO 2005). Feeding damage for *S. dorsalis* leaves bronzed scars on the petals, leaves, and surface of fruits (Asaf-Ali et al. 1973, Tataru and Furuhashi 1992, Shibao 1996a, Chandrasekaran 2005). This damage is frequently described as greater than an infestation by other thrips. Some researchers suggest that a protease in the saliva may be responsible for the additional damage (Dev 1964, Raizada 1965).

S. dorsalis is often found in the flowers and terminal shoots of vegetables and ornamental plants (Shibao et al. 1993), and will feed upon pollen (Saxena et al. 1996). Some authors suggest that it is primarily a foliar thrips, but many authors have observed feeding in floral structures. Saxena et al. (1996) demonstrated that in an olfactometer test, a greater number of *S. dorsalis* were attracted to scents of pollen than to nectar or plant-tissue.

Like many thrips, *S. dorsalis* appears to prefer feeding on new growth and young plants (Dev 1964, Shibao et al. 1990, Seal et al. 2006a), and is often found on the newer abaxial surface of leaves on smaller plants. Physically manipulating the host by removing preferred feeding sites has been shown to reduce thrips density on the plant, but also to increase the relative rate of between-plot dispersal (Shibao et al. 1993).

Family Thripidae is particularly notorious for members with broad host ranges, and the majority of pest thrips come from this family (Bailey 1940, Ananthkrishnan 1993). Feeding by *S. dorsalis* has been described on over a hundred species of plants representing over forty separate families, and new hosts are being identified as the creature expands into Florida's environment (Silagyi and Dixon 2006).

Many of the hosts identified for *S. dorsalis* have been common agricultural crops and ornamental plants, but these should not be thought of as the limits of the organism's host range, as these records may represent an error of observation. Many pest organisms are only reported when a commodity is scrutinized on a regular basis, or when feeding damage on a particular host increases to noticeable levels. Other hosts of less economic value may go underreported and serve as a reservoir for establishing an invasive species.

Historically, *S. dorsalis* has not been documented on all possible hosts across its global range, and the population density of the thrips on the same species of host may be very different in geographically disparate environments (Hoddle and Mound 2003). As an example, in spite of the availability of citrus hosts throughout *S. dorsalis*' range, it has only been described as a significant pest on citrus in Taiwan (Chang 1995), Japan (Tatara and Furuhashi 1992), and Thailand (Bansiddhi and Poonchaisri 1995). More recently, this thrips has been observed as a possible pest on mango in Puerto Rico, but not in nearby Florida (Klassen et al. 2008). This

regional variation may be due to variation in abiotic conditions, competition with established herbivore and predator communities, the availability of a given host in an area, or different standards for local IPM. An alternative hypothesis is offered by Hoddle et al (2008), who provide strong evidence that *S. dorsalis* may represent a cryptic species complex. Regional populations of this thrips may be locally adapted, and therefore present slightly different host profiles.

It is also possible that the stated number of hosts actually overestimates the host range of this thrips. Due to their small size and broad dispersal the misidentification and synonymy of insect samples are problems frequently encountered in the literature of Thysanoptera (Mound and Palmer 1981, Mound and zur Strassen 2001, Diffie et al. 2008). Samples are frequently collected from plants where adults may be feeding, but upon which the insect may be incapable of completing development (Ananthakrishnan 1993). Masui observed many adult *S. dorsalis* feeding upon citrus, but found significantly lower numbers of nymphs on citrus relative to other nearby hosts (2007b). These results, and others like it, lead some authors to suggest that this discrepancy could be resolved by specifying whether the strength of the host-association in the literature was for a “feeding” or “reproductive” host.

While host selection is usually dependent on many stimuli, the factors leading to thrips attraction are poorly understood, and are frequently species-specific (Jan de Kogel and Koschier 2002). Many leaf and flower-feeding insects have been selected to identify their prey through visual cues (Lewis and Taylor 1964), with a species-specific response to lighting stimuli of various wavelengths (Lewis 1973). *S. dorsalis* is no exception, and there is considerable evidence demonstrating that it does rely upon visual stimuli to identify hosts. Studies with chili peppers demonstrated that morphological characters of plants, including height, leaf size, petiole

length, and leaf internode distance can have an impact on populations of *S. dorsalis* (Pramanick and Mohasin 2004). Experiments conducted by Shibao (1996b) and Mochizuki and Honma (2001) have shown that screens or mulches reflecting light in the ultraviolet spectrum can be used to effectively reduce seasonal populations of *S. dorsalis*. Larger numbers of *S. dorsalis* adults are captured on yellow (Tsuchiya et al. 1995, Chu et al. 2006) or yellow and green (Tsuchiya et al. 1995) sticky traps. This appears to conflict with the findings of Rani and Sridhar (2003) and Gahukar (2003), in which more adults of *S. dorsalis* were recovered on red or orange rose petals than yellow ones in a small arena choice-test. Saxena et al. (1996) noted more adults of *S. dorsalis* were captured on white traps than on yellow, red, green, blue, or black colored traps placed in a pepper field. All of these results may be true at different spatial scales, with *S. dorsalis* relying on different cues to identify and select hosts at different distances. Both Rani and Sridhar and Gahukar's choice-tests occurred in small arenas within the lab, whereas the other tests were performed in the field. Saxena et al. speculate that their results may show an ability of the thrips to identify the contrast of brighter flowers against the darker background foliage, while Tsuchiya and Chu suggest that their results may be similar to the coloration of younger foliage - this thrips' preferred feeding location. These general cues would be valuable to a thrips descending from great distance.

The components used in host selection are probably not exclusively visual, and this may help to explain the apparently contradictory results of Rani and Sridhar to Gahukar's findings. *Scirtothrips dorsalis* may have been attracted to the scent of rose petals as well as to color, and volatile chemical compounds may be of greater importance to local dispersal. While poorly documented, chemical communication is believed to be important to the group (Blum 1991). Anal secretions are produced in the hindgut (Howard et al. 1983), and released along the

posterior setae as predator deterrents (Lewis 1973, Howard et al. 1983, Tschuch et al. 2002) in some thrips, and elements such as floral scent may play a role in host identification. Volatile compounds released by plants during thrips feeding have been documented to act both as an aggregation kairomone (Ananthakrishnan 1993), and as a deterrent (Delphia et al. 2007). Saxena et al. also demonstrated that in an olfactometer choice-test, a greater number of *S. dorsalis* were attracted to scents of pollen than nectar or plant tissue.

Host selection is important to the thrips, as host characteristics may impact developmental time. Shibao observed 294.1 degree-days on *Vitis vinifera* L. (grape) (1996c), while Tatara recorded 265 degree-days on *Citrus reticulata* Blanco (mandarin orange) (1994), and Raizada (1965) documented 267 degree-days on castor. At the other extreme, Dũng (2005) found only 188 degree days were required for full development on *Citrus*. Over the last thirty years, authors have generally observed at least one peak period of growth in mid-summer (Raizada 1965, Okada and Kudo 1982b, Shibao et al. 1990, Shibao 1996a, Mukhopadhyay et al. 1997, Duraimurugan and Jagadish 2002, Shibao et al. 2004, Masui 2007a) after approximately sixty to ninety degree-days had passed, with further peaks every three hundred additional degree days (Tatara 1994, Shibao 1996c). Some researchers have observed a second population peak occurring in late fall (Raizada 1965, Okada and Kudo 1982b, Shibao 1996b, Paul and Konar 2005). The developmental rate observed increases linear to temperature (Tatara 1994, Varadharajan and Veeravel 1995, Saxena et al. 1996, Shibao 1996c, Paul and Konar 2005) and the number of sunlit hours in a day (Saxena et al. 1996, Gahukar 2003, Paul and Konar 2005), and *S. dorsalis* development continues between critical thresholds of 9.7° - 32°C, with an ideal generation rate of fifteen days at 25C (Tatara 1994, Shibao 1996c).

Negative linear correlations have been observed with increasing humidity (Varadharajan and Veeravel 1995, Saxena et al. 1996, Lingeri et al. 1998, Paul and Konar 2005) and rainfall (Lewis 1973, Varadharajan and Veeravel 1995, Saxena et al. 1996, Lewis 1997, Lingeri et al. 1998, Paul and Konar 2005, Singh 2005). At least one researcher has described a positive correlation to increasing humidity (Singh 2005), but his observations were made at a lower relative humidity than other researchers cited, and may suggest a lower threshold for humidity beyond which desiccation afflicts the small soft-bodied insect. All researchers generally suggest that hot and dry conditions with low intensity rainfall promote the best population growth for this thrips. It is speculated that this is because hard rain will wash adults and nymphs from the leaves to the ground, where many of them will not return successfully to their host plant for feeding after falling (Lewis 1997).

Like all Terebrantia, *S. dorsalis* undergoes two nymphal stages followed by two pupal stages (Dev 1964), but research has shown that length of these life-history stages are flexible within a group depending on an individual's access to nutrients (Mound 2005) and temperature (Tatara 1994). Nymphs begin the metamorphic process by dropping off of the plant, and tend to pupate in loose soil or leaf litter at the base of their host, but have been observed to pupate in any dark and humid crevice low on the plant, including bark and lower leaves (Okada et al. 1981) or flowers. The pupal process can range from two days to a full week (Tatara 1994). In temperate regions where the temperature falls below the critical lower threshold, non-diapausing adults are reported to overwinter in the soil or apical buds (Okada and Kudo 1982a, b, Shibao et al. 1990). Colder temperatures may drive pupation, but this has not been experimentally confirmed (personal observation).

Adults begin to emerge again in early summer in Japan (Shibao 1996c, Shibao et al. 2004), and it is believed that the greatest dispersal and distance propagation occurs during the emergence post-pupation immediately following winter (Masui 2007b). Six flight peaks have been observed in Japan (Masui 2007a, b), and three peaks in India (Varadharajan and Veeravel 1995), running from early summer to late fall. These flight peaks do not necessarily correlate to population densities or abundances on plant, suggesting that dispersal behavior is not linked exclusively to population density (Shibao 1996c). However, some authors have noted that when generations are tracked, flight peaks do tend to occur after populations have built up to peak densities on hosts (Masui 2007a, b), and it is possible that Shibao's results are caused by overlapping generations in the field.

Post-emergence, females have a pre-oviposition period of one to two days (Tatara 1994). Using their ovipositor, females lay single eggs within the plant tissue (Lewis 1973), and lay an average of forty eggs during their lifetime (Tatara 1994). Females of *S. dorsalis* prefer to lay their eggs inside of young leaves and buds at the apical meristem of plants, but as populations increase, will lay their eggs within the surface of mature leaves (Dev 1964, Raizada 1965). Depending on temperature, eggs may gestate for one to three weeks (Tatara 1994). After hatching, nymphs will migrate from older leaves to the newer growth at terminals (Onkarappa and Mallik 1998). *S. dorsalis* is often found feeding in the newer growth and top leaves of younger plants (Dev 1964, Shibao et al. 1990, Seal et al. 2006a), although individual plant morphology and chemistry may result in some distributional differences (Shibao et al. 1990). Nymph populations will continue to increase so long as new shoots are allowed to grow (Shibao et al. 1993), and adults are permitted to land (Shibao 1996b).

Integrated Pest Management Strategies for *Scirtothrips dorsalis*

As thrips are a significant global pest for greenhouse and field producers, there is already considerable authoritative literature recommending generic management strategies that could be applied to most species of thrips. As *S. dorsalis* has been a pest for some time in India and East Asia, there is already a quantity of literature specific to this species that suggests several strategies by which this thrips might be managed in Florida and the United States.

Detection and Sampling

The feeding damage of established thrips populations are usually the first sign of their presence (Lewis 1981). The feeding damage of *S. dorsalis* is distinctive, even among thrips, and in some cases may be considered diagnostic of the pest (EPPO 2005). This damage may appear superficially similar to spider-mite damage, but it can be distinguished from mites and other thrips by the characteristic bronzed scars and stippling on the petals, leaves, and surface of fruits (Asaf-Ali et al. 1973, Tatara and Furuhashi 1992, Shibao 1996a, Chandrasekaran 2005). Concerned growers should look for flowers with small spots or blemishes, wrinkled and shriveled petals, or curled, wrinkled and dry new growth (Duraimurugan and Jagadish 2004b). If the infestation has proceeded long enough, there should be stippled scarring on the abaxial leaf surface. With sufficiently large populations, exuviae may be present on the lower leaf surface. These cast skins are distinct and can be distinguished from those of aphids.

Once active populations have been identified, plant populations can be estimated by sampling a number of flowers appropriate to the size of the plot (Lewis 1981, Casey et al. 2007). Remove the infested flower or leaf, rinse it in a solution of 75% ethanol, and pour the runoff through a sieve with a 25 μm grating (Seal and Baranowski 1993). The number, stage, and sex of thrips counted can be given a preliminary field identification under a dissection scope at a minimum of 12x magnification (Seal et al. 2006a, Funderburk et al. 2007), but slides should

quickly be prepared using the methods of Bisevac (1997) for a detailed examination and species confirmation at 200x magnification (Moritz et al. 2001, Moritz et al. 2004, Seal and Ciomperlik 2004).

To detect adult populations before they become established and damage becomes visible, it has been recommended to hang one sticky card at flower height per thousand square feet of residential landscape, or one per ten thousand square feet if a commercial grower (Lewis 1981, Casey et al. 2007). Historically, sticky traps have been valuable tools used to accurately predict on-plant population estimates of thrips in the field (Pearsall and Myers 2000b, a, Rhains and Shipp 2003, Rhains et al. 2005), and have been used to successfully predict populations of *S. dorsalis* on nearby plant hosts (Shibao et al. 1990). Research suggests that either yellow (Tsuchiya et al. 1995, Chu et al. 2006) or yellow and green (Tsuchiya et al. 1995) sticky traps are most preferred by this thrips. Casey et al. (2007) recommend a generalized damage threshold of twenty-five to fifty thrips per sticky-trap, or less than two thrips per bud in order to maintain flower production, but some authors (Shibao et al. 2004, Seal et al. 2006a, Shibao et al. 2006) suggest that lower numbers of *S. dorsalis* are recommended for successful agricultural or ornamental plant production.

Mechanical Controls

Before attempting other measures, certain mechanical processes may be changed in order to discourage or eliminate the thrips. While potentially labour-intensive, these changes may be among the most cost-effective and least damaging to the surrounding environment.

As *S. dorsalis* lay the majority of their eggs in the fresh flush of new growth and the opening buds of flowers (Onkarappa and Mallik 1998, Duraimurugan and Jagadish 2004b), Shibao et al (1993) demonstrated that the adult population density in a field of grape could be reduced by removing the flowers and growth terminals of nearby alternate hosts. It has also been

suggested that as with other thrips, regular pruning of older leaves and sweeping the leaf litter beneath infested plants may reduce the number of eggs and pupae (Lewis 1973, 1997).

Duraimurugan and Jagadhish demonstrated the effectiveness of this technique in rose, showing a reduction in nymph and adult populations, and a reduction in feeding damage (2004a).

Alternatively, regular streams of high-pressure water simulating heavy rains may be used to reduce thrips populations by washing away nymphal thrips or by disturbing adults (Lewis 1973), but this technique may not be dependable. Schuch et al. observed that while this technique reduced adult numbers of *Frankliniella* sp., it was not as effective against nymphs who may have found hiding spaces on the plant (Schuch et al. 1998).

Caging plants may prove effective as a physical barrier, but using an ultraviolet (UV) reflective tarp has an additional effect. The UV reflective barrier reduces the number of adult *S. dorsalis* landing on grape, and thereby the number of nymphs produced (Shibao 1996b). While the screening may block some landings, the reflection of UV light is presumed to play an additional role by interfering with the thrips' ability to locate hosts. UV-reflective mulch was also observed to reduce *S. dorsalis* feeding damage on tea by as much as eighty percent (Mochizuki and Honma 2001).

Cultural Controls

Changing human behavior can be a key component to controlling outbreaks of any arthropod pest. Growers should do their best to inspect all plants for thrips before transporting them into an area where the thrips might expand. Ideally, one should keep plants in a quarantine area for up to two weeks, as this should allow sufficient time for *S. dorsalis*' rapid life cycle to force it to reveal itself (Lewis 1981). Removing alternate hosts from nearby a production area may also provide a control mechanism (Lewis 1973, Shibao et al. 1993), as hidden populations of *S. dorsalis* may migrate from these alternative hosts to a preferred host (Masui 2007b).

Temporally shifting plantings of agricultural crops may not prove an effective strategy against this thrips, as the peak growth season for many of these crops may also be most adventitious to this thrips, and its broad host range should allow it some refuge. This strategy may also prove ineffective to ornamental plant hosts for similar reasons, as the host range of this thrips includes many perennials, and it would be difficult to eradicate it from all potential hosts in an environment. A more compelling management technique would be to develop, discover, or plant existing strains of commercially available crops that are naturally resistant to this thrips.

Resistance can be defined as “all plant responses resulting in the ability to withstand infestation, and to support insect populations that would severely damage susceptible plants” (Horber 1980), and it comes in many forms. Xenobiosis excludes pests by discouraging feeding through physical or chemical barriers. Tolerance can be described as an elevated pest-threshold before a plant begins to show additional damage when compared to a susceptible plant (Fery and Schalk 1991). Several varieties of plant have already been screened for resistance to *S. dorsalis*, including peanut (Ekvised et al. 2006), pepper (Krishna Kumar et al. 1996, Pramanick and Mohasin 2004), and rose (Onkarappa and Mallik 1998, Gahukar 2003, Rani and Sridhar 2003).

An increase in the concentration of free amino acids in plant tissues has also been shown to attract pest insects (Slansky and Rodriguez 1987), and adding nitrogen-based fertilizers to a plant will also allow for a higher growth rate for feeding insects (Mattson 1980). This trend holds true for the Thysanoptera, with elevated concentrations of fertilizer resulting in a higher growth rate of *Frankliniella occidentalis* (Chau et al. 2005), but this process will be mediated by the endogenous resistant factors produced by specialized cultivars (Schuch et al. 1998) or by particular hosts (Reitz 2002). Duraimurugan and Jagadish (2004a) observed increasingly higher populations of *S. dorsalis* on rose fertilized with 15 grams of nitrogen. Varghese and Giraddi

(2005) recommended halving the fertilizer used on chili in conjunction with azadirachtin when controlling for *S. dorsalis*. While nitrogen levels are important, the work of Abro et al. (2004) in cotton suggests that controlling other micronutrients may not significantly affect *S. dorsalis* populations.

Chemical Controls

While insecticides are among the fastest and most effective methods by which to deal with a pest, they are not always the first solution selected for pest-management. Off-target environmental contamination and resistance should always be considered before application. The evolution of pesticide resistance is of particular importance to thrips, due to their high generation rate, and the ability of an individual resistant female to parthenogenetically reproduce and replace a population.

The Rutgers IR-4 (Palmer and Veal 2008) and Seal et al. (Seal et al. 2006b) studies currently provide the most exhaustive and recent tests for insecticide efficacy against *S. dorsalis* on several ornamental and vegetable hosts. While many of the compounds tested demonstrate success in controlling thrips populations, chlorfenapyr, spinosad, imidacloprid, and azadirachtin appear to be the most effective pesticides at suppressing populations of *S. dorsalis*. Permethrin has also been used effectively on citrus (Shibao 1997b), and Nair et al. recommend dimethoate and phosphamidon at 0.05% as the most effective on rose (1991).

Traditional methods, such as ground neem seeds, have also proven effective in controlling *S. dorsalis* on chili (Varghese and Giraddi 2005, George and Giraddi 2007). A solution of macerated Lepidopteran larvae has been shown to induce volatile compounds that deter other Thysanoptera (Delphia et al. 2007), and might also prove effective against *S. dorsalis*. Resistance to these pesticides and methods has yet to be documented in the literature, but such a possibility remains a significant concern.

The application of a systemic pesticide such as imidacloprid to seed or young plants early in development is critical to preventing or stopping an attack that will overwhelm their defenses and destroy a crop (Kannan et al. 2004). Control of *S. dorsalis* on mature plants can be achieved using an evenly applied foliar spray of a contact insecticide, but this topical application may miss some members of the population feeding within closed buds or unfurling leaves. As *S. dorsalis* are cryptophilic, systemic formulations with high penetration are critical to controlling this pest.

Classical Biological Control

Invasive species can potentially avoid accumulating a high predator load in a new environment, as local predators may have yet to adapt to the behaviors and chemical signals that signify a new prey resource to exploit. In some situations, an invading species may demonstrate greater fitness in their adventive environment when compared to their precinctive populations of origin. This “predator free space” may last as long as ten years, and may grant invasive species the competitive advantage they need to outperform established competitors using similar resources (Cornell and Hawkins 1994).

The class of predators most likely to accumulate on invasive species early in their expansion is a generalist (Cornell and Hawkins 1994). These are polyphagous predatory organisms that will utilize any organism that falls within their foraging strategy as a food resource. As thrips appear to have operated under selection favoring small size and cryptophilic behavior within the tight confines of early plant growth, they represent a difficult prey item to exploit, and have accumulated few specialist predators (Loomans et al. 1997). As most of the pest-thrips have such broad global ranges, it has been difficult to find a precinctive range where native specialist predators might control their growth (Loomans 2003). As a result, generalist predators that specialize in thrips are usually selected as the most promising option for long-term suppression of many thrips species (Funderburk et al. 2000, Loomans 2003). Some research has

already looked at the effectiveness of several generalist predators in suppressing populations of *S. dorsalis*.

The Hymenopteran egg-parasitoid, *Megaphragma* (Hymenoptera: Trichogrammatidae) could repress populations of *S. dorsalis* when released in sufficient quantities (Takanashi et al. 1996), sometimes parasitizing as much as fifty-one percent of all host eggs, but proved seasonally incompatible (Shibao et al. 2000). The Trichogrammatids never established themselves during periods of peak thrips population growth, and were rejected as a control mechanism in Japan. It remains possible that these wasps would prove more effective in an environment where its time of peak fecundity and activity matched that of the thrips intended as hosts.

One of the most-recommended predators for control of thrips have been bugs of genus *Orius* (Hemiptera: Anthocoridae) (Funderburk et al. 2000). These insects can be mass-reared commercially, and provide an inexpensive and potentially self-sustaining population. They prey primarily upon the nymphs of many species of thrips (Kajita 1986), but will feed opportunistically on other small herbivorous pests, and maintain their populations using pollen as a protein source when prey is not available. However, there remains some concern that *Orius* might ignore *S. dorsalis* in the presence of alternative prey items. This possibility has already been raised by choice tests for *Orius* between the larger and more docile *Frankliniella occidentalis* and the smaller and more mobile *F. bispinosa* (Reitz et al. 2006). As *S. dorsalis* is smaller bodied and relatively long-legged thrips (Raizada 1965) noted for its activity (Dev 1964), it is probable that *Orius* might ignore this prey item in favor of less difficult and more rewarding prey, giving this thrips a competitive advantage against other thrips already present in the landscape. This avenue of research merits further investigation, as it is possible that certain

smaller species of *Orius* may engage in niche-specialization, and choose to prey on the smaller thrips.

Phytoseiid mites have also enjoyed great success as a biocontrol of thrips (McMurtry and Croft 1997), although primarily in greenhouses. Shibao et al (2004) demonstrated a proportional increase in predator density of *Euseius sojaensis* in response to an increase in the density of nymphal *S. dorsalis* on grape, but the seasonal growth peak arrived too late in the season to control *S. dorsalis* before damage could occur to host plants. Other species of mite, including *Neoseiulus cucumeris* Oudemans and *Amblyseius swirskii* (Athias-Henriot), have proven effective predator in studies of field and greenhouse vegetables (Arthurs et al 2009).

Thrips of genus *Scolothrips* have been observed feeding on juvenile *S. dorsalis* on castor in India (Dev 1964, Raizada 1965), as have thrips of genus *Franklinothrips*. However, mass rearing of predatory thrips has frequently proved more difficult than encouraging naturally established populations.

In the end, the most effective biocontrol for *S. dorsalis* may prove to be the ubiquitous mycopathogens (Raizada 1976) or a durable strain of nematode (Sims et al. 2005). A sustainable culture of entomopathogenic fungi grown on-plant, such as *Fusarium* (Mikunthan and Manjunatha 2008), might provide enduring protection.

Conclusions

Thrips are a diverse and abundant group of insects whose life histories are relatively understudied, given the significant potential for economic damage that they represent. *Scirtothrips dorsalis* has recently invaded Florida, and presents an excellent opportunity to explore the seasonal population dynamics of this insect. The literature indicates that this thrips demonstrates variable performance on different hosts, but it remains unanswered whether *S. dorsalis* actively selects hosts of higher performance or whether it disperses randomly. A broad

range of host plants in Florida have already been reported with significant damage and large populations of these thrips, but the extent to which certain hosts are susceptible has been poorly documented.

The factors determining the selection and timing of reported outbreaks of *S. dorsalis* are also poorly understood. While the literature suggests that this insect prefers warmer weather with reduced rainfall, the annual population dynamics of this thrips in southern Florida have not yet been documented. Knowledge of this thrips' seasonal performance could be very valuable to the design of a more efficient pest management program, allowing more preventative plans that anticipate periods of peak activity and dispersal.

The conditions leading to outbreak and dispersal among all thrips and herbivorous insects are poorly understood, and using *S. dorsalis* to test hypotheses of dispersal and host selection would be valuable to preparing a control regime for this species, and may provide insight into certain broad questions of thrips ecology.

Table 1-1. *Scirtothrips dorsalis* Hood (1919) was first described on chili peppers in India, and as is common with the order, has since undergone considerable synonymization.

<i>Genus</i>	<i>species</i>	Authority	Year
<i>Scirtothrips</i>	<i>dorsalis</i>	Hood	1919
<i>Heliethrips</i>	<i>minutissimus</i>	Bagnall	1919
<i>Anaphothrips</i>	<i>andreae</i>	Karny	1925
<i>Neophysopus</i>	<i>fragariae</i>	Girault	1927
<i>Scirtothrips</i>	<i>padmae</i>	Ramakrishna	1942

Table 1-2. *Scirtothrips dorsalis* has been implicated in the transmission of several tospoviruses.

Virus	Abbreviation	Reference
Peanut yellow spot virus	PYSV	(Reddy et al. 1991)
Groundnut bud necrosis virus	GBNV	(Reddy et al. 1992)
Peanut chlorotic fanspot virus	PCFV	(Chen and Chiu 1996)
Watermelon silver mottle virus	WSMoV	(Chiemsombat et al. 2008)
Capsicum chlorosis virus	CaCV	(Chiemsombat et al. 2008)
Melon yellow spotted virus	MYSV	(Chiemsombat et al. 2008)

CHAPTER 2

DISPERSAL OF *Scirtothrips dorsalis* HOOD (THYSANOPTERA: THIRIPIDAE) FROM KNOCK OUT ® ‘RADRAZZ’ ROSE TO TWO ALTERNATIVE ORNAMENTAL HOSTS IN SOUTHERN FLORIDA

Introduction

Scirtothrips dorsalis Hood (1919) is a polyphagous insect pest whose global distribution has expanded rapidly over the last twenty years, becoming established in southern and central Florida (Silagyi and Dixon 2006). This insect pest shows considerable potential for expansion into the rest of North America (Venette and Davis 2004, Meissner et al. 2005, Nietschke et al. 2008), and impacts several fruit and vegetable hosts of economic significance, including *Fragaria x annanasa* Duchesne (strawberry), *Mangifera* spp. L. (mango), *Capsicum* spp. L. (pepper), *Citrus* spp. L., *Gossypium* spp. L. (cotton), *Glycine max* (L.) Merr (soybean), and *Arachis hypogaea* L. (peanut). The fruit and vegetable crops potentially affected by this thrips added nearly 1.4 billion dollars to the Florida economy in 2005 (Jerado 2006).

For many hosts, damage from this thrips results in reduced floral and vegetative growth, increased plant stress, scarred foliage, and can result in death (Tatara and Furuhashi 1992, Shibao 1996). Ornamental hosts are particularly sensitive to feeding damage, as even minimal scarring can render a plant unsalable. Among these host plants are popular landscaping plants including *Rosa* spp. L., *Raphiolepis indica* (L.) Lindl. ex Ker Gawl. (Indian hawthorn), *Ligustrum* spp L. (ligustrum), *Conocarpus erectus* var *erectus* L. (‘Green’ buttonwood), and *Schefflera arboricola* Forst & Forst (‘Emerald Green’ schefflera).

Schefflera (‘Emerald Green’) and buttonwood (‘Green’) were identified as ornamental hosts of significance after early reports by nurseries to extension agents in south and central Florida (C. Mannion, personal communication). Both plants are common in southern Florida and have a broad distribution because landscapers make frequent use of both species as hedges or

borders. This practice could permit the thrips a natural corridor for establishment throughout the state (Morse and Hoddle 2006).

As this thrips is a pest for both ornamental and agricultural crops it may develop resistance to commercial pesticides in one area and the resistant strain may spread rapidly to another (Kirk and Terry 2003). Growers and homeowners must simultaneously apply a comprehensive integrated pest management program that incorporates both of their unique environments to prevent the establishment of reservoir populations, or the development of resistance to commercial pesticides. An awareness of the presence of this thrips upon common ornamental plants will be valuable in constructing a part of a fully integrated pest management program.

Environmental cues may also be important to an organism's dispersal behaviors. Natural selection has driven many leaf and flower-feeding insects to identify their host through visual cues, and therefore tend to fly by day (Lewis and Taylor 1964). Daytime flight is not uncommon for thrips, and other flower feeding thrips such as *Frankliniella occidentalis* have been documented as diurnal fliers (Pearsall 2002) with a species-specific response to light of various wavelengths (Lewis 1973). Chu et al. (2006) discovered that yellow sticky traps captured more individuals of *S. dorsalis* than sticky traps of other colors, indicating that this thrips is probably a daytime flier. Seal (personal communication) reported peak flight activity within greenhouses between 1000 and 1400.

Recent research has emphasized the importance of local dispersal to the success of colonization by thrips (Rhainds et al. 2005), and understanding the patterns by which thrips disperse within a plot are key to establishing a successful long-term control strategy (Groves et al. 2003, Nault et al. 2003). An awareness of peak flight activity may allow growers to better target the application of pesticides when thrips populations are at their highest. An improved

understanding of the timing and environmental conditions during which this species of thrips increases flight behaviors may help to predict the overall rate of dispersal for the thrips through the Gulf coast region.

The purpose of this study was to determine the influence of host plant and wind conditions on thrips dispersal. Also observed were the time of day and environmental conditions during which the thrips was most likely to disperse.

Materials and Methods

Dispersal behaviors of *S. dorsalis* were evaluated using rose, schefflera, and buttonwood. Schefflera and buttonwood were grown from cuttings harvested at the University of Florida Tropical Research and Education Center (TREC) campus in Homestead, Florida. Prior to the initiation of the test, all schefflera ('Green Emerald') and buttonwood ('Green') plants were rigorously inspected to be certain that they were clear of thrips. Twelve eight month old Knock Out® 'Radrazz' roses originally purchased from Treemendous Landscapes (Homestead, Florida) were randomly selected from an established research plot heavily infested by *S. dorsalis* (with three *S. dorsalis* per square centimeter in flowers), and placed in an outdoor growing area on the TREC campus. These roses were arranged in four replicates with clusters of three roses whose canopies overlapped per replicate. Each cluster of three rose plants served as a source point for *S. dorsalis* populations by surrounding them with uninfested alternate host plants (schefflera and buttonwood). One schefflera and one buttonwood were placed at each of the cardinal points at a distance of one meter from the roses.

All plants remained exposed to ambient environmental conditions (mean temperature of 80 ± 0.3 °F, mean relative humidity of $78 \pm 0.7\%$) throughout the experiment, and were irrigated with 93 ± 15 mL water using an overhead system running for half an hour at six in the morning and two in the afternoon. All plants were fertilized monthly with an application of 3.96 grams of

liquid fertilizer (Peter's Professional, Scotts Company, Marysville, Ohio) (NH_3 : NO_3 : $(\text{NH}_2)_2\text{CO}$: P_2O_5 : K_2O = 4:6:10:20:20), and 7.5 grams of pellet fertilizer (NH_3 : NO_3 : P_2O_5 : K_2O = 15:9:12) (Osmocote Plus, Scotts Company, Marysville, Ohio) once every other month.

Population Estimates on Two Hosts

Thrips population estimates for buttonwood and schefflera were assessed by randomly sampling one terminal bud from each plant once per week. Plant samples were consistently selected from similar positions within each plant's canopy, and were of similar age and development. All samples were removed with pruning shears and sealed immediately in small plastic containers with two drops of 95% ethanol. Samples that could not immediately be processed were stored at -6°C . The total number and life stages of thrips in a sample was recorded by washing the samples with 75% ethanol and pouring the runoff through a $25\ \mu\text{m}$ mesh, as per Seal and Baranowski (1993), and then examining the collected debris under a dissection scope at a minimum of 12x magnification, with additional magnification and slide-mounting as necessary. The Funderburk et al. (2007) key to species of ornamental thrips was used as a primary aid in identification. *Scirtothrips dorsalis* could rapidly be differentiated from other thrips present in samples by their relative size and other distinguishing characters, including antennal, pronotal, and abdominal characters. Plant samples were then dried overnight and the area of each dried sample was determined using a leaf area meter (LI-3000, LiCor, Lincoln, Nebraska) to determine the density of thrips populations per unit area ($\text{thrips}/\text{cm}^2$).

To develop an estimate of thrips flights among host plants, yellow 7.6×12.7 cm sticky cards were placed on posts six centimeters behind each pot of the schefflera and buttonwood plants. The sticky cards were positioned at one meter in height. Sticky cards were replaced weekly. Cards were removed, wrapped in saran wrap, labeled, and stored at -6°C if they could not be immediately processed.

Plant quality and feeding damage was rated weekly, using a damage scale similar to that described by Krishna Kumar et al. (1996) for pepper. Plants were rated from zero, no symptoms, to five, defoliated. A Florida Automated Weather Network (FAWN, <http://fawn.ifas.ufl.edu/>) located a hundred meters from the research plot was used to collect wind speed and direction data throughout the experiment.

Samples were collected weekly for eleven weeks from 19 July 2007 until 27 September 2007, and voucher specimens were sent to the Florida Department of Plant Industry to confirm species identification throughout the experiment.

Daily Flight Behavior

Daily thrips flight patterns were evaluated in a set of experiments conducted in greenhouses and field plots at TREC and at the University of Florida Mid-Florida Research and Education Center (MREC) in Apopka, Florida. The greenhouse at TREC contained chili pepper and cotton, two key hosts of *S. dorsalis*. New chili peppers were planted and placed within the greenhouse every other week to maintain the colony of thrips. The greenhouse at MREC contained other hosts of the thrips, including *Vaccinium corymbosum* L. (Northern highbush blueberry), cotton, and chili pepper.

Four yellow 7.6x12.7 cm sticky cards were placed in each greenhouse on posts at a meter and a half in height, and within one-half meter of one of the known host plants in the greenhouse. Preliminary experiments (A.I.D., unpublished data) did not detect nighttime flights for this species of thrips, so sticky cards were replaced every hour during daylight, beginning one hour before dawn at six AM and ending one hour after dusk at nine PM. An electronic sensor (HOBO® H8 Pro Series, Onset Computer Corporation, Bourne, MA) recorded temperature and relative humidity in each greenhouse throughout the experiment.

Small field plots of twenty infested Knock Out Rose ® grown in 11.36 liter containers at MREC and TREC were also used in this experiment. Four sticky traps were placed on posts at approximately half a meter in height a third of a meter from the inside corners of each plot. These cards were collected and replaced every hour during daylight, beginning one hour before dawn at six AM, and ending one hour after dusk at nine PM, using a protocol identical to the greenhouse experiment. Collected sticky cards were stored in an identical fashion to the previous experiment, and *S. dorsalis* were identified and counted using the same magnification and keys as in the previous experiment. The FAWN stations were used at both field sites to record environmental variables including temperature, humidity, and wind speed.

Analysis

Analysis for the plant-to-plant movement experiment focused on the number and stage of thrips and the observed feeding damage for each host plant as well as the adult trap catch. A two-way ANOVA was performed to determine if there was interaction between host and direction for all variables tested. Treatments were compared using the ANOVA function of JMP (SAS Institute 2007), and means were separated using Student's *t*-test or Tukey's HSD when sample *n* was not constant for all treatments (due to loss of sticky cards by birds or weather). Degree hours began accumulation at six AM when traps were first placed. Analysis for the daily flight pattern focused on the number and sex of thrips collected each hour. Least square means were used to fit the general linear model and determine a relationship between wind direction and thrips captures.

Results

In the plant-to-plant movement experiment, no significant interaction was observed between host plant and direction of dispersal for any variable tested, including damage rating, the total number of thrips of any instar on plant, thrips density, and the number of thrips captures on sticky traps. The data were pooled for analyses.

Stadia

The number of nymphs on the plants did not vary significantly throughout the experiment, with the exception of the second week of the experiment (25 August 2007), where significantly more nymphs were collected on buttonwood than for all other sample dates ($F = 2.01$; $df = 10, 313$; $p = 0.0321$) (Figure 2-1). The number of adult thrips captured on plants did not vary significantly from week to week ($F = 1.64$, $df = 10, 313$; $p = 0.0951$), but the number of thrips captured on sticky cards varied significantly with time ($F = 9.21$; $df = 10, 274$; $p < 0.0001$). There was no correlation between the number of nymphs or adults captured on the plant and the number of adults captured with flight traps (Figure 2-2).

Host Plant Damage

Although the amount of damage observed on either host plant was very low (< 1), with only minor scarring at the bases of petioles and wrinkled new growth, there was a significantly higher damage rating for schefflera than buttonwood ($t = 1.97$; $df = 350$; $p < 0.0001$) (Figure 2-3). There were no significant differences for total numbers of *S. dorsalis* sampled from the two host plants, but there was a significantly higher density of thrips (thrips/cm²) on schefflera than on buttonwood ($t = 2.03$; $df = 182.6717$; $p < 0.05$) (Figure 2-4), and significantly more adult thrips were captured on sticky traps placed behind buttonwood than behind schefflera ($t = -3.07$; $df = 245.0794$; $p < 0.003$) (Figure 2-5).

Direction

No significant difference was observed for damage rating, total number of thrips, or thrips density on the host plants located in the four cardinal directions from the infested rose plants. However, a significantly larger number of thrips were captured on western sticky cards ($t = 1.97$; $df = 281$; $p < 0.0001$), which are in the direction of the prevailing winds (Figure 2-6). The mean

wind direction was observed from 113 ± 2.18 (MSE) degrees, from east by slightly southeast to the west by slightly northwest.

Daily Flight Behavior

Hourly flight activity was measured in two environments (the field and greenhouse) at two locations in south and central Florida (TREC and MREC). Significant differences were detected between the two locations ($F = 19.36$; $df = 1$; $p < 0.0001$), and between the two environments ($F = 101.53$; $df = 1$; $p < 0.0001$), with a greater number of thrips collected per hour at MREC and in greenhouses. An interaction effect was detected between locations and environment ($F = 19.90$; $df = 1$; $p < 0.0001$), and so each population was considered independently.

There was no significant difference between hourly thrips captures for field data at TREC or MREC ($t = 0.669$; $df = 706$; $p = 0.5035$). However, there was a significant difference in the hourly thrips captures between TREC and MREC greenhouses ($t = -3.17$; $df = 298$; $p = 0.0008$) at ten AM ($t = -2.17$; $df = 18$; $p = 0.0228$) and seven PM ($t = -2.57$; $df = 18$; $p = 0.0097$) (Figure 2-7). At all four sites, there was a rapid increase in captures early in the morning, with peak captures occurring at approximately noon, which then declined to a constant but low number of flights until sunset. Sites differed by what time the daily peak was reached, and the number of thrips captured at each time of day. The greenhouse at MREC and the field site at TREC both reached their peak by ten in the morning, the TREC greenhouse peaked at noon, and the MREC field site peaked at two in the afternoon just prior to daily rainstorms.

The TREC greenhouse site had two percent higher humidity than MREC greenhouse ($t = 2.05$; $df = 278$; $p = 0.0205$) at 75.6%, and was on average four degrees warmer ($t = 5.99$; $df = 278$; $p = 0.0001$) at 86.0 °F. The TREC field site was also four percent more humid than the MREC field site ($t = 3.79$; $df = 690$; $p = 0.0002$) at 76%. Afternoon rainstorms in Apopka

reduced the effectiveness of hourly sampling at MREC, and no thrips were collected during periods of rain.

Temperature was significantly correlated with thrips captures for the TREC field site ($r = 0.67$; $p = 0.0029$), the TREC greenhouse ($r = 0.80$; $p = 0.0002$), and the MREC field site ($r = 0.54$, $p = 0.0205$). Across the range observed, increasing temperatures tended to result in an increase in the mean number of hourly thrips captures. Relative humidity was significantly correlated with thrips captures at the TREC field site ($r = -0.64$; $p = 0.0048$) and greenhouse ($r = -0.80$; $p = 0.0002$). With increasing humidity, less thrips captures were observed. After observing this correlation, flight captures were plotted by degree hours for all four locations (Figure 2-8). Morning flight peaks occurred at all four sites after the accumulation of three to four hundred degree hours. A second peak occurred at the MREC field site after the accumulation of approximately seven hundred degree hours just before a rainstorm.

Discussion

As *S. dorsalis* is a minute insect, it was not surprising that the greatest number of flight captures occurred in the direction of the prevailing winds. Thrips' low mass and the high surface area created by their fringed wings allow them to easily be carried by the winds (Lewis 1973). However, most local dispersal for minute insects occurs within the "boundary layer" near to the ground (Taylor 1974). The plant canopy protects this layer of relatively immobilized air, and small insects may fly short distances through this space undisturbed. Populations of *S. dorsalis* found in St. Vincent (Seal et al. 2006) supported this hypothesis. Within a large plot, researchers observed aggregated population clusters randomly distributed throughout the field, suggesting an initially random colonization event within the crop followed by gradual growth and local expansion to proximate hosts.

The fact that neither host plant received a damage rating greater than one, or a mean abundance greater than two thrips per terminal suggests that these plants may not be key hosts in the preference hierarchy of this thrips when compared to the Knock Out ® rose, which was used as the source point of thrips. This was surprising, given the poor health of heavily infested plant samples of the same species received at extension centers. This discrepancy might be explained by the choice of infested source plants used in this experiment. It is probable that the infested Knock Out ® roses used as a source population are more attractive hosts to *S. dorsalis* than schefflera and buttonwood, and that populations chose to remain on the source host rather than migrate to alternate hosts. It was assumed that as population densities built up on the rose that the thrips would migrate to alternative hosts where there might be less competition or a greater concentration of nutrients. Recent research (A.I.D., unpublished data) suggests that the Knock Out ® rose can support a large infestation of thrips before reaching critical population thresholds that result in plant death and increased dispersal from the host. Higher dispersal rates might have been achieved by reducing the quality of the rose source host. It is also possible that the damaged plant samples received from nurseries were growing in a greenhouse where an enclosed and growing population of thrips had nowhere else to disperse to, or that they had been heavily fertilized to push plant growth, making them a more nutritionally attractive host than tested plants.

In spite of reduced dispersal from the source plants, significant differences remained between the two hosts tested in thrips density, thrips damage, and flight captures. Schefflera had higher damage ratings and thrips densities, but more thrips were captured on sticky traps near the buttonwood than the schefflera. One interpretation of the results might be to suggest that schefflera is a more attractive host to dispersing *S. dorsalis* than buttonwood. The higher thrips

density on schefflera may represent a larger total population on the whole plant. It is also possible that plant architecture has resulted in slightly different captures. The canopy of buttonwood may be looser and allow greater airflow around the host, while the denser canopy of schefflera may act to trap dispersing thrips, as a large hedge used as a windbreak in a crop situation (Lewis 1997). This would also explain the higher numbers on sticky cards behind buttonwood, and the greater density of thrips on the schefflera.

Records of hourly flights at the four test sites have reveals information about the efficacy of sampling methods in different locations and local thrips populations. The greater numbers collected per hour on greenhouse traps was not surprising, given that the thrips within the greenhouse were operating within an enclosed space with a limited volume within which to disperse. These greenhouses also lacked the strong air currents created by wind in the field setting, and as such a larger number of thrips were probably able to land upon and become ensnared by traps. This suggests that the use of sticky traps as a monitoring device in the field by growers is probably less cost effective than in greenhouse environments. To be effective monitoring devices, field traps should probably be exposed for longer periods of time than one hour.

The early morning flight peak followed by a low but continuous number of flights is a pattern common to thrips. Thysanoptera are small poikilothermic insects requiring the accumulation of a certain number of degree hours to heat flight muscles before takeoff (Ellington 1980), and are then carried over a great distance by the rise and fall of daily convection currents (Lewis 1973). It appears that the majority of *S. dorsalis* that take flight do so as soon as they are able, resulting in an increasing number of flights that peak towards the middle of the day, and then a gradual decline in flights as fewer members of the population take flight.

The negative relationship observed between increasing humidity and flight captures may suggest a behavior of flight-avoidance on rainy days. Both rainfall (Lewis 1973, Varadharajan and Veeravel 1995, Saxena et al. 1996, Lewis 1997, Lingeri et al. 1998, Paul and Konar 2005, Singh 2005) and increasing humidity (Varadharajan and Veeravel 1995, Saxena et al. 1996, Lingeri et al. 1998, Paul and Konar 2005) have been documented to reduce the rate of population growth. It is possible that thrips have adapted to avoid flight when environmental conditions are suggestive of approaching rainfall.

This information will be important to continuing an integrated pest management program for this insect. Growers will quarantine plants downwind of their crops, and will be aware to increase their inspections downwind of infested plants. The management community will also be prepared to spray plants either early in the morning or late in the evening before or after the thrips becomes active and might leave the plant long enough to avoid the effective period of the pesticide.

Acknowledgments

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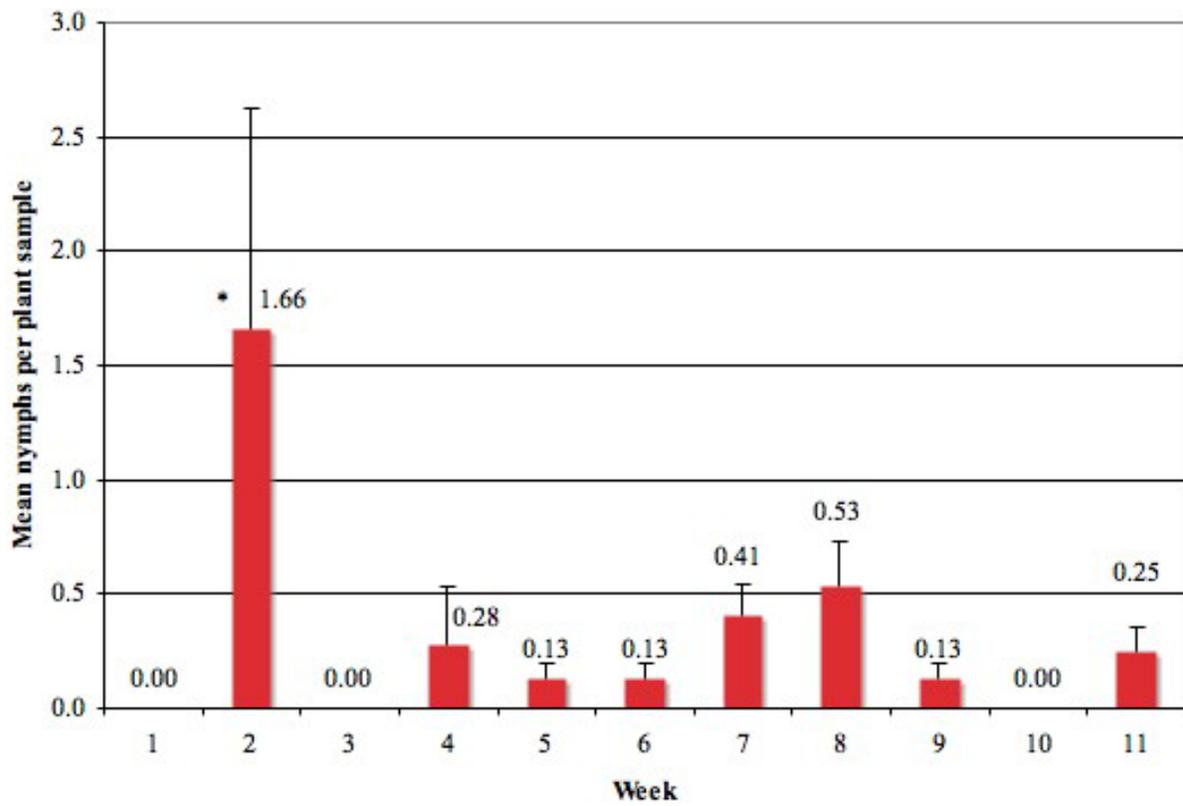


Figure 2-1. Mean weekly *S. dorsalis* nymphs plus standard error on buttonwood foliage (* = significantly different by pairwise *t*-test comparisons at $\alpha = 0.05$).

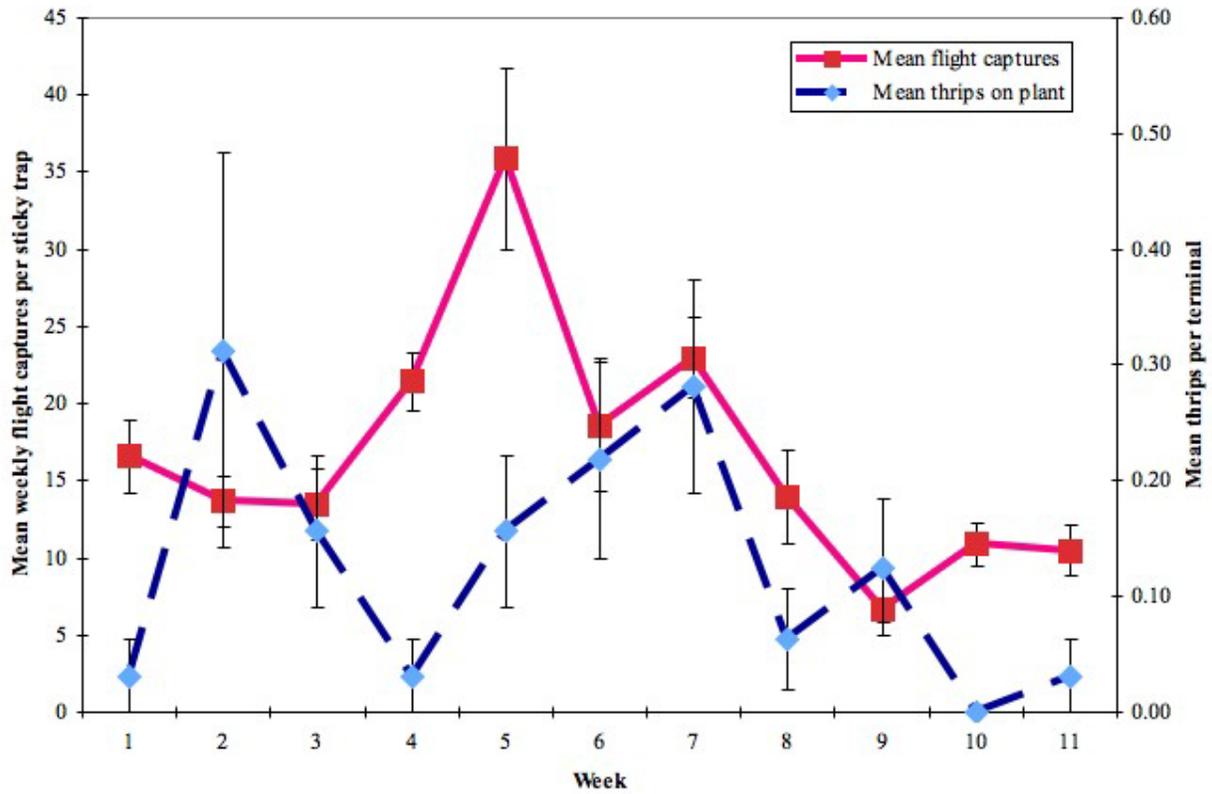


Figure 2-2. Weekly flight captures of *S. dorsalis* plus standard error on sticky cards behind *Conocarpus erectus* and *Schefflera arboricola* and weekly samples of *S. dorsalis* plus standard error washed from plant terminals on both hosts.

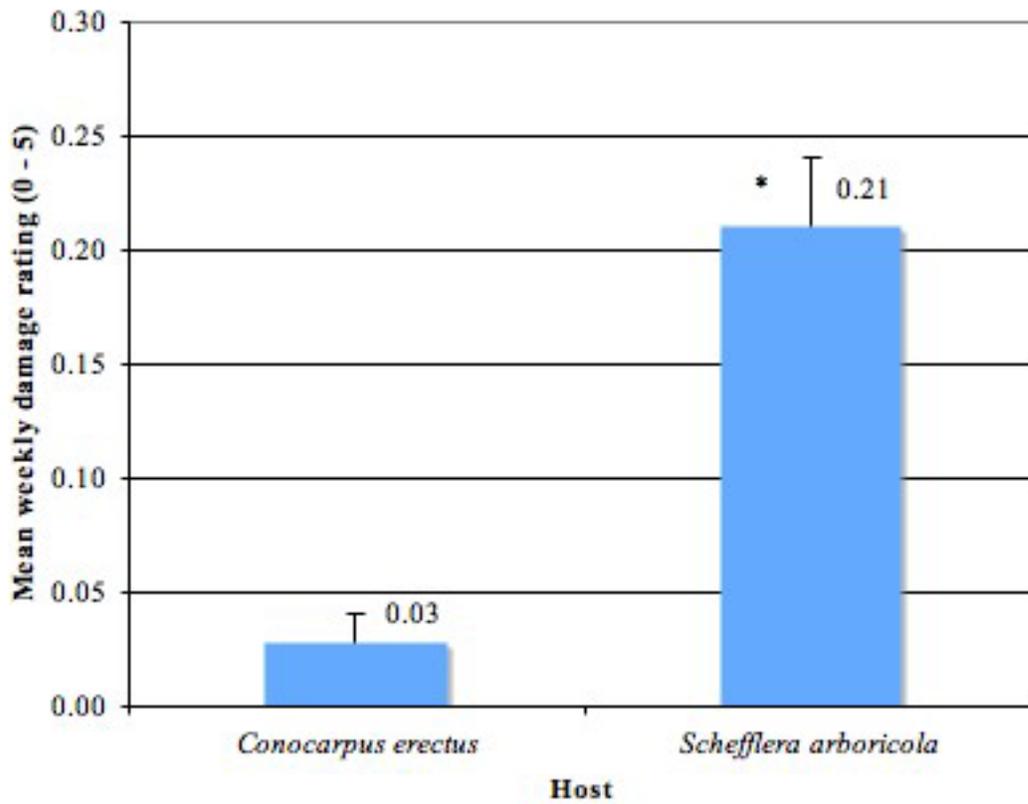


Figure 2-3. Mean damage rating plus mean standard error for *Conocarpus erectus* and *Schefflera arboricola* (* = significant difference by ANOVA with $\alpha = 0.0001$).

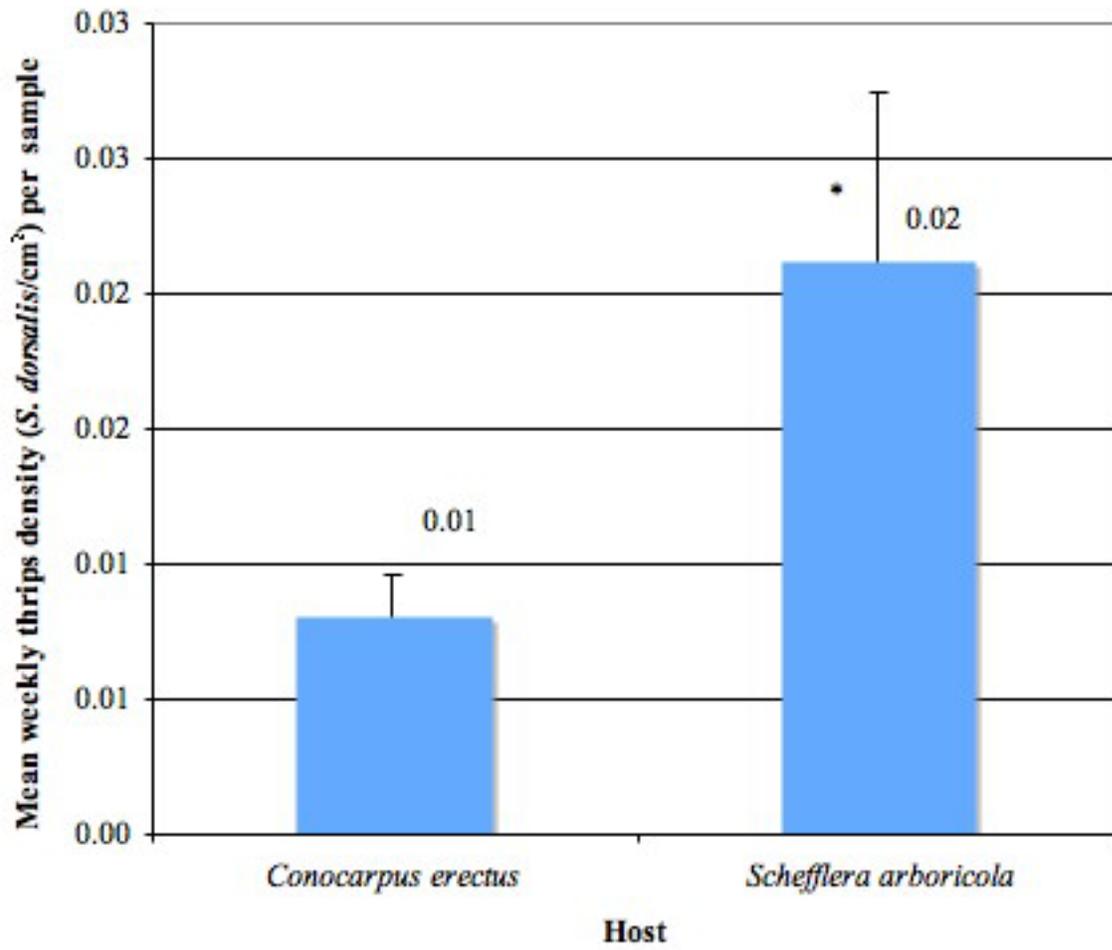


Figure 2-4. Mean thrips density (*S. dorsalis*/cm²) plus mean standard error for *Conocarpus erectus* and *Schefflera arboricola* (* = significant difference by ANOVA at $\alpha = 0.05$).

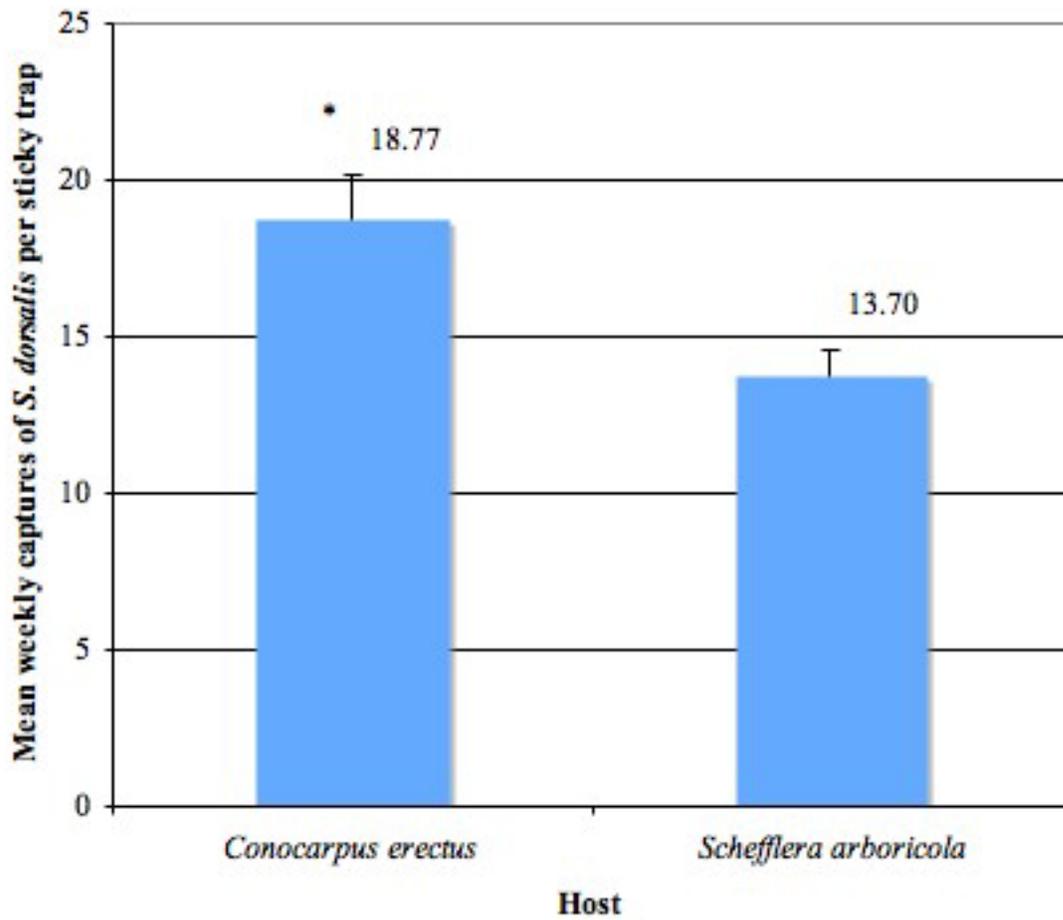


Figure 2-5. Mean captures of *S. dorsalis* plus mean standard error on yellow sticky cards placed behind *Conocarpus erectus* and *Schefflera arboricola* (* = significant difference by ANOVA at $\alpha = 0.05$).

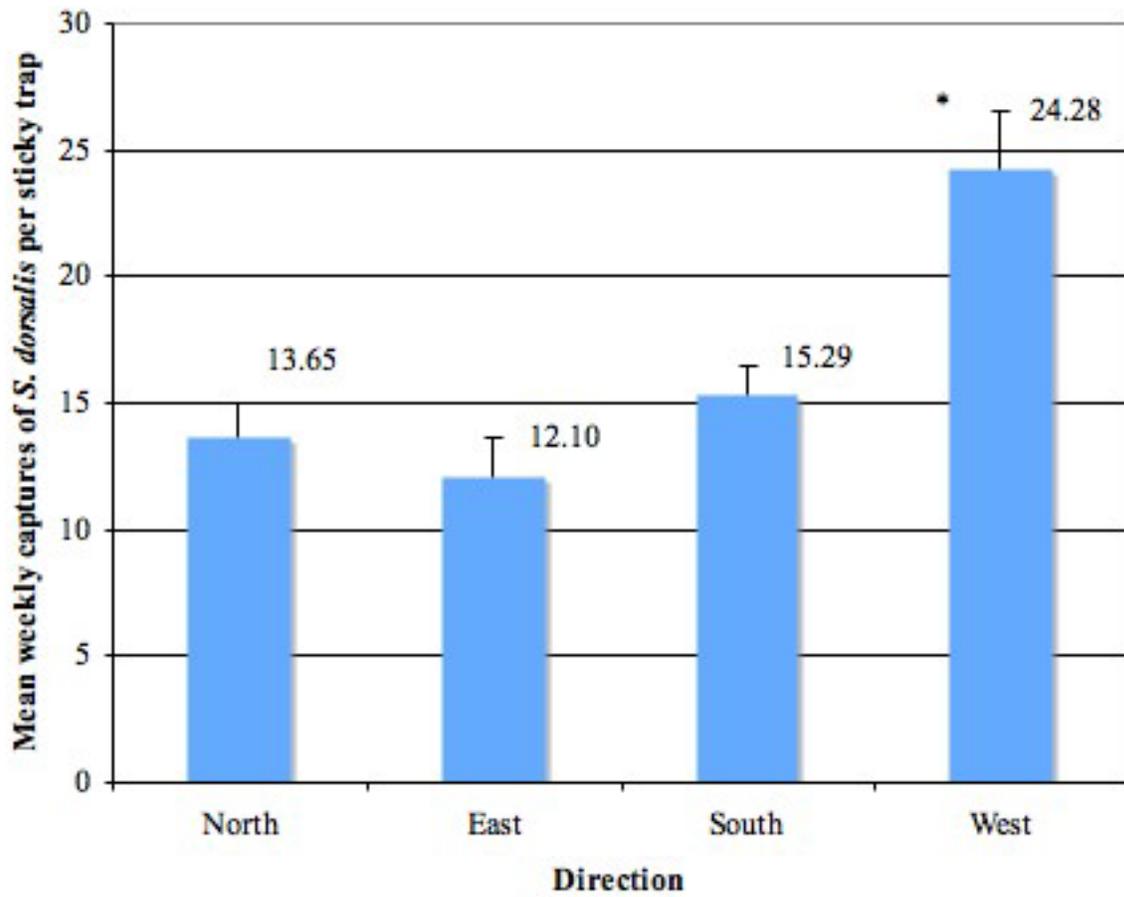


Figure 2-6. Mean *S. dorsalis* captures plus mean standard error on yellow sticky cards by direction (* = significant difference by pairwise *t*-tests at $\alpha = 0.0001$).

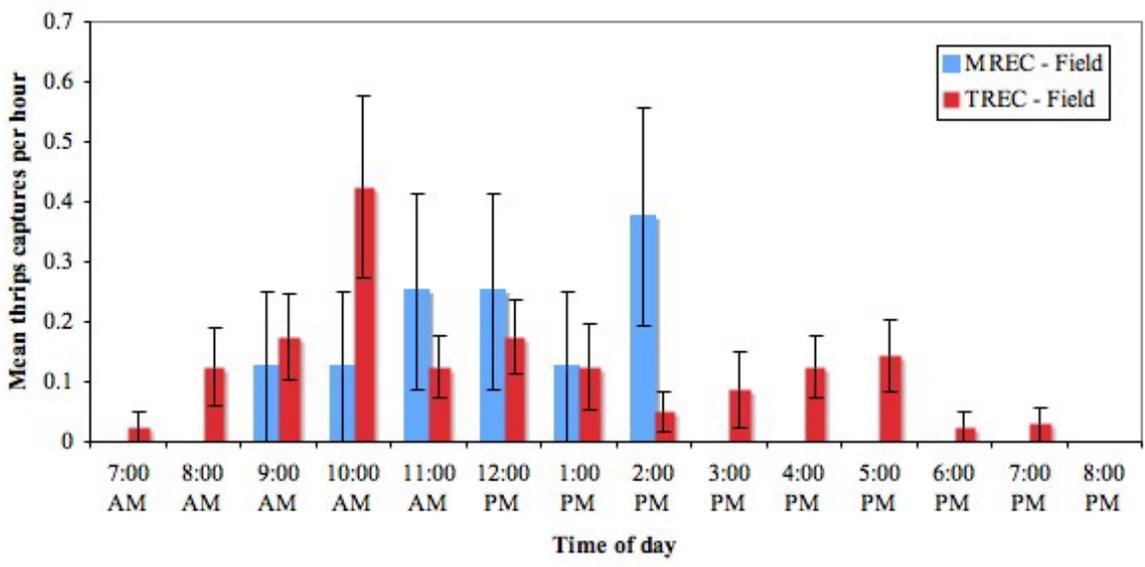
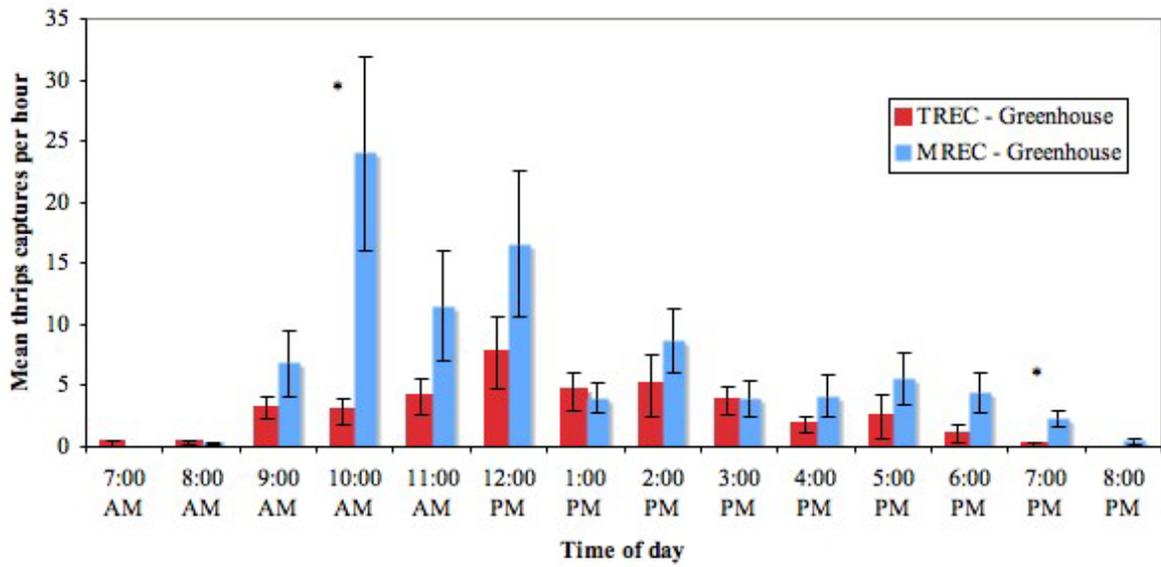


Figure 2-7. Mean hourly thrips captures plus standard error for greenhouse and field sites at TREC and MREC (* = significant difference between sites determined using ANOVA at $\alpha = 0.05$).

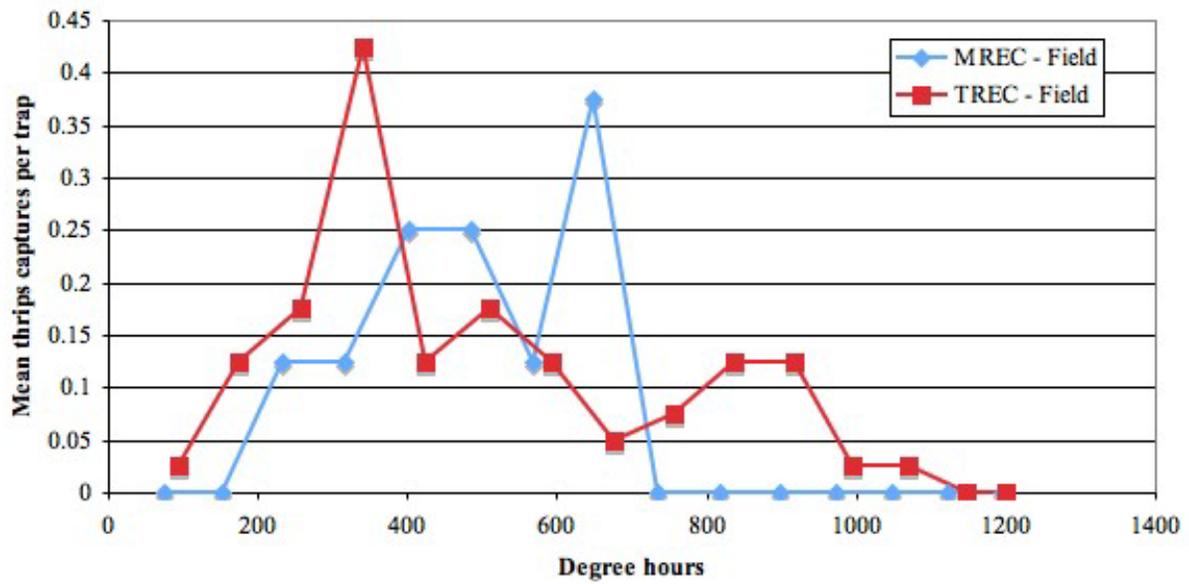
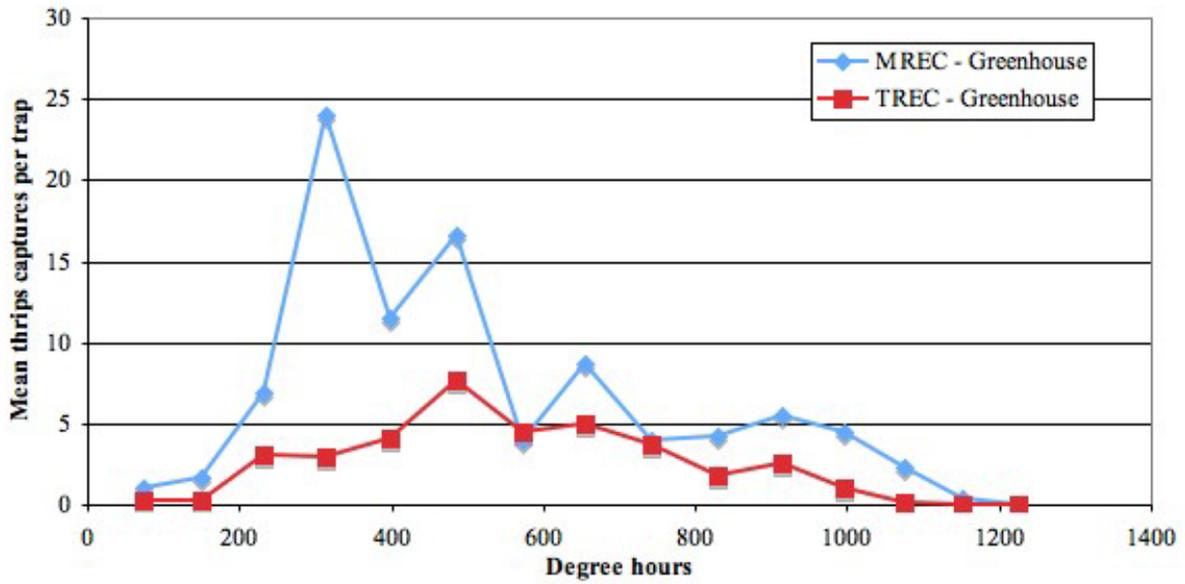


Figure 2-8. Mean thrips captures by degree-hour for greenhouse and field sites at TREC and MREC.

CHAPTER 3
POPULATION DYNAMICS OF *Scirtothrips dorsalis* HOOD (THYSANOPTERA:
THRIPIDAE) ON TWO ORNAMENTAL HOSTS IN SOUTHERN FLORIDA

Introduction

Scirtothrips dorsalis Hood (1919) is a minute insect pest whose global distribution has expanded rapidly over the last twenty years (Morse and Hoddle 2006). It was first identified in the United States at a Palm Beach nursery in 2005, and has since become established in southern and central Florida (Silagyi and Dixon 2006). It is a polyphagous thrips with a broad host range including many ornamental and vegetable hosts of economic importance (Mound and Palmer 1981, Venette and Davis 2004, Nietschke et al. 2008). Recent reports suggest that this thrips has the potential to expand from Florida to occupy much of the southeast, the Gulf coast region, and the western coast of the United States (Venette and Davis 2004, Nietschke et al. 2008).

The success of an invasive species depends on its ability to find an ecological niche that it can exploit successfully (Crawley 1986). As a polyphagous thrips, *S. dorsalis* has been documented as a serious pest on fruit and vegetable hosts such as *Fragaria x annanasa* Duchesne (strawberry), *Mangifera* spp. L. (mango), *Capsicum* spp. L. (pepper), *Citrus* spp. L., *Gossypium* spp. L. (cotton), *Glycine max* (L.) Merr (soybean), and *Arachis hypogaea* L. (peanut). The fruit and vegetable crops potentially affected by this thrips added nearly 1.4 billion dollars to the Florida economy in 2005 (Jerado 2006). For many hosts, damage from this thrips results in reduced floral and vegetative output, increased plant stress, scarred foliage, and potentially death (Mound and Palmer 1981, Tatara and Furuhashi 1992, Shibao 1996a). Ornamental plant hosts are particularly sensitive to feeding damage, as even minimal scarring can render a plant unsalable. Among these host plants are popular landscaping choices including *Rosa* spp. L., *Raphiolepis indica* (L.) Lindl. ex Ker Gawl. (Indian hawthorn), *Ligustrum* spp L. (ligustrum), *Viburnum* spp. L. (viburnum), and *Jasminum multiflorum* Lindl. (star jasmine).

Initial reports cited the Knock Out Rose ®, *Rosa* ‘Radrazz’ (Radler 2001) as an important host for this thrips in the Florida landscape environment (Silagyi and Dixon 2006), and it appears capable of sustaining large populations of this pest for long periods of time before succumbing to pest pressure. Green buttonwood, *Conocarpus erectus* var *erectus* L., is another common landscape plant in southern Florida that has been reported with severe thrips damage from *S. dorsalis*. Landscapers make frequent use of both species as ornamental hedges, and so both plants are common and have a broad distribution in southern and central Florida. These plants, as well as others, could potentially provide the thrips a natural corridor for establishment throughout the state (Morse and Hoddle 2006).

As a group, thrips have demonstrated great adaptive potential for pesticide resistance. Anecdotal reports indicate that certain populations of this species may have already developed limited resistance to neonicotinoid pesticides. The cost to develop novel pesticides is high, and this has resulted in increased expense to management programs stressing chemical maintenance of crops. This underlines the need to develop additional methods of non-chemical management, or to improve the specificity and use of existing strategies.

As this thrips is a pest of ornamental and agricultural crops it may develop resistance to commercial pesticides in one area, and then spread to other locations (Kirk and Terry 2003). Growers and homeowners must simultaneously apply a comprehensive integrated pest management program that considers both of their unique environments to prevent the establishment of reservoir populations, or the development of resistance to commercial pesticides. Knowledge of peak seasons of population increase is critical to the development of a proactive management program, as thrips-prevention is frequently less difficult than eradication

or control (Lewis 1997). An awareness of this thrips' seasonal presence upon common ornamental plants will be valuable in constructing a fully integrated pest management program.

While much research regarding the control and management of this thrips has begun, there is no literature available on the seasonal population dynamics of this thrips in the Florida environment. This study explores the annual population dynamics of this thrips on *Rosa* 'Radrazz', and *Conocarpus erectus* var *erectus*, two structurally different hosts under ambient environmental conditions in southern Florida.

Materials and Methods

The *S. dorsalis* used in this study were obtained from naturally established populations local to southern Florida, and from a colony raised and maintained by Dr. Dakshina Seal at the University of Florida Tropical Research and Education Center (TREC).

Twenty green buttonwood (*Conocarpus erectus* var *erectus* L.) were grown from cuttings harvested at the TREC, and twenty Knock Out Roses ® (*Rosa* 'Radrazz' PP#11836) were purchased from Tremendous Landscapes (Homestead, Florida), and placed in 11.36 liter containers in a medium consisting of 50% Canadian sphagnum peat moss, 25% processed pine bark, and a mixture of perlite and vermiculite (Fafard 3B Mix, Conrad Fafard Inc., Agawam, Massachusetts). These plants were infested with naturally established populations of *S. dorsalis* beginning on 12 July 2007. Each species plot consisted of a four by five grid with each plant separated from their neighbors by a third of a meter. All plants remained exposed to ambient environmental conditions throughout the experiment, and were irrigated with 93 ± 15 mL using an overhead system at six in the morning and two in the afternoon, according to local water restrictions and extension office recommendations. All plants were fertilized monthly with an application of 3.96 grams of liquid fertilizer (Peter's Professional, Scotts Company, Marysville, Ohio) (NH₃: NO₃: (NH₂)₂CO: P₂O₅: K₂O = 4:6:10:20:20), and 7.5 grams of pellet fertilizer

(NH₃: NO₃: P₂O₅: K₂O = 15:9:12) (Osmocote Plus, Scotts Company, Marysville, Ohio) once every other month.

On-plant Measures

The plants were sampled from 12 August 2007 to 4 September 2008. The total number of flowers and buds were counted weekly on roses. A damage estimate similar to that described by Krishna Kumar et al (1996) for pepper was developed during preliminary observations and used to visually rate the feeding damage of plants each week (Table 3-1).

Thrips population estimates for the two hosts were assessed by sampling an organ from each plant in every other week, alternating between plots of buttonwood and rose. Buttonwood samples always included five-centimeter sections of the terminal bud.

As roses presented more complex structural morphology, different plant organs were selected based on the availability and development of individual terminals. Flowers of approximately one week in age were always the preferred choice, but if none were available, rosebuds approximately five days old were selected. If no rosebuds were available, a rose growth terminal was taken. If no terminals were present, then a mature compound leaf was sampled.

All samples were removed with pruning shears and sealed immediately in small plastic containers with two drops of 95% ethanol. Samples that could not immediately be processed were stored at -6 °C. The total number and life stages of thrips in a sample was recorded by washing the samples with 75% ethanol and pouring the runoff through a 25 µm mesh, as per Seal and Baranowski (1993), and then examining the collected debris under a dissection scope at a minimum of 12x magnification. Plant samples were then dried overnight and the area of each dried sample was determined using a leaf area meter (LI-3000, LiCor, Lincoln, Nebraska) to determine the density of thrips populations in each sample (thrips/cm²).

Flight Measures

Four 7.6x12.7 cm yellow sticky traps (Chu et al. 2006) were hung at approximately half a meter in height on posts placed approximately half a meter within the inside corner of each plot to develop an estimate of the thrips population in flight throughout the experiment. Sticky traps were replaced weekly. Collected traps wrapped in clear plastic, labeled, and stored at -6 °C if they could not be immediately processed.

Thrips Identification

All thrips were identified using a dissection scope at a minimum of 12x magnification, with additional magnification and slide-mounting as necessary. Thrips were identified using the keys provided in Funderburk et al. (2007), and Moritz (2001, 2004) when possible. Samples of unknown thrips and voucher specimens were collected and sent to the Florida Department of Plant Industry for confirmation and for further identification. *Scirtothrips dorsalis* could rapidly be differentiated from other thrips present in the environment by their relative size and other distinguishing characters, including antennal, pronotal, and abdominal characters.

Environmental Factors

The Homestead station of the Florida Automated Weather Network (FAWN, <http://fawn.ifas.ufl.edu/>) was located a hundred meters from the research plot, and was used to provide environmental data including wind speed and direction, relative humidity, and the ambient temperature at 60 centimeters throughout the experiment.

Analysis

Thrips density was transformed to homogenize variance and normalize data for analysis by adding one to the total number of thrips, and then applying the natural log. Host plots were compared using ANOVA and means were separated using *t*-tests or Tukey's HSD when sample *n* was not constant for all treatments (due to loss of samples by birds or weather). Degree-days

began to accumulate from 12 July 2007, when plants were first exposed to natural infestations. Least square means were used to fit the general linear model and determine the strength of relationships between thrips populations, hosts, and environmental factors. All statistical analysis was conducted using JMP (SAS Institute 2007).

Results

On-plant Measures

Sampling resulted in the collection of 560 buttonwood terminals, 470 rose flowers, 131 rosebuds, 41 rose terminals, and 31 rose leaves. Only buttonwood terminals, rose flowers, and rosebuds were collected on all sampling dates.

The grid that plants were placed in for each plot was analyzed as separate rows running from north to south, and as columns running from east to west to determine the spatial distribution of the thrips within the plot. No row or column of plants within the plot of buttonwood ($F = 0.54$; $df = 19, 540$; $p = 0.9449$) or rose ($F = 0.55$; $df = 19, 672$; $p = 0.9377$) was significantly different from any other for total number of thrips or thrips density throughout the year.

The total number of thrips collected from the wash samples for both plant hosts was 21,304 thrips, and 95.2% of all thrips collected were *S. dorsalis* (Table 3-2). While 20,610 thrips (96.74% of all thrips) collected occurred on rose, there was no significant difference in the proportion of *S. dorsalis* relative to other species collected on rose or buttonwood, and all life stages of *S. dorsalis* were present on both hosts year-round.

The total number of thrips ($t = 13.82$; $df = 1232$; $p < 0.0001$) and thrips densities ($t = 1831.21$; $df = 1232$; $p < 0.0001$) for *S. dorsalis* were significantly different by host, with an average of almost twenty-eight more (2.25 per square centimeter) *S. dorsalis* counted on rose samples than on buttonwood.

Plant organ was also found to have a significant effect upon the total number of thrips ($F = 120.27$; $df = 3, 1229$; $p < 0.0001$) (Figure 3-1) and thrips density ($F = 74.35$; $df = 3, 1229$; $p < 0.0001$) (Figure 3-2) on the hosts, with rosebuds and rose terminals having the greatest density of thrips, followed by rose flowers, rose leaves, and buttonwood terminals. Because of these distributional differences, plant organs will also be considered separately.

Approximately $67.2 \pm 3.69\%$ of all adults collected were female, and this proportion was not significantly different between hosts ($t = -0.19$; $df = 638$; $p = 0.8462$) or plant organs ($F = 1.23$; $df = 3, 636$; $p = 0.2980$). The proportion of females fluctuated significantly among rose over time without an obvious trend ($F = 2.30$; $df = 25, 425$; $p = 0.0004$) with a range of 28.57% to 100% and an average of $65.32 \pm 8.43\%$. The proportion of females on buttonwood was not affected by time ($F = 1.13$; $df = 24, 164$; $p = 0.3143$), but ranged from 0% to 100%, with an average of $65.48 \pm 19.04\%$.

Thrips density fluctuated significantly without any directional trend over time for most plant organs, including buttonwood terminals ($F = 8.35$; $df = 26, 533$; $p < 0.0001$), rose flowers ($F = 15.55$; $df = 27, 442$; $p < 0.0001$), rosebuds ($F = 3.64$, $df = 26, 104$; $p < 0.0001$), and rose terminals ($F = 0.06$; $df = 10, 30$; $p = 0.0003$). Rose leaves ($F = 2.37$, $df = 4, 26$; $p = 0.0782$) did not change significantly over the sampling period. However, as only buttonwood terminals and rose flowers were collected on all sample dates, only these parts were used to assess changes in the thrips population over time (Figure 3-3).

Population densities on both hosts changed throughout the year, with peak density occurring in November through December of 2007 and July of 2008 for buttonwood, and peaks in August and October of 2007 and January and July of 2008 for rose. Increasing mean rose flower densities were significantly correlated with increasing rosebud densities ($r = 0.53$; $p =$

0.0028). Rose flower densities were also significantly correlated with buttonwood terminal densities, but the relationship was not as strong ($r = 0.37$; $p = 0.0384$).

Significant differences in the proportion of adult *S. dorsalis* were detected for host and plant organ, with buttonwood having the largest proportion of adults and rose leaves the smallest number of adults relative to the number of nymphs (Table 3-3). Using the rose flower data, the proportion of the population that was adult changed significantly with time ($F = 3.98$; $df = 27, 431$; $p = 0.0001$), ranging from 8.6% to 54% with a mean of $20.3 \pm 1.8\%$. This value was inversely proportional to the total size of the population at that time. The proportion of adult population also changed significantly with time on buttonwood ($F = 1.56$; $df = 26, 243$; $p = 0.0459$), ranging from 3.7% to 100% with a mean of $47.7 \pm 4.2\%$, and this percentage was also inversely proportional to the size of the population. While the number of nymphs captured in samples ranged from a mean of 5.13 to 65.14 nymphs, the number of adults only ranged from a mean of 0.53 to 25.88 adults. This gap was proportionately larger on buttonwood than on rose.

While damage ranged from a rating of zero to two (moderate damage), on buttonwood, no significant relationship could be detected between damage and the total number of thrips or thrips density.

The small number of rose leaves and rose terminals collected prevented a significant comparison of damage ratings to population estimates by parts sampled. As rose flowers were collected on all sample dates, and displayed the most visible elements of floral damage, they were used to compare plant damage to populations of *S. dorsalis*. Roses experienced damage ratings ranging from zero to four (critical damage) (Figure 3-4). Population estimates were lower (but not significantly) for roses at the more severe end of the scale than at moderate damage. A significant but weak positive correlation was observed between the total number of thrips and

damage estimates ($r = 0.29$; $p = 0.0001$), and a significant but somewhat stronger correlation was observed between thrips densities and damage ratings ($r = 0.43$; $p = 0.0001$). There was also a significant but weak correlation between increasing damage and a reduction in the total number of flowers and buds produced ($r = 0.15$; $p = 0.0009$) and the mean floral area ($r = 0.33$; $p = 0.0001$). There was no significant relationship between the total number of thrips, density, and the total number of flowers and buds produced. While the mean number of flowers and buds decreased by an average of four flowers as damage ratings increased (Figure 3-5), the mean area of each inflorescence decreased by almost half (Figure 3-6).

There was a much stronger correlation for both hosts when biweekly samples were pooled to develop a monthly average for populations and damage. The positive correlation between increasing thrips density and damage could be seen over time for buttonwood ($r = 0.90$; $p = 0.0001$) (Figure 3-7), with peaks in density and population occurring from December 2007 to January 2008, and again in July of 2008. On rose, peaks in population density and damage occurred in August and October of 2007, and again in January and June of 2008 ($r = 0.78$; $p = 0.0003$) (Figure 3-8). However, no significant correlation could be found between buttonwood and rose populations, suggesting that the two populations are independent of one another.

Monthly averages for buttonwood and rose flowers were used also instead of biweekly averages to relate thrips populations to ambient environmental conditions. On rose, no significant correlations were observed between thrips population estimates and environmental factors. However, positive relationships between mean monthly thrips density and mean temperature ($r = 0.42$; $p = 0.0679$), minimum monthly temperatures ($r = 0.45$; $p = 0.0509$), and mean monthly degree-days ($r = 0.43$; $p = 0.0614$) were nearly significant. For buttonwood, a weak but significant negative relationship was observed between thrips density and maximum monthly

temperature ($r = 0.52$; $p = 0.0412$), and between mean the total number of thrips and average monthly maximum wind speed ($r = 0.53$; $p = 0.0358$).

Flight Measures

No significant differences in the number of adults were detected among sticky traps based on their location within the plot, so all trap data could be pooled. *Scirtothrips dorsalis* proved to be the predominant thrips collected on yellow sticky traps above both host plots, representing 84.04% of the 31,785 thrips captured. The next two species accounting for the second and third largest proportions were *Frankliniella schultzei* (Trybom) at 3.59%, and *Gynaikothrips uzeli* Zimmerman at 3.05% of all captures (Figure 3-9). *G. uzeli* is the only thrips that occurred more frequently on sticky traps placed in the buttonwood plot than in the rose plot. Most of the thrips on the sticky traps (83.84%) were captured over rose. *S. dorsalis* represented $75.39 \pm 22.96\%$ of all captures in any given week, and were a significantly higher proportion of weekly captures above rose ($78.81 \pm 17.96\%$) than buttonwood ($71.64 \pm 26.97\%$) ($t = 3.29$; $df = 367.2377$; $p < 0.005$).

Although the total captures for other species were low relative to the total, certain fluctuations over time were observed for particular genera and species. Genus *Frankliniella* showed peaks occurring for all three species identified in July 2007, and April through May 2008. *F. schultzei* showed additional peaks in December 2007, and in July 2008 (Figure 3-10). *G. uzeli* showed small peaks from August to October 2007, and from February to March 2008. A large number of *G. uzeli* were captured in July 2008 (Figure 3-11). A peak of *Thrips palmi* Karny was observed from August to October 2007, and numbers of *T. tabaci* Lindeman were low throughout the year (Figure 3-12). A peak of *Merothrips* spp. was observed from January to February 2008 (Figure 3-13). A peak of *Echinothrips americanus* Morgan was identified from July to August 2007 (Figure 3-14). Several small peaks of *Chirothrips* spp. were observed from

August to September 2007, from November of 2007 to February 2008, and May to August 2008 (Figure 3-15). A small peak of *Heliothrips haemorrhoidalis* (Bouché) was observed in May 2008 (Figure 3-16). A small peak of *Selenothrips rubrocinctus* was observed in August 2007 (Figure 3-17). *Chaetanaphothrips orchidii* (Moulton) were present in low but constant numbers throughout the year (Figure 3-18). A small peak of *Holopothrips inquilinus* (Bournier) was observed from March to June 2008 (Figure 3-19). The predatory thrips, *Scolothrips sexmaculatus* (Pergande) was the most abundant predatory thrips present, with nineteen individuals intercepted throughout the year (Figure 3-20).

Other species of thrips were captured, but as less than fifteen individuals of each species were collected, and some specimens were incomplete or damaged, they could not be identified to species. This group totaling sixty-six thrips were summed together and recorded as “unidentified genera” (Figure 3-21). This group includes putative individuals from the genera *Aeolothrips*, *Aleurodothrips*, *Franklinothrips*, and *Karnyothrips*, with no obvious peaks for any individual thrips collected.

S. dorsalis adults occurred year-round over both buttonwood and rose hosts, with sticky traps over rose capturing significantly more thrips than traps placed over buttonwood ($t = 10.64$; $df = 461$; $p < 0.0001$). The number of thrips captured changed significantly throughout the year for both hosts ($F = 7.09$; $df = 59, 403$; $p < 0.0001$), with peak captures observed over buttonwood in May and June of 2008, and peak captures observed over rose in August, October, November of 2007 and June 2008. Both rose and buttonwood had their lowest captures from January to early May in 2008 (Figure 3-22), and showed significant and strong correlation on thrips captures between hosts ($r = 0.78$; $p = 0.0006$).

There was no statistical difference between the proportion of *S. dorsalis* females captured over buttonwood and rose ($t = -0.04$; $df = 377$; $p = 0.9656$), but the proportion of females captured over hosts changed significantly over the year ($F = 3.32$; $df = 47, 331$; $p < 0.001$) ranging from 27.1% in August 2008 to 77.2 % in January 2008 with an average of $49.3 \pm 1.6\%$.

There was a positive significant relationship between monthly mean flight captures and monthly mean temperature ($r = 0.47$; $p = 0.0459$), monthly minimum temperature ($r = 0.54$; $p = 0.0213$), and mean monthly degree-days ($r = 0.48$; $p = 0.0413$). No significant relationship was detected between mean monthly buttonwood captures and any environmental factor.

Comparing Flight Measures to On-plant Estimates

Thrips captures on sticky traps above rose were far more diverse than thrips collected from rose, with only *S. dorsalis*, *F. bispinosa*, *F. occidentalis*, *F. schultzei*, and *T. palmi* showing more than one on-plant capture during the experiment. Both rose ($r = 0.62$; $p = 0.0079$) and buttonwood ($r = 0.50$; $p = 0.0408$) showed moderate and significant correlation between increasingly mean monthly host density and greater mean monthly flight captures, but did not show significant or strong correlation between densities on one host and flight captures above the other ($r < 0.47$; $p > 0.0936$). Both rose ($r = 0.62$; $p = 0.0079$) and buttonwood ($r = 0.50$; $p = 0.0408$) also demonstrated significant correlation with greater mean monthly sticky trap captures and higher mean monthly estimates of plant damage for that host, but did not show significant correlation between damage on one host and sticky trap captures from the other plot ($r < 0.06$; $p > 0.3480$).

The proportion of female thrips measured on plants (66%) was significantly different from the proportion of females captured (49%) on sticky traps ($t = 4.31$; $df = 24$; $p > 0.0001$), but there was strong and significant correlation between an increasing percentage of females on-plant and a larger percentage of females captured in flight ($r = 0.61$; $p = 0.0346$).

Discussion

Examining the distribution of thrips within each plot showed that no row of plants from north to south, or column from east to west of hosts within a plot was significantly different from any other row or column for the total number of thrips of any instar, or for thrips density. This suggests that the thrips have distributed themselves evenly across each host species of without edge effects. Weekly flight captures show the same findings, as down-wind traps did not show higher mean captures than those up-wind. This homogenous distribution is similar to the results observed by Rhainds et al. (2005), where adult female flower thrips maintained a fairly uniform density within a plot of chrysanthemum. This uniform distribution between plants may help to reduce intraspecific competition on plants based on available plant nutrients, and to encourage more active dispersal.

While the majority of thrips captured on traps and on both host plants were *S. dorsalis*, a far greater diversity and abundance of thrips were captured on rose when compared to buttonwood. A greater diversity of thrips was observed on sticky traps than actually captured on plants. Most relevant to this study, significantly higher numbers and densities of *S. dorsalis* were recorded on rose than on buttonwood throughout the year, suggesting that the rose is a more attractive host for this pest. These results on plants were repeated with the number of adults captured in the traps above each plot of hosts. In addition to the larger numbers of nymphs collected on rose, the relative proportion of adult thrips was greater on buttonwood than on rose, suggesting that this host is less advantageous for *S. dorsalis*' reproduction. However, as the thrips did persist on buttonwood throughout the year, and nymphs were recovered from all buttonwood plants, it is possible for this insect to complete its reproductive cycle on this host. This suggests that the pest can and will persist in an environment with less optimal hosts, and

then migrate to preferred hosts when the opportunity becomes available, as observed by Masui (2007a).

As has been suggested by many other researchers for this thrips, roses most probably represent a preferred host choice for *S. dorsalis*. Given that roses have already featured prominently in extension reports of this thrips, it is probably best that future scouting continue to emphasize this host when surveying for this pest. It remains that buttonwood in isolation can still develop significant levels of infestation (A.I.D., personal observations and unpublished data). In the absence of other more preferred hosts, the thrips can survive and reproduce on this substrate year-round, and it has the potential to serve as both a reservoir and roadway for migrant populations of thrips moving between primary hosts.

Together, these results imply that *S. dorsalis* has probably become well established in Florida, and even if this thrips were to be completely eliminated from agricultural or landscape environments, it will probably persist somewhere in the environment. These reservoir populations will gradually re-colonize lost territory from unmanaged areas, and a realistic management program would focus on controlling or limiting this thrips during periods of peak growth.

Studies of the relationship between damage ratings and thrips populations might have been improved through the use of a more refined scale, allowing for a more specific description of damage using more quantitative variables, but the system does provide usable results. While results for buttonwood were inconclusive but suggestive of increasing damage with increasing thrips density, increasing thrips densities on rose resulted in an increase in both damage to the plant, and in the number of thrips dispersing about the plant. However, it should be noted that the relationship between measures of thrips and damage were not exclusively linear. The

observations taken from rose suggest that thrips populations are slightly smaller at the upper range of the damage scale than at middle values. This suggests that the thrips may have damaged the plant beyond its capacity to maintain maximum thrips populations, or that other factors play a role in damage. As the greatest damage was measured during the hottest parts of the year, it is possible that the plant stress due to a high-temperature environment also plays a role in mediating damage to the plant. However, only ten plants were ever recorded with a damage rating of four, and all ten observations were made on the same sample date in late October. This coincided with a period during which thrips densities began to decline. It is therefore unlikely that the thrips density observed with this damage rating is representative of the populations on a heavily damaged plant.

Interestingly, while damage to the plant increased with thrips populations and the total number of flowers and buds produced decreased significantly, the difference was a mean of four less flowers. However, the mean floral area of those flowers decreased by almost half. This suggests that while roses continue to produce florets at growth terminals, the nutrient resources available to do so may have been diverted by the thrips. Growers concerned that they might have a thrips infestation should therefore be aware of the mean size of flowers more than the total number of flowers produced.

Monthly population averages are more correlated to plant damage ratings than biweekly sample averages. This suggests that there is some lag between the level of population growth or decline and the display of damage or healing on the host. As such, use of the damage rating system may not be a good predictive measure by which to proactively estimate populations of *S. dorsalis* in order to preventatively apply pesticides. By the time a grower detects host damage, populations may already have grown too large for easy management.

Flight populations also showed high correlation to population density on plants, but were only correlated with the host over which they were sampled. This is an important distinction, as it suggests that the populations captured above the host are probably related to the presence of that host and are not merely ambient populations created by some other significant source. This was not an unexpected result, but it is important to realize that indirect sampling of the thrips using regularly replaced sticky traps as a sentinel system might be able to detect and anticipate outbreaks of *S. dorsalis* before they became too large and begin to significantly damage hosts in a growing system.

Among the more unusual results observed was that the proportion of females measured on each plant was significantly greater than the proportion of females captured in the air above each host. Masui (2007b) observed an increased proportion of female *S. dorsalis* dispersing at greater distances from preferred hosts. It is generally believed that male Thysanoptera have not been selected for dispersal, given their relatively small size when compared to females and their inability to independently establish a new colony (Lewis 1997). It is possible that this experiment only recorded local dispersal, as traps were only placed within the plot being studied. Had traps been placed at increasing distances from each of the two studied plots, an increasing proportion of female thrips might have been observed at greater distances, as per Masui's results (2007b). Males may be more active in local dispersal within a plot in order to slightly increase the amount of gene flow within the population, and this would also help to explain our apparently inconsistent results.

The low number of rose leaves and terminals collected prevented any realistic use of different plant organs as a factor when estimating thrips populations, but the data is suggestive of certain trends. For all samples, *S. dorsalis* was found in significantly higher densities on the

rosebuds and rose terminals than on rose flowers or leaves. The thrips density of rose leaves was not significantly different from the leaves of buttonwood, or the density from the petals of rose flowers. This is not atypical behavior for thrips, as many Thripidae appear to prefer the upper part of the plant canopy and the outer extremities of their hosts (Reitz 2002, Hansen et al. 2003). It has been suggested that thrips prefer these areas because the flow of free nitrogen in plants is often towards these areas of new growth (Lewis 1997). This is not inconsistent with prior research regarding this thrips on chili pepper (Seal et al. 2006), castor (Raizada 1965), or tea (Dev 1964). Females of *S. dorsalis* prefer to lay their eggs inside of young leaves and buds at the apical meristem of plants, but as populations increase, will lay their eggs within the surface of mature leaves (Dev 1964, Raizada 1965). After hatching, nymphs will migrate from older leaves to the newer growth at terminals (Onkarappa and Mallik 1998).

While thrips were not present in high densities or abundances on the leaves, the nymphs left evidence of their presence through their distinctive feeding damage. More importantly, *S. dorsalis* was present on leaves in densities that were not significantly different than those within the petals of flowers. This should not be surprising, as the petals of flowers are merely developmentally modified leaves distributed within a much smaller volume. This may help to explain a discrepancy in the literature where this thrips is sometimes referred to as a flower thrips, and in other references is referred to as an exclusively foliar thrips. *S. dorsalis* may thrive equally well on both substrates, and exogenous environmental factors such as heavy precipitation, predation, or competition may determine the distribution of populations within the plant.

There was some correlation between environmental conditions and populations of *S. dorsalis*. Rose and buttonwood populations of thrips appeared to respond to environmental

factors in a similar fashion. Prior studies have shown that population levels are positively associated with increasing temperature (Tatara 1994, Varadharajan and Veeravel 1995, Saxena et al. 1996, Shibao 1996b, Paul and Konar 2005) and the number of sunlit hours in a day (Saxena et al. 1996, Gahukar 2003, Paul and Konar 2005). These results were also observed during this study, with the largest populations occurring in months with the greatest cumulative degree hours. As daily average and maximum temperatures were fairly constant, this suggests that the most variable measurement of temperature, the daily minimum, may be one of the most important factors defining potential populations of *S. dorsalis* in southern Florida.

Other researchers have observed a negative association between population density and increasing relative humidity (Varadharajan and Veeravel 1995, Saxena et al. 1996, Lingeri et al. 1998, Paul and Konar 2005) and rainfall (Lewis 1973, Varadharajan and Veeravel 1995, Saxena et al. 1996, Lewis 1997, Lingeri et al. 1998, Paul and Konar 2005, Singh 2005). At least one researcher (Singh 2005) observed a positive correlation between population density and humidity, but their observations were made at a lower relative humidity than that of other sources cited. Results observed by this study are suggestive of these trends, but not conclusive.

All researchers suggest that dry conditions with low intensity rainfall promote the best population growth for this thrips. It has been suggested that this is because hard rain will wash adults and nymphs from the leaves to the ground, where many of them will not return successfully to their host plant for feeding after falling (Lewis 1997). During the period of observation in southern Florida, colder months were drier and warmer months tended to be rainier which may have made the effects of these factors less obvious.

The predictive limitations of this portion of the study may also be a result of the limited range of environmental variability during the period of the experiment. The subtropical

environment of southern Florida does not allow for much environmental variation across the environmental factors tested. A larger study incorporating a longer period of observation or several sites across Florida as a whole might help to refine these conclusions and better explore the annual performance of this thrips.

Table 3-1. Symptoms of feeding damage prevalent at each stage of the infestation by *Scirtothrips dorsalis* for *Conocarpus erectus* var *erectus* L. (green buttonwood) and *Rosa* ‘Radrazz’ (Original Knock Out ® rose).

Score	<i>Conocarpus erectus</i>	<i>Rosa</i> ‘Radrazz’
0	No symptoms.	No symptoms.
1	Scarring along veins of leaves.	Scarring along sepals. One or two outer petals of each bloom display scarring. A few newer leaves may show stippling.
2	Scarring at base of petiole. Wrinkled new growth.	New growth becomes wrinkled. Recent flush shows scarring along the base of veins. Scarring on most sepals and petals. Some mature leaves may show scarring.
3	Blackened new growth. Scarring on older leaves becomes prominent.	Whole surface of newer leaves may be crisscrossed with scar tissue radiating outward from veins. Little new growth, and terminals may be blackened at tips. Shorter mean bud length relative to healthy plants, and smaller petal area when flowers open.
4	Leaves brown and withered. Little new growth.	Leaves brown and wither, reduced production of flowers and buds. No new growth. Mature leaves show significant feeding damage. Bud tips are small and blackened.
5	Defoliation.	Defoliation and possible death of the plant.

Table 3-2. Total thrips captures of each life stage on both host plants.

Host	<i>S. dorsalis</i>				Other thrips				Total
	Nymph	Pupa	Adult	Total	Nymph	Pupa	Adult	Total	
Knock Out ® rose	16,203	412	3,000	19,615	707	12	275	994	20,609
Buttonwood	386	2	270	658	23	0	14	37	695
TOTAL	16,589	414	3,270	20,273	730	12	289	1031	21,304

Table 3-3. Proportion of adult *Scirtothrips dorsalis* on each plant organ.

Plant organ	<i>n</i>	Mean (%)	± SEM	Level
Rose leaves	31	7.19	± 0.06	c
Rosebuds	131	15.85	± 0.02	c
Rose flowers	470	20.92	± 0.01	bc
Rose terminals	41	31.32	± 0.04	b
Buttonwood terminals	560	44.98	± 0.02	a

Plant organs not connected by the same letter are significantly different by Tukey’s at $\alpha = 0.05$

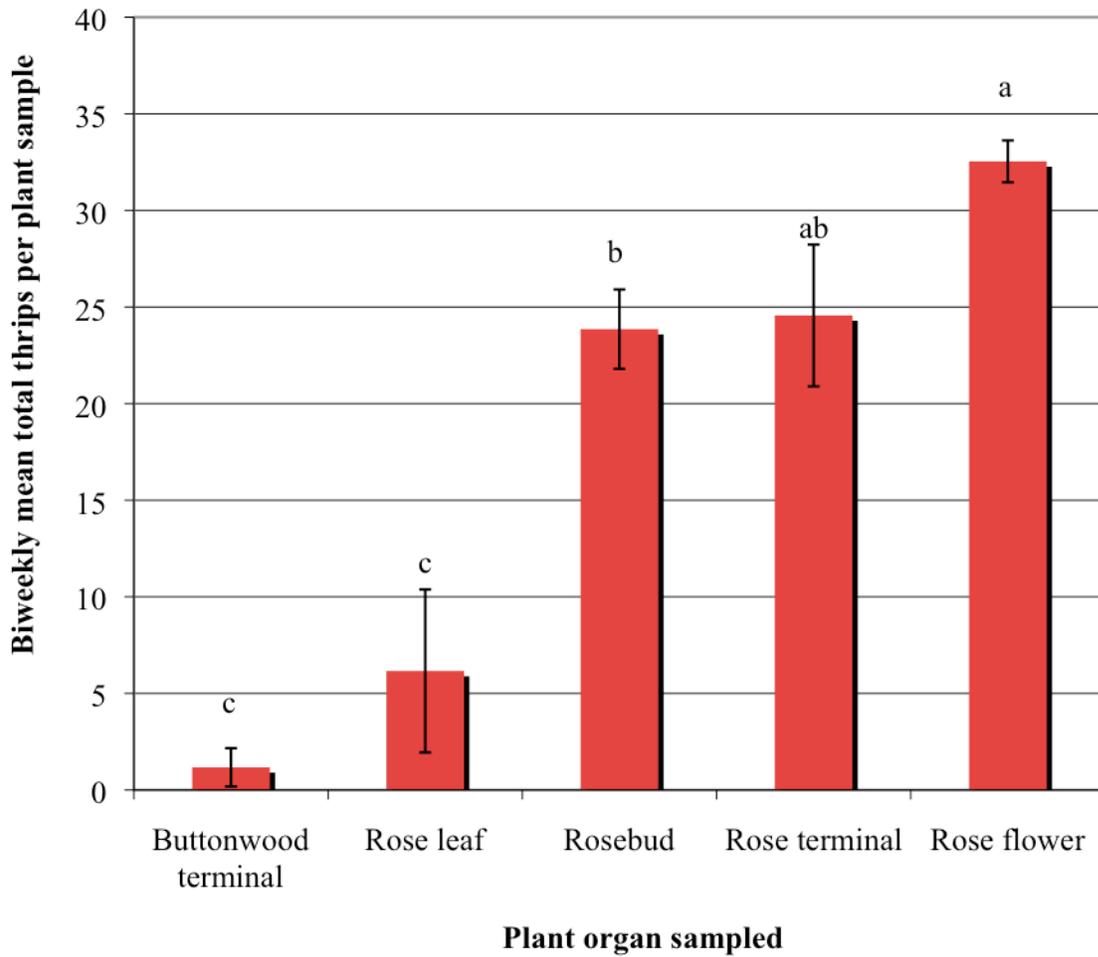


Figure 3-1. Biweekly mean total thrips by plant organ plus standard error (organs connected by the same letter are not significantly different by Tukey-Kramer at $\alpha = 0.05$).

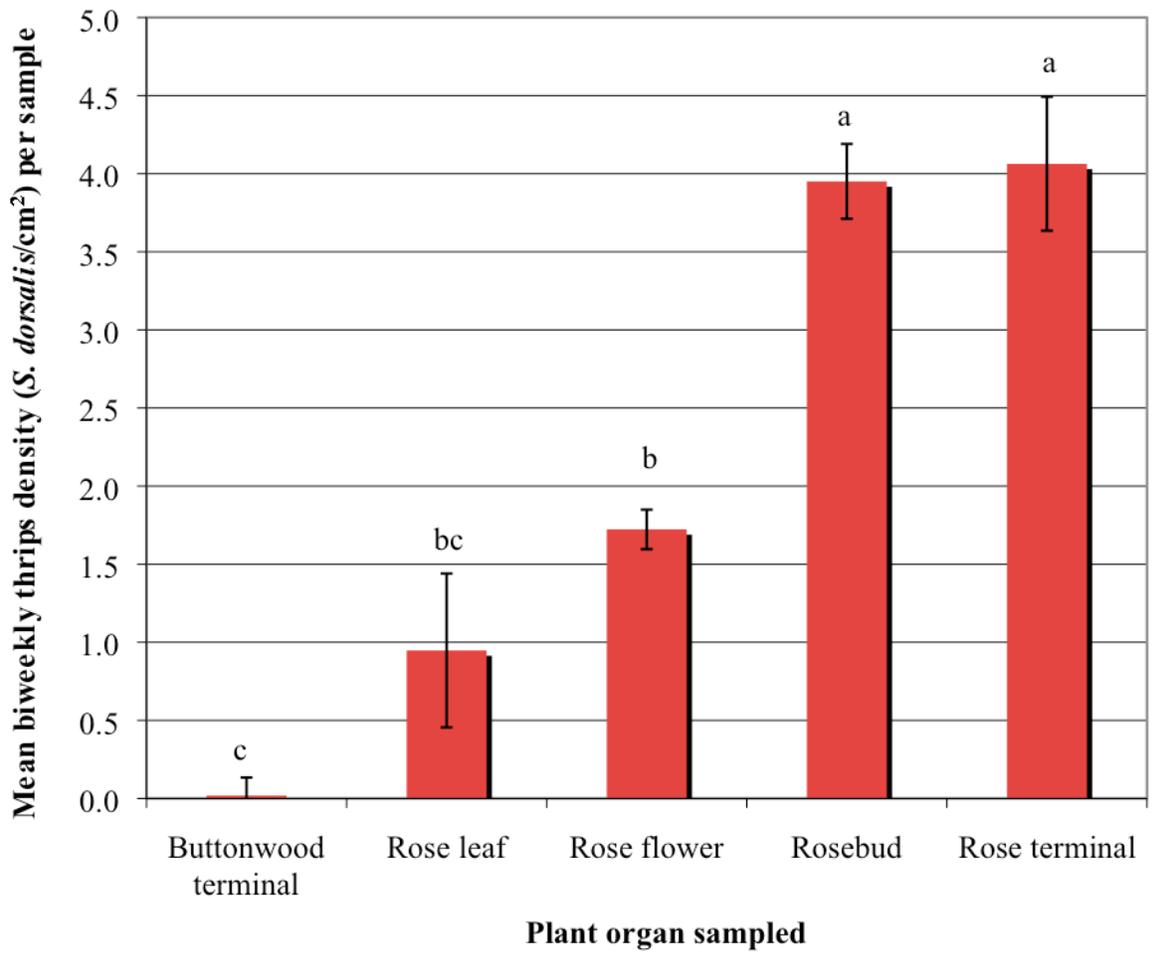


Figure 3-2. Mean thrips density (*S. dorsalis*/cm²) plus mean standard error by plant organ (organs connected by the same letter are not significantly different by Tukey-Kramer at $\alpha = 0.05$).

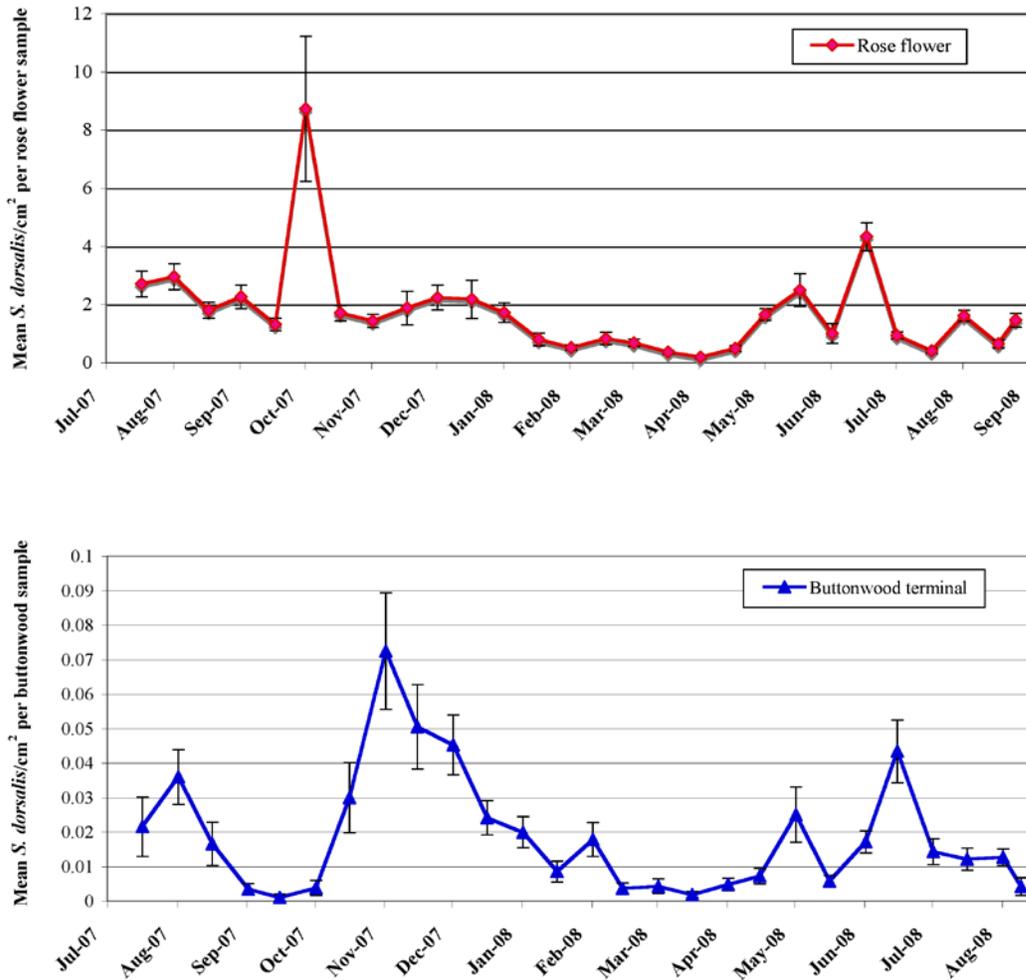


Figure 3-3. Biweekly mean thrips density (*S. dorsalis*/cm²) plus mean standard error per rose flower and buttonwood sample over time.

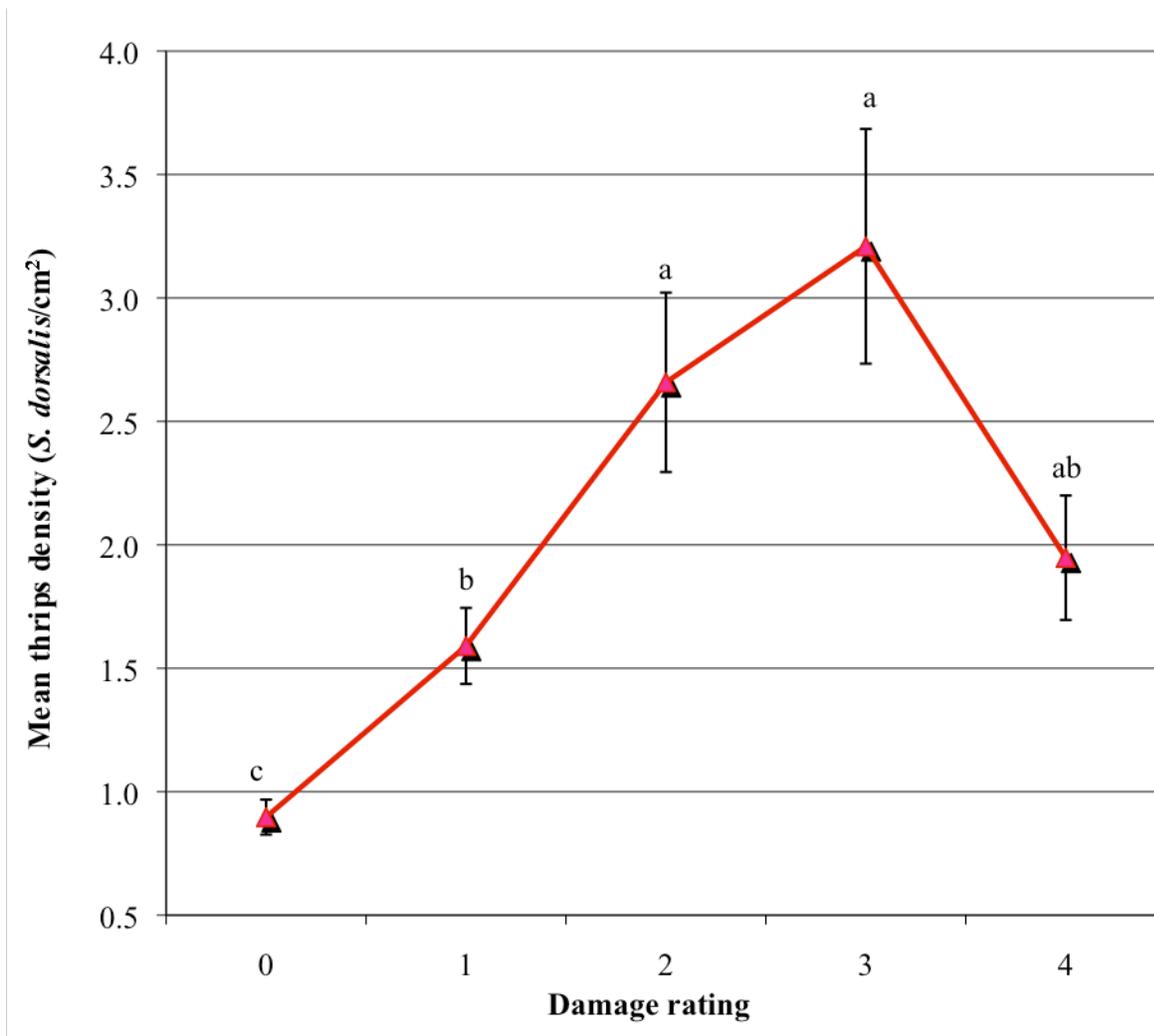


Figure 3-4. Mean thrips floral density (*S. dorsalis*/cm²) plus mean standard error observed at each damage rating on Knock Out® rose (ratings connected by the same letter are not significantly different by Tukey-Kramer at $\alpha = 0.05$).

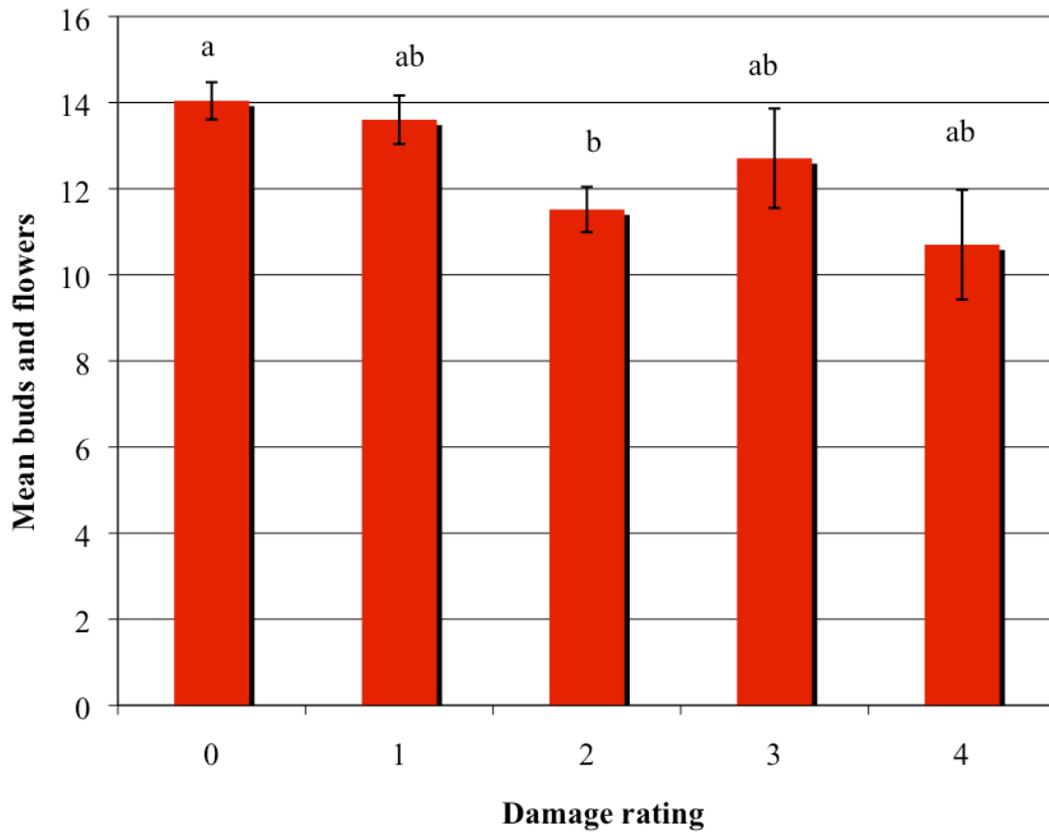


Figure 3-5. Mean total buds and flowers plus mean standard error for Knock Out® rose observed at each damage rating (ratings connected by the same letter are not significantly different by Tukey-Kramer at $\alpha = 0.05$).

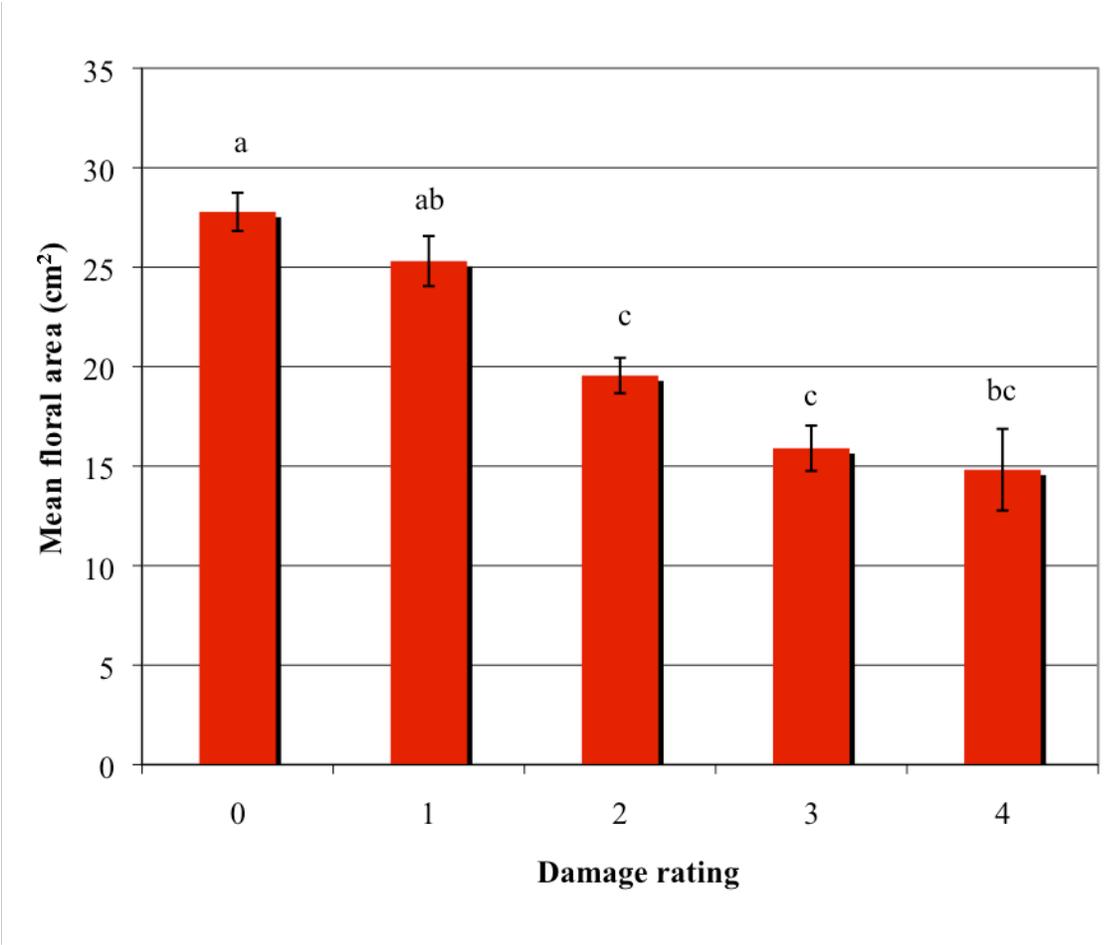


Figure 3-6. Mean floral area (cm²) plus mean standard error for Knock Out ® rose observed at each damage rating (ratings connected by the same letter are not significantly different by Tukey-Kramer at $\alpha = 0.05$).

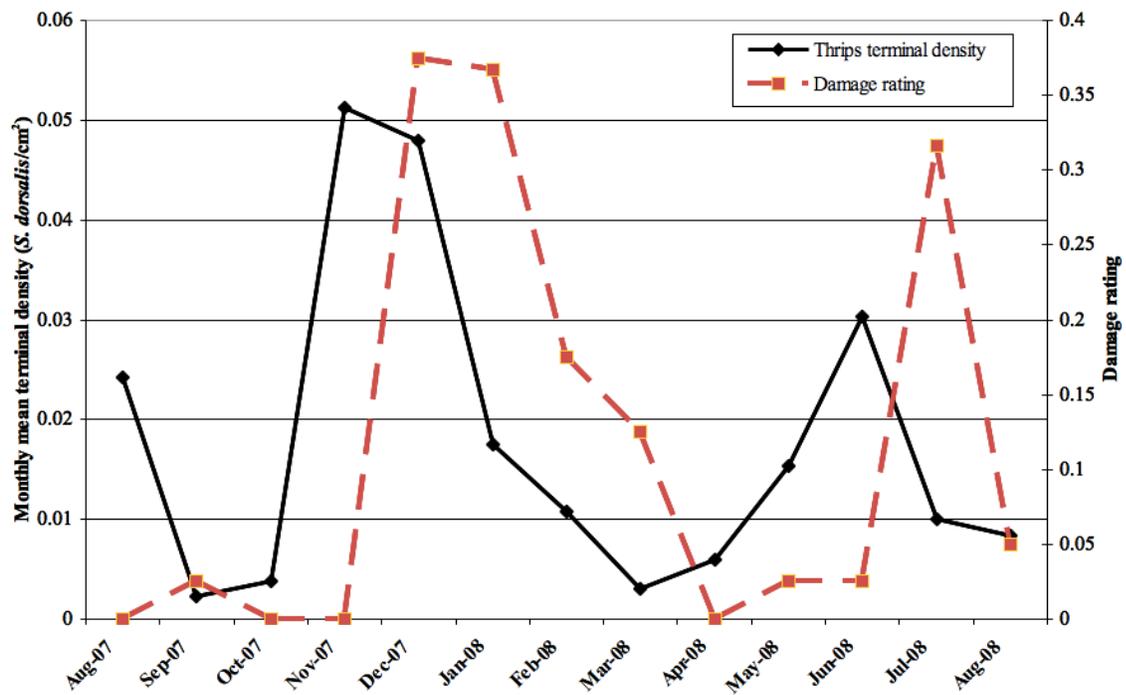


Figure 3-7. Monthly mean thrips terminal density (*S. dorsalis*/cm²) and damage rating on buttonwood over time.

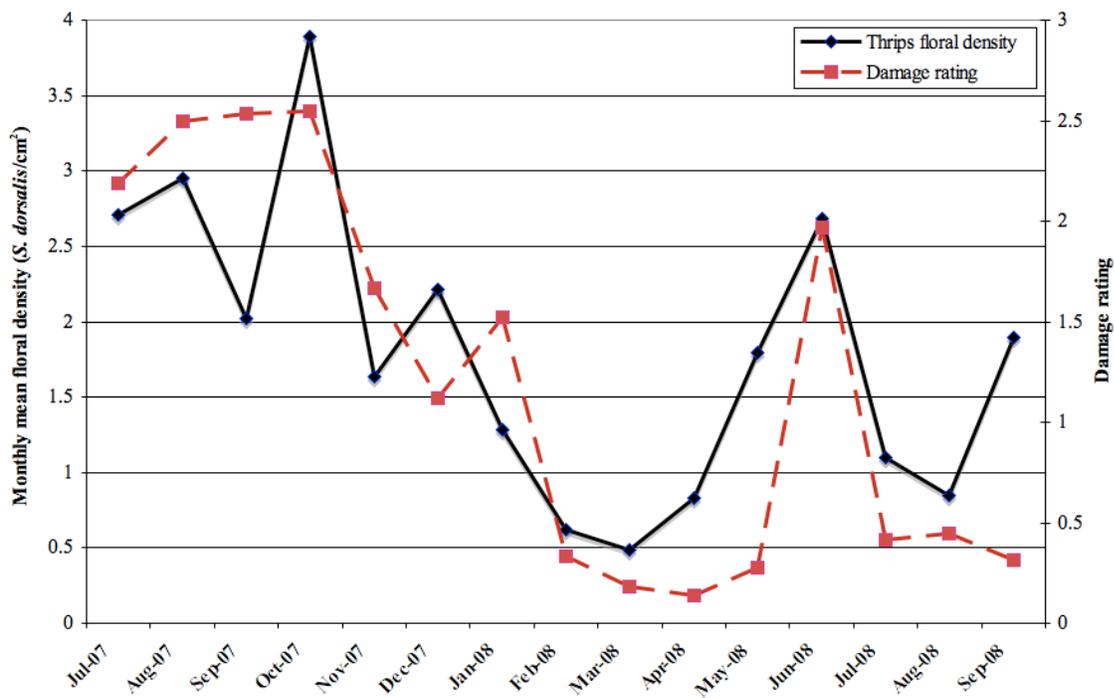


Figure 3-8. Monthly mean thrips floral density (*S. dorsalis*/cm²) and damage rating on Knock Out® rose over time.

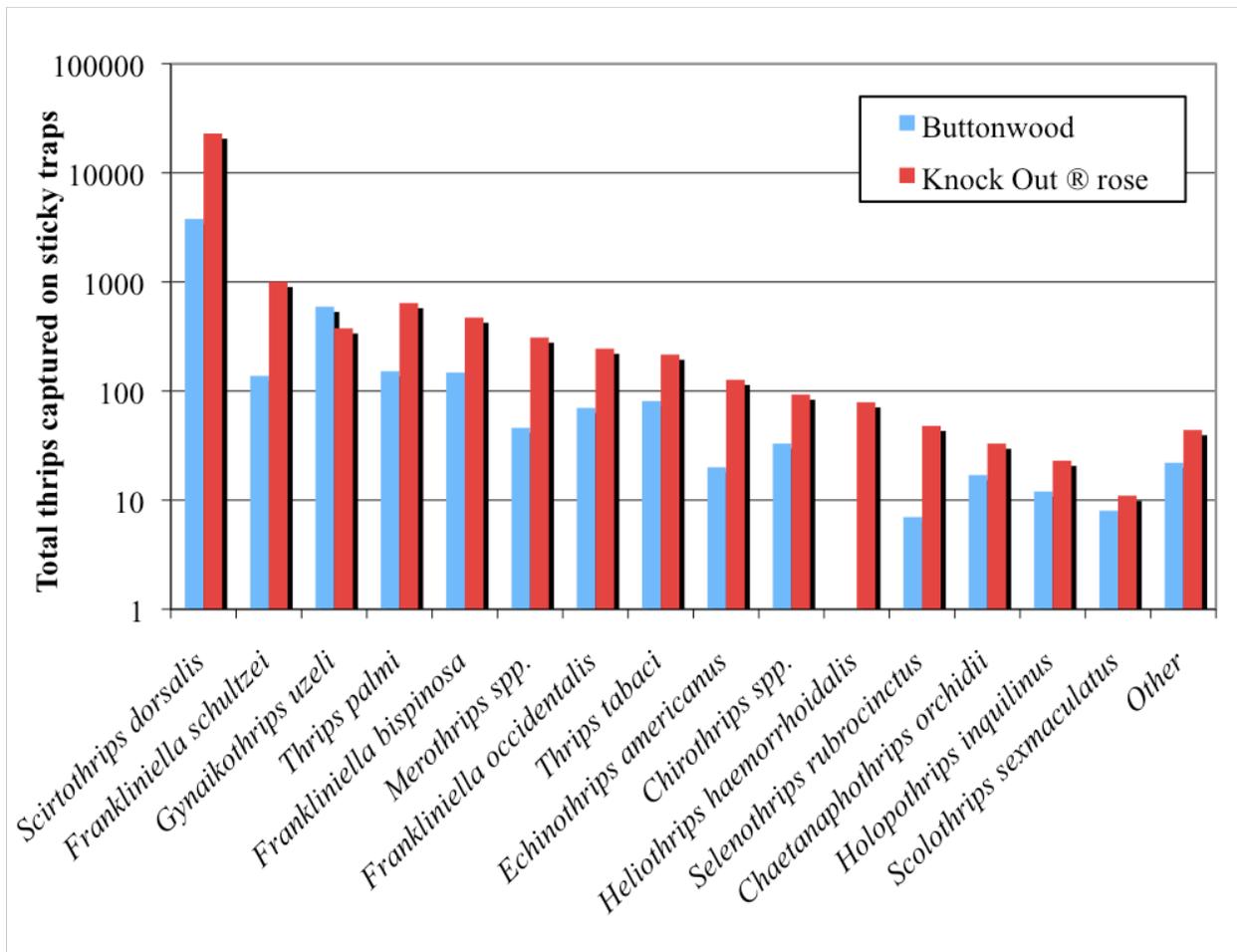


Figure 3-9. Total number of each species of thrips collected above each host plot from August 2007 to September 2008 using yellow 7.6x12.7 cm sticky traps.

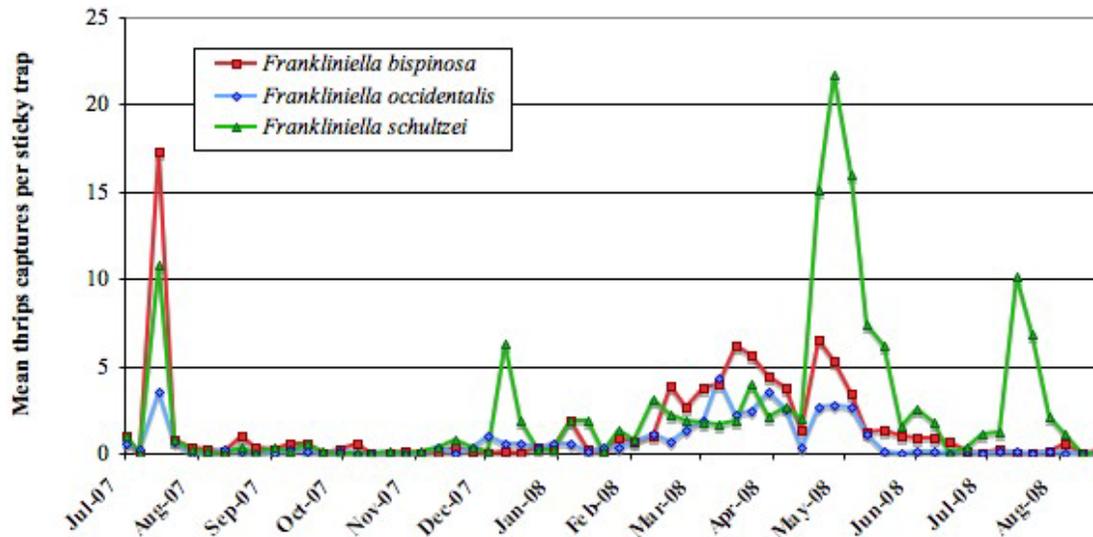


Figure 3-10. Weekly mean captures of genus *Frankliniella* on yellow sticky traps placed above buttonwood and Knock Out® rose.

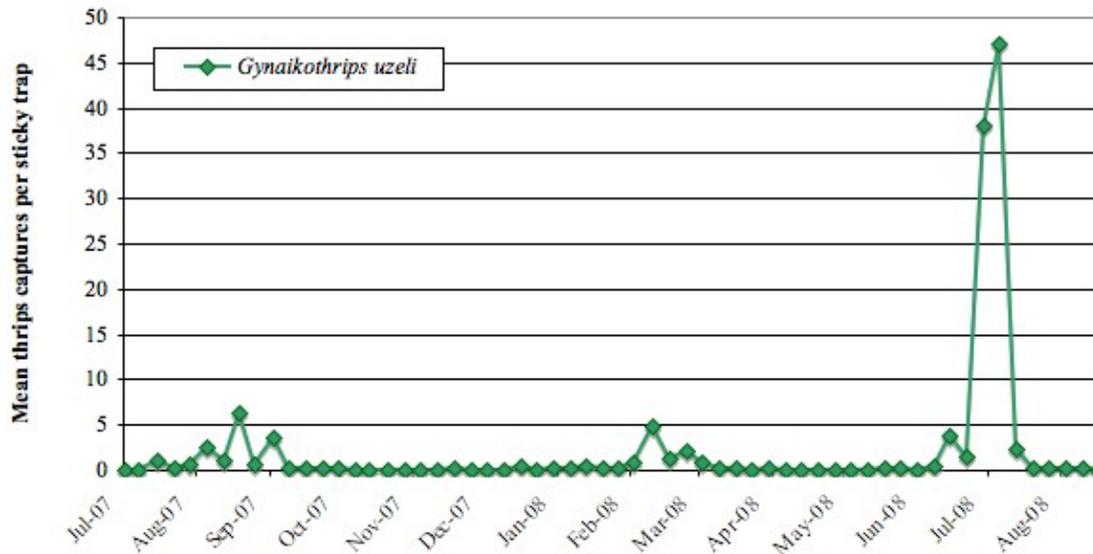


Figure 3-11. Weekly mean captures of *Gynaikothrips uzeli* on yellow sticky traps placed above buttonwood and Knock Out® rose.

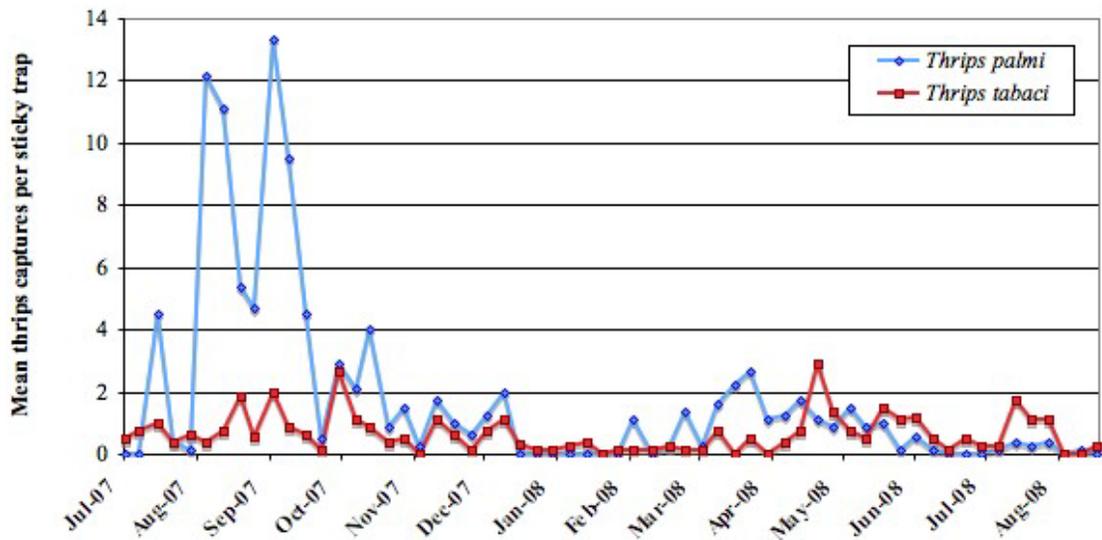


Figure 3-12. Weekly mean captures of genus *Thrips* on yellow sticky traps placed above buttonwood and Knock Out® rose.

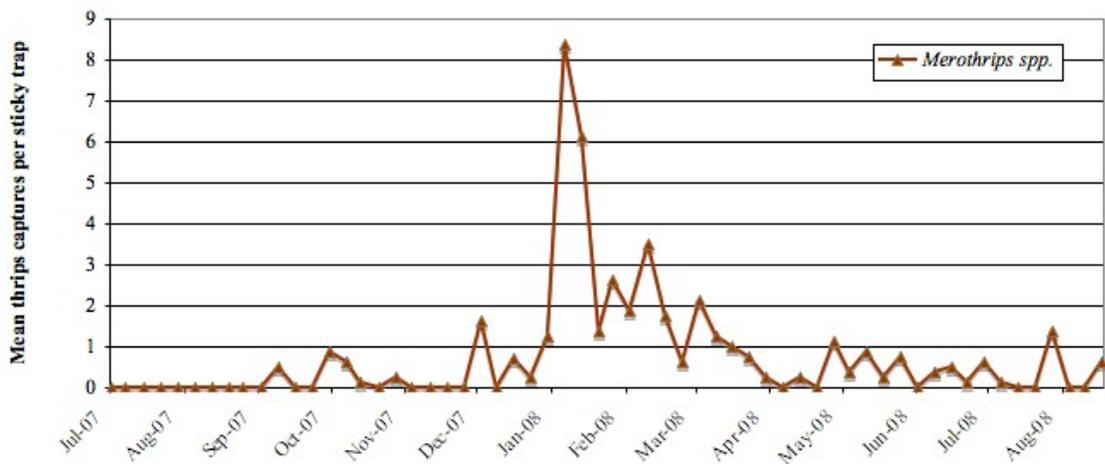


Figure 3-13. Weekly mean captures of *Merothrips* spp. on yellow sticky traps placed above buttonwood and Knock Out® rose.

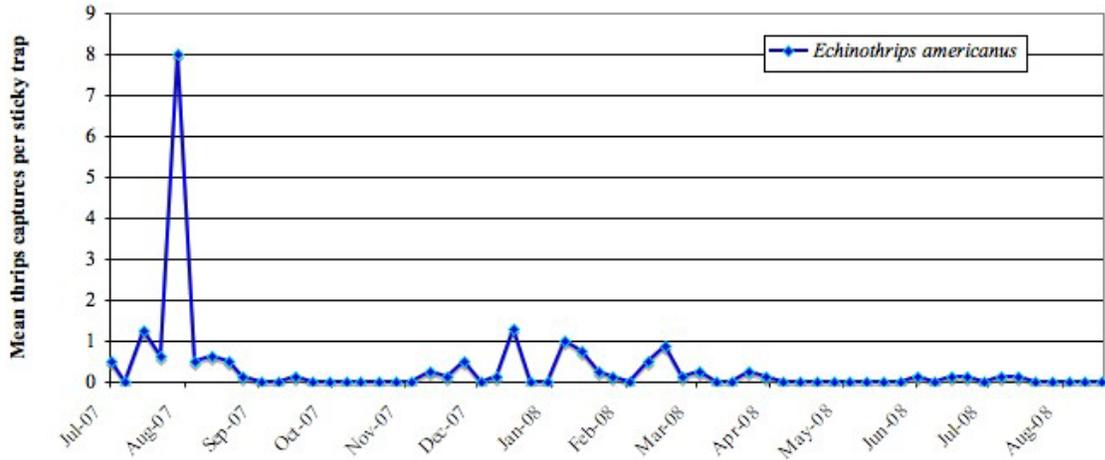


Figure 3-14. Weekly mean captures of *Echinothrips americanus* on yellow sticky traps placed above buttonwood and Knock Out ® rose.

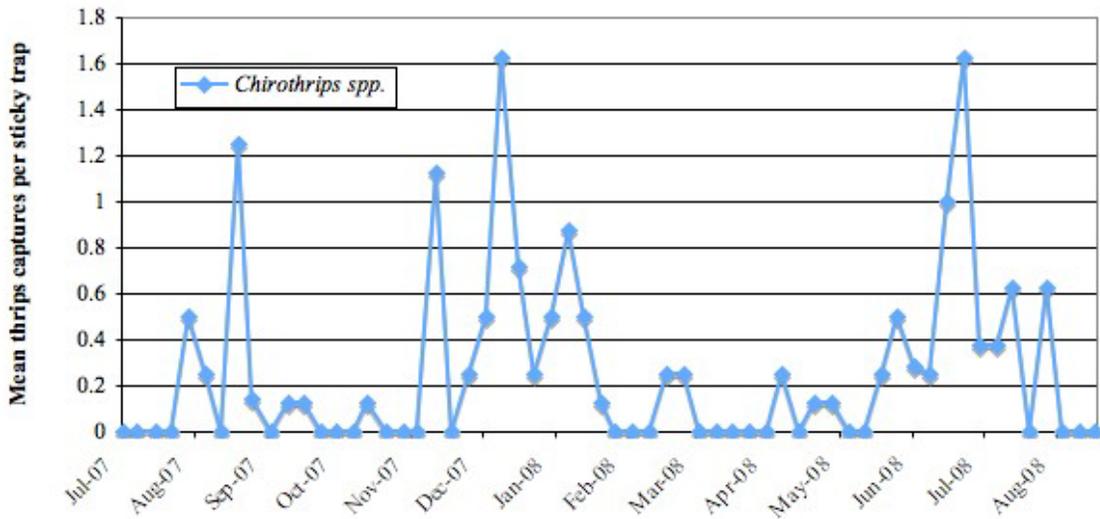


Figure 3-15. Weekly mean captures of *Chirothrips spp.* on yellow sticky traps placed above buttonwood and Knock Out ® rose.

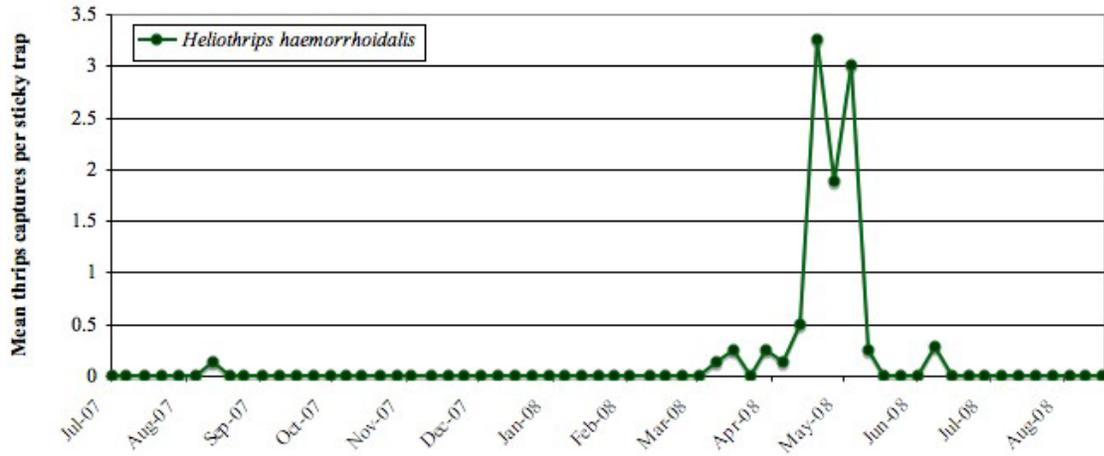


Figure 3-16. Weekly mean captures of *Heliethrips haemorrhoidalis* on yellow sticky traps placed above buttonwood and Knock Out® rose.

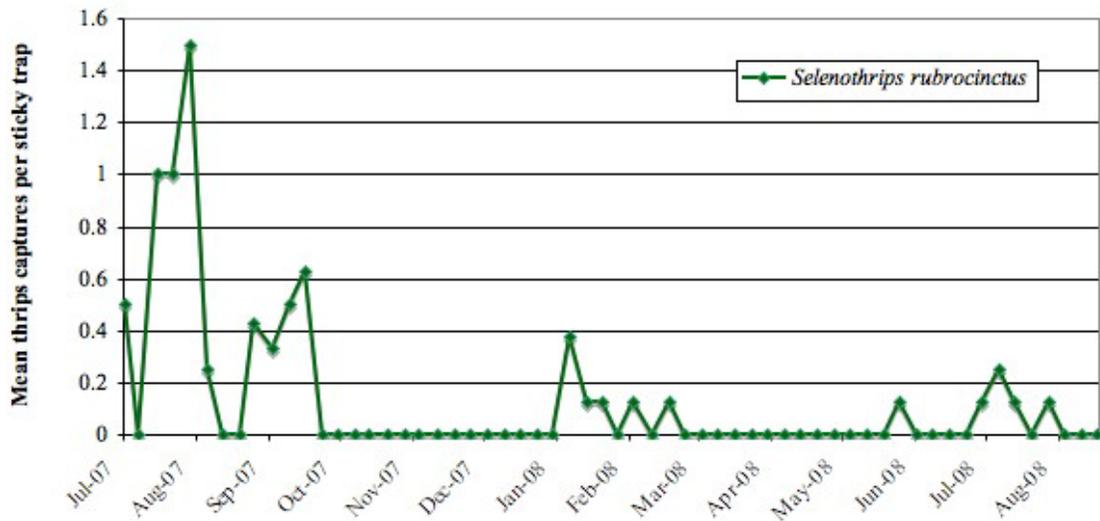


Figure 3-17. Weekly mean captures of *Selenothrips rubrocinctus* on yellow sticky traps placed above buttonwood and Knock Out® rose.

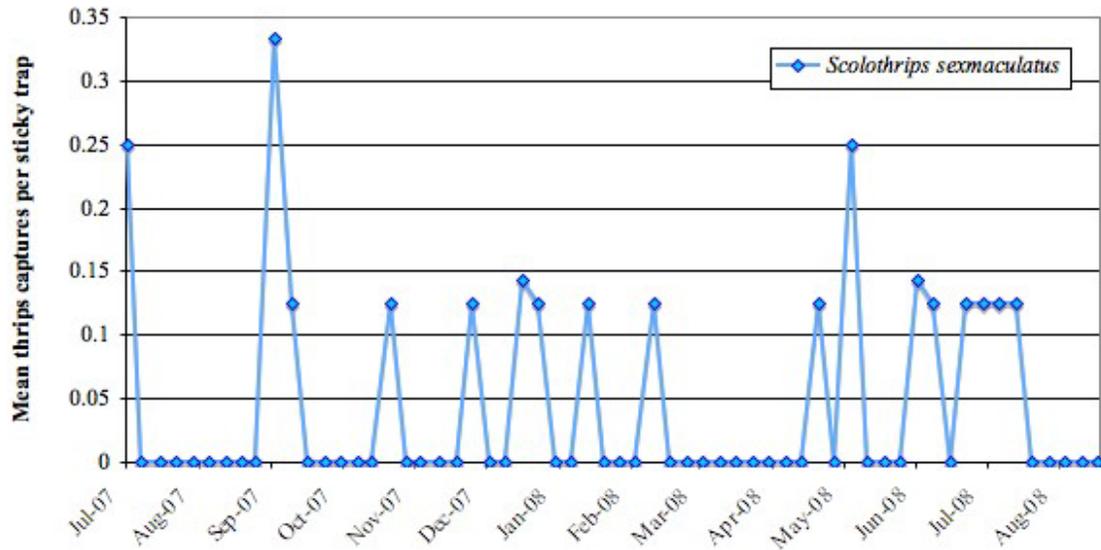


Figure 3-20. Weekly mean captures of *Scolothrips sexmaculatus* on yellow sticky traps placed above buttonwood and Knock Out ® rose.

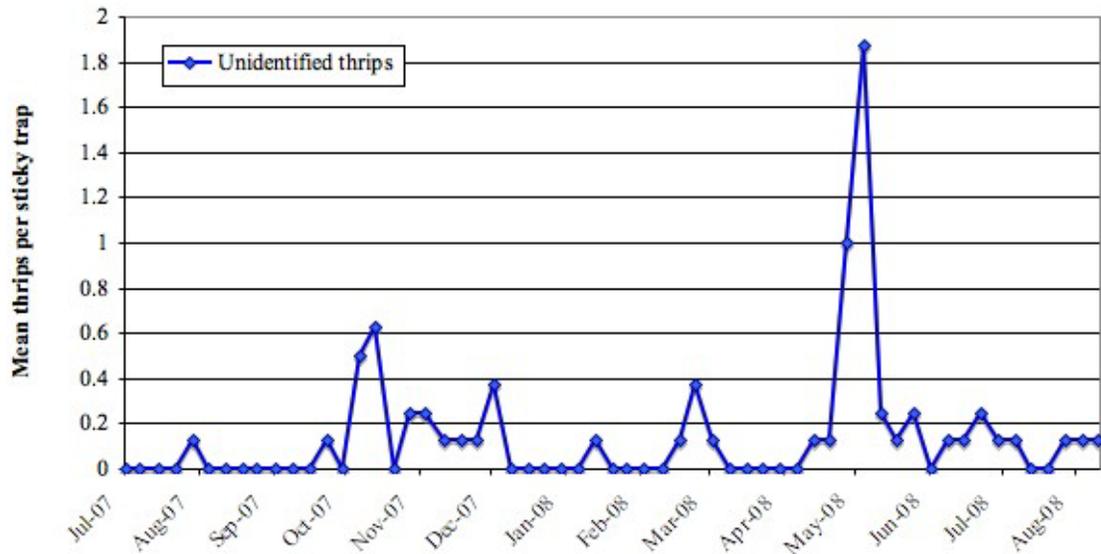


Figure 3-21. Weekly mean captures of low-abundance low-frequency unidentified thrips on yellow sticky traps placed above buttonwood and Knock Out ® rose.

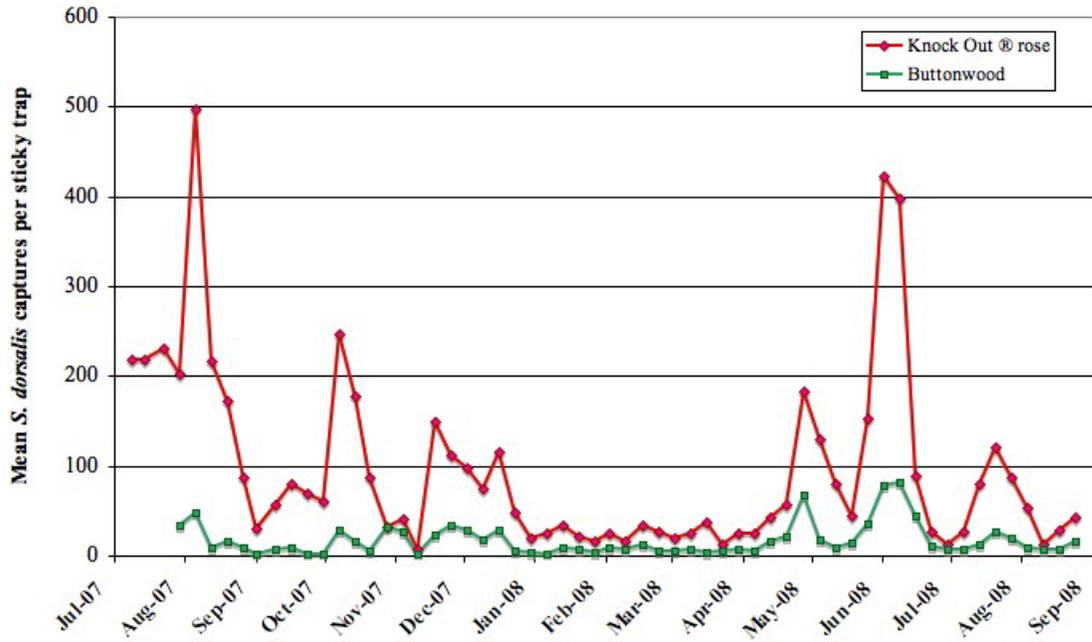


Figure 3-22. Weekly mean captures of *Scirtothrips dorsalis* on yellow sticky traps placed above buttonwood and Knock Out® rose.

CHAPTER 4
EFFECTS OF FERTILIZER RATE AND ROSE CULTIVAR ON POPULATIONS OF
Scirtothrips dorsalis HOOD (THYSANOPTERA: THIRIPIDAE) IN SOUTHERN FLORIDA

Introduction

Scirtothrips dorsalis Hood (1919) is a polyphagous insect pest whose global distribution has expanded rapidly over the last twenty years, becoming established in southern and central Florida (Silagyi and Dixon 2006). This insect pest shows considerable potential for expansion into the rest of North America (Venette and Davis 2004, Meissner et al. 2005, Nietschke et al. 2008), and impacts several fruit and vegetable hosts of economic significance, including *Fragaria x annanasa* Duchesne (strawberry), *Mangifera* spp. L. (mango), *Capsicum* spp. L. (pepper), *Citrus* spp. L., *Gossypium* spp. L. (cotton), *Glycine max* (L.) Merr (soybean), and *Arachis hypogaea* L. (peanut).

This thrips is also a pest on ornamental hosts, and has proved a key pest of rose for the cut-flower industry in India, reducing the quality, number, size, and appearance of the flowers produced (Onkarappa and Mallik 1998, Duraimurugan and Jagadish 2004a). Leaves, sepals, and petals develop a characteristic bronze scarring (Dev 1964, Chandrasekaran 2005), and prolonged high-density infestations leave plants looking scorched, or result in the death of the plant (Mound and Palmer 1981). Damaged plants are considered unattractive, and do not sell.

Several authors have explored the damage caused by and preferences of *S. dorsalis* on different cultivars of rose. Gahukar (2003) tested the cultivars Gladiator, Folklore, and Landora, while Onkarappa and Mallik (1998) worked with 'Redgold', and Duraimurugan and Jagadish (2004a, b) worked with 'Local Red'. Recently, researchers have documented the impact and performance of this thrips on the Knock Out Rose ® in Florida and Texas (Palmer and Veal 2008). Only Gahukar (2003) compared the effect of cultivar on thrips populations. He showed that while there was a high degree of variability from year to year and among cultivars, plots of

‘Gladiator’ had the highest infestation rate, the highest abundance of thrips in blooms, and greater numbers of thrips for all sizes of flower. Gahukar also showed that the color of blooms had an effect on population distribution, with red flowers holding more thrips than orange and yellow flowers.

The Knock Out Rose ®, *Rosa* ‘Radrazz’ (Radler 2001) has become a popular landscape choice in Florida due to its abundant flowers, low maintenance requirements, and strong resistance to black spot, *Diplocarpon rosae*, in Florida’s humid environment (Brown 2007). Unfortunately, the Knock Out Rose ® has also proven to be an important ornamental host to the invasive thrips, *S. dorsalis* (Silagyi and Dixon 2006). This has led to a change in the ornamental landscape as fewer nurseries in south Florida offer and fewer landscapers recommend the previously popular rose to homeowners out of concern for the damage caused by the thrips (personal observation).

The Conard-Pyle company recently developed a new cultivar of Knock Out Rose ®, the Sunny Knock Out ®, *Rosa* ‘Radsunny’ (PP#18562). It is reputed to have similar foliage and disease resistance to the original Knock Out Rose ®, *Rosa* ‘Radrazz’ (PP#11836), but produces bright yellow blooms that fade to white as they age, and the petioles release a strong “sweetbriar” fragrance. However, the susceptibility of this new cultivar to *S. dorsalis* has not yet been determined.

There is concern that the common nursery practice of adding nutrients to promote or “push” the growth of ornamental plants may be aggravating populations of *S. dorsalis*. Plants provided with higher nitrogen content are frequently more attractive to pest insects (Slansky and Rodriquez 1987). Heavily fertilized plants have more free amino acids in their tissues, allowing for the rapid growth of the plant and the populations of pest insects feeding upon them (Mattson

1980). Fertilized plants may provide additional attractive cues to pest populations by increasing plant height or the size and number of blooms produced.

This trend holds true for the Thysanoptera, with elevated concentrations of fertilizer resulting in a higher growth rate of *Frankliniella occidentalis* (Chau et al. 2005). This process will be mediated by the specialized secondary compounds produced by resistant cultivars (Schuch et al. 1998) or by particular host species (Reitz 2002). With higher fertilizer rates, Duraimurugan and Jagadish (2004b) observed larger populations of *S. dorsalis* on rose. Varghese and Giraddi (2005) recommended halving the amount of fertilizer used on chili in conjunction with azadirachtin application when controlling for *S. dorsalis*.

As this thrips may thrive in both agricultural and ornamental landscapes, both grower and homeowner must simultaneously apply a comprehensive integrated pest management program that considers both of their unique environments to prevent the establishment of reservoir populations, or the development of resistance to commercial pesticides. Additional knowledge and awareness of the specific impact of this thrips upon additional varieties of landscape roses popular in Florida would be valuable in constructing techniques for integrated pest management.

The purpose of these experiments was to evaluate the effect of two recommended fertilizer rates and cultivar on the population density of thrips and host plant damage.

Materials and Methods

Fertilizer Rate with ‘Radrazz’

The first experiment (May to August), examined two recommended fertilizer rates on ‘Radrazz’ using eighteen ‘Radrazz’ roses of approximately one year in age. These were grown in 11.36 liter containers in a medium consisting of 50% Canadian sphagnum peat moss, 25% processed pine bark, and a mixture of perlite and vermiculite (Fafard 3B Mix, Conrad Fafard Inc., Agawam, Massachusetts). They were placed in an outdoor area at the University of Florida

Tropical Research and Education Center (TREC) campus in Homestead, Florida. These plants had established infestations derived from naturally occurring populations of *S. dorsalis*. Six plants were then randomly assigned to one of three treatments.

The “high” fertilizer treatment was recommended by local growers to accelerate plant growth, which were fertilized with an application of 7.92 grams of liquid fertilizer (Peter’s Professional, Scotts Company, Marysville, Ohio) (NH₃: NO₃: (NH₂)₂CO: P₂O₅: K₂O = 4:6:10:20:20) every other week, and 13.0 grams of pellet fertilizer (NH₃: NO₃: P₂O₅: K₂O = 15:9:12) (Osmocote Plus, Scotts Company, Marysville, Ohio) once every other month. The “maintenance” fertilizer treatment was recommended by local growers to maintain plants, which were fertilized with 3.96 grams of liquid fertilizer once per month, and 7.5 grams of pellet fertilizer once every other month. The control plants received only water when other plants received their application of liquid fertilizer, and no solid fertilizer amendments. All plants were then randomly placed in an uneven four by five grid that separated each plant from their neighbors by a third of a meter.

Fertilizer Rate with ‘Radsunny’ and ‘Radrazz’ Cultivars

The second experiment (August to October) compared the effect of fertilizer rate on ‘Radrazz’ and ‘Radsunny’ cultivars. Twenty-four ‘Radrazz’ and ‘Radsunny’ bare-root rose plants provided by the Conard-Pyle Company were raised in a thrips-free greenhouse in 11.36 liter containers using identical media to the first experiment for three months, and then transferred to an outdoor growing area at the TREC campus. These plants were exposed to ‘Radrazz’ roses previously infested (three *S. dorsalis*/cm² in flowers) with naturally established populations of *S. dorsalis* by placing them half a meter downwind of an infested plot. Four replicates containing one of each treatment and cultivar were randomly placed within a six by eight grid that separated each plant from their neighbors by a third of a meter. Eight plants of

each cultivar were randomly assigned to one of three fertilizer treatments identical to the rates used in the previous experiment.

Susceptibility of Six Cultivars

The third experiment (September to November) compared populations of *S. dorsalis* on the top five selling cultivars of rose in Florida, and an additional Knock Out ® cultivar. Five plants from each of six cultivars of rose in 11.36 liter containers were donated by Nelson's Florida Roses in Apopka, Florida. These cultivars included Angel Face, Don Juan, Radcon (PP# 15070), Pink Summer Snow, St. Patrick (PP #9591), and Sun Flare. They were transported to the TREC on September 9th, 2008 and exposed to naturally occurring populations of thrips. Five replicates with one plant from each of six cultivars were placed in a random location within a five by six grid that separated each plant from their neighbors by a third of a meter.

All plants in all experiments remained exposed to ambient environmental conditions throughout the experiments, and were irrigated with 93 ± 15 mL using an overhead system at six in the morning and two in the afternoon, according to local water restrictions and extension office recommendations. The total number of buds and flowers was counted on each plant biweekly to develop a measure of the total floral output of the plant. A damage estimate similar to that described by Krishna Kumar et al (1996) for pepper was developed during preliminary observations and used to rate the damage to plants each week. Plants were rated from zero, with no symptoms, to five, at which point the plant was defoliated and near death.

For the first two experiments, mean thrips population estimates were assessed by randomly sampling a bud or flower (as available) from each plant every other week at three in the afternoon, as per Duraimurugan and Jagadish (2004a). In the third experiment, one flower, one leaf, and one bud was sampled from each plant at approximately three in the afternoon once every other week in order to determine the distribution of the pest within the plant as per

Onkarappa and Mallik (1998). For consistency, only mature leaves, buds, and flowers of a similar age were sampled. All samples were removed with pruning shears and sealed immediately in small plastic containers with two drops of 95% ethanol. Samples that could not immediately be processed were stored at -6 °C.

The total number and life stages of thrips in a sample was recorded by washing the samples with 75% ethanol and pouring the runoff through a 25 µm mesh, as per Seal and Baranowski (1993), and then examining the collected debris under a dissection scope at a minimum of 12x magnification. The Funderburk et al. (2007) key to species of ornamental thrips was used as a primary aid in identification. *Scirtothrips dorsalis* could rapidly be differentiated from other thrips present in the sample by their relative size and other distinguishing characters, including antennal, pronotal, and abdominal characters. Plant samples were then dried overnight and the area of each dried sample was determined using a leaf area meter (LI-3000, LiCor, Lincoln, Nebraska) to determine the density of thrips populations in each sample (thrips/cm²).

Biweekly sampling for the first experiment was conducted from 29 May 2008 to 7 August 2008. For the second experiment, floral samples were collected biweekly from 1 September 2008 to 22 October 2008. In the third experiment, samples were collected on the day of arrival in Homestead, and then biweekly thereafter from 11 September 2008 to 11 November 2008. Voucher specimens were collected and sent to the Florida Department of Plant Industry for preservation and to reconfirm species identification throughout the experiment.

The total number, proportion at each life stage, density of thrips, the size and number of flowers, and the recorded damage by cultivar and fertilizer treatment were compared among treatments. The total number of thrips and thrips densities were transformed by applying the square root to homogenize variance before analysis. Treatments were compared by ANOVA

using JMP statistical software (SAS Institute 2007). Means from the first two experiments were separated using pairwise *t*-test comparisons, and by Tukey's HSD in the third experiment. A two-way ANOVA was used to test for interactions between cultivar and fertilizer rate in the second experiment. Least square means were used to fit the general linear model and determine the strength of relationships between various factors in each experiment.

Results

Damage to plants during these experiments did not exceed a rating of two, where the new growth was wrinkled, and recent flush had scarring along the base of veins. Most sepals showed signs of scarring, and the outer petals of flowers and most leaves showed some stippling. Roses with a damage rating of one had damage on some sepals, but only a few petals and leaves showed any stippling.

Fertilizer Rate with 'Radrazz'

In the first experiment, there were no significant differences among treatments for the total number of thrips ($F = 0.48$; $df = 2, 108$, $p = 0.6124$) (Figure 4-1), thrips density ($F = 0.50$; $df = 2, 108$; $p = 0.6062$) (Figure 4-2), damage ratings ($F = 1.62$; $df = 2, 108$; $p = 0.2036$), or the mean area of sampled flowers ($F = 0.52$; $df = 2, 108$; $p = 0.5989$) for any and all evaluation dates, but mean values for all variables tested were greater for high and normal fertilizer rates than the controls, and total number of flowers and buds produced was significantly higher for the high and maintenance rates compared to the controls ($F = 4.28$; $df = 2, 108$; $p = 0.0163$).

Fertilizer Rate with 'Radsunny' and 'Radrazz' Cultivars

In the second experiment, no significant interaction was detected between cultivar and fertilizer rates for any of the tested variables, so treatment data could be compared independently by cultivar and fertilizer rate for analysis. No significant difference was observed between 'Radrazz' and 'Radsunny' cultivars for thrips abundance for any life stage or sex, thrips

densities, damage rating, floral area, or the total number of flowers and buds produced ($p > 0.24$).

A significant difference was observed among fertilizer treatments for the total number of thrips ($F = 3.46$; $df = 2, 232$; $p = 0.0330$) (Figure 4-3), for the total number of nymphs ($F = 3.99$; $df = 2, 232$; $p = 0.0197$) and adults ($F = 3.24$; $df = 2, 232$; $p = 0.0411$), for damage rating ($F = 5.07$; $df = 2, 232$; $p = 0.0070$) (Figure 4-4), but not for thrips densities (thrips/cm²) ($p = 0.1505$). For all variables, high and normal rates of fertilizer had higher mean values than the unfertilized control. Further analysis by week showed that these significant and increasing differences had occurred in the total number of thrips after five ($F = 3.32$; $df = 2, 44$; $p = 0.0455$) and seven weeks ($F = 4.53$; $df = 2, 44$; $p = 0.0162$) (Figure 4-5) after treatments had begun. There were no significant weekly differences between treatments in mean thrips density (thrips/cm²) (Figure 4-6).

A significant difference was not observed among fertilizer treatments for the total number of flowers and buds ($F = 2.38$; $df = 2, 232$; $p = 0.0951$) or for the mean area of flowers produced ($F = 2.98$; $df = 2, 150$; $p = 0.0538$). However, mean values for the high and normal fertilizer treatments did tend to be greater than the mean values for the controls.

During the experiment, no plant received a damage rating greater than two (moderate damage) in any given week. Due to the limited range of damage expressed, the predictive relationship of damage ratings to thrips populations could not be described. However, damage appeared to be more predictive of the total number of thrips than thrips density, and the scale was better at predicting the more abundant nymphs than adult populations.

Susceptibility of Six Cultivars

In the third experiment, preliminary sampling of the roses revealed a large number of *Frankliniella bispinosa* (Morgan) (Thysanoptera: Thripidae). Throughout the entire period of the

experiment, *F. bispinosa* accounted for a quarter of all thrips sampled, but the mean number and percentage of *F. bispinosa* nymphs and adults collected on plants steadily fell while the number and percentage of *S. dorsalis* captures increased (Figure 4-7).

No significant interaction was observed between cultivar and time for thrips abundance, density, or damage. Thrips density was observed to increase on all hosts for the first five weeks, and then stayed statistically constant (Figure 4-8). After five weeks, *S. dorsalis* were detected on all plants for all cultivars of rose tested.

Cultivar ($F = 3.55$; $df = 5$; $p = 0.0037$) and plant organ ($F = 96.09$; $df = 2$; $p < 0.0001$) had a significant effect upon thrips densities, but no interaction was detected between cultivar and plant organ ($F = 1.81$; $df = 10$; $p = 0.0562$).

The significant difference in thrips density between cultivars ($F = 2.23$; $df = 5, 519$; $p = 0.0496$) (Figure 4-9) suggested three tiers of hosts. ‘Radcon’ had the highest thrips density at 1.64 ± 0.31 thrips/cm² (MSE); followed by ‘Don Juan’, ‘Pink Summer Snow’, and ‘St. Patrick’ with approximately 1.10 ± 0.27 thrips/cm²; and ‘Angel Face’ and ‘Sun Flare’ with approximately 0.59 ± 0.16 thrips/cm² per weekly sample.

Plant organs sampled also showed significant differences ($F = 89.14$; $df = 5, 519$; $p < 0.0001$) (Figure 4-10), with buds showing 0.56 more thrips/cm² than petals or leaves.

While no plant was observed with a damage rating greater than one during the experimental period, a significant difference was detected in mean damage ratings for each cultivar ($F = 5.42$; $df = 5, 519$; $p < 0.0001$) (Figure 4-11).

Discussion

The results of the first and second experiment comparing different rates of fertilizer appear to conflict. In the first experiment, fertilizer rate had no significant effect upon either thrips populations or floral traits, while in the second experiment fertilizer rate had a significant effect

upon thrips populations. The lower number of samples per treatment in the first experiment certainly reduced the power of the test, but the data was suggestive of trends observed in the second experiment. There are other possible explanations: in the first experiment, fertilizer treatments were applied to plants with an established infestation of *S. dorsalis*, and in the second experiment, fertilizer treatments were applied to thrips-free plants without an established infestation. Established populations that have not yet reached capacity may be less susceptible to assortment and dispersal pressures, and less indicative of thrips' host choices.

While the 'Radsunny' and 'Radrazz' cultivars of Knock Out Rose ® can easily be distinguished by their different foliar appearance, the obvious difference in petal color, and by a very distinct floral scent, populations of *S. dorsalis* seem to be evenly distributed throughout both hosts without regard to cultivar. This might appear surprising, as this thrips has been captured in greater frequencies on yellow (Tsuchiya et al. 1995, Chu et al. 2006) or yellow and green (Tsuchiya et al. 1995) sticky traps than those of other colors. However, Rani and Sridhar (2003) and Gahukar (2003), recovered more adults of *S. dorsalis* on red or orange rose petals than yellow ones in a small arena choice-test. While these results may appear to conflict, it is possible that *S. dorsalis* uses different cues and selection criteria to choose a host at different spatial scales. Rani and Sridhar, and Gahukar's choice-tests occurred in small arenas within the lab, while Tsuchiya et al. and Chu et al. performed their choice tests in the field. Comparing those observations to the results of the second experiment suggests that at a range of less than one meter, *S. dorsalis* does not appear to choose between the two Knock Out ® roses based on criteria that are obvious to human observers, such as color or scent. Other factors may be more important to *S. dorsalis*' local dispersal and distribution.

This experiment does reveal that some choice of host is occurring, and hints at some of those hidden criteria, as there is an uneven distribution of *S. dorsalis* among fertilizer treatments. Populations of *S. dorsalis* were significantly more abundant on hosts that have been treated with fertilizer than those that were untreated. Interestingly, thrips density between the three fertilizer rates remained relatively constant, suggesting that populations of this thrips have distributed themselves evenly across the plants in order to exploit resources with minimum competition. It is possible that with higher pest pressure and a higher total population of thrips, crowding would begin to occur. High nutrient plants would show significantly greater densities as a larger proportion of free nutrients should still be available when compared to unfertilized hosts. However, it is also possible that there are physical upper limits on the number of thrips that might exploit a host simultaneously.

Each thrips destroys mesophyll cells when it feeds, and leaves a patch of scarred and cellulosic tissue behind. Therefore higher densities may well exceed the ability of the afflicted plant to replace damaged tissue. The relationship between thrips density and observed feeding damage might have been better described by a different damage rating scale than the one used. The limited range of damage observed made it difficult to draw strong conclusions about the relationship between thrips populations and damage. With this in mind, the scale was predictive of the number of nymphs and adults detected in flowers, but could not account for a large proportion of the variation present in populations.

Perhaps most surprising was that while the highest fertilizer rate tested did produce significantly more and larger blooms than the controls, the higher rate did not produce significantly more or larger blooms than the maintenance treatment of fertilizer. This suggests that the maintenance level provides sufficient nutrients for near-maximum floral growth, with

diminishing returns in additional flowers grown with nearly twice the investment of fertilizer. It is possible that the higher rate of fertilizer allowed for a greater proportion of vegetative growth, a variable not tested in this experiment. However, flowers produced by the high nutrient plants also showed significantly higher damage, and analysis suggests that this is due in part to the larger populations of thrips identified on the plant. Varghese and Giraddi's (2005) recommendations to halve the fertilizer used on chili can probably be used as a control mechanism to limit populations and damage caused by *S. dorsalis* in the Knock Out® and other cultivars of rose.

When comparing absolute counts of thrips on the other cultivars tested, 'St. Patrick', 'Don Juan', and 'Radcon' had the largest mean populations of *S. dorsalis*, but when looking at thrips density per square centimeter, the smaller flowers of 'Radcon' and 'Pink Summer Snow' were not statistically different than those of the larger 'St. Patrick' and 'Don Juan' roses. This is similar to the findings of Gahukar (2003), in that large open flowers can play host to larger absolute numbers of thrips, but smaller and more compact flowers may have a relatively greater number of thrips per unit area. This suggests that these hosts provide similar environments for *S. dorsalis*, and that vegetative size should determine total thrips population. Factors endogenous to the cultivar of rose still appear to play a role, as the Angel Face cultivar had a lower mean density of thrips and experienced less damage relative to thrips density than the other cultivars tested. This may represent host resistance preventing growth, or a thrips preference based on the structural, chemical composition of a particular cultivar.

It should be noted that while thrips densities are valuable for comparing different cultivars of rose or different species of plant, the total number of thrips may be important to questions of population expansion and control. Larger populations are better able to persist through

catastrophic ecological events, and increase pressure on surrounding environments (Memmott et al. 1997, Fagan et al. 2002), especially if the larger roses have a greater overall floral area, or produce a larger number of buds.

S. dorsalis was found in significantly higher densities on the rose buds than on rose flowers or on leaves. Many Thripidae appear to prefer the upper part of the plant canopy and the outer extremities of their hosts (Reitz 2002, Hansen et al. 2003), and removing growth terminals in citrus resulted in increased migration of *S. dorsalis* populations away from treated plants (Shibao et al. 1993, Shibao 1997). It has been suggested that thrips prefer these areas because nutrient flow in plants is towards these areas of new growth (Lewis 1997). This is not inconsistent with prior research regarding this thrips on *Capsicum annuum* L. (chili pepper) (Seal et al. 2006), *Ricinus communis* L. (castor) (Raizada 1965), or *Camellia* spp. L. (tea) (Dev 1964). Females of *S. dorsalis* prefer to lay their eggs inside of young leaves and buds at the apical meristem of plants, but as populations increase, will lay their eggs within the surface of mature leaves (Dev 1964, Raizada 1965). After hatching, nymphs will migrate from older leaves to the newer growth at terminals (Onkarappa and Mallik 1998).

While thrips were not present in high densities or abundances on the leaves, the nymphs left evidence of their presence through their distinctive feeding damage. More importantly, *S. dorsalis* was present on leaves in densities that were not significantly different than those within the petals of flowers. This should not be surprising, as the petals of flowers are merely developmentally modified leaves distributed within a much smaller volume. This may help to explain a discrepancy in the literature where this thrips is sometimes referred to as a flower thrips, and in other references is referred to as an exclusively foliar thrips. *S. dorsalis* may thrive equally well on both substrates, and exogenous environmental factors such as heavy

precipitation, predation, or competition may determine the distribution of populations within the plant.

There was no interaction between plant organ and cultivar, further evidence suggesting that this thrips will exploit all roses in a similar fashion, even as they afflict some varieties in greater densities than others. This was not necessarily the expected result, as Shibao et al. (1990) observed that while overall populations of *S. dorsalis* were similar between two varieties of grape, there were still internal distributional differences. This implies that the method by which this thrips exploits these plant resources is fairly similar, in spite of the roses' morphological (and presumably chemical and nutrient) diversity.

Of the cultivars tested, 'Radcon', 'Don Juan', and the 'Sun Flare' experienced the worst damage relative to their thrips abundance and density. Of the three, the 'Sun Flare' had the highest susceptibility to damage by this thrips, with the highest damage relative to the number and density of thrips present. However, of the cultivars tested, the 'Radcon' consistently scored higher damage ratings, abundances, and densities than most of the other five cultivars tested. This continues to lend credence to the initial speculation by extension agents that the Knock Out® variety of rose may be an important host to consider when surveying for this thrips.

While damage ratings never exceeded a value of two, prior research (personal observations) suggests that this may not be unusual for this thrips' behavior during the fall season that this experiment was conducted in south Florida. It is possible that damage and thrips density would increase on all cultivars during seasons that are more inclement to population growth of *S. dorsalis*, thereby aggravating the plants with more pest pressure and increasing the observable differences between cultivar responses to the pest. Furthermore, it is possible that the presence of multiple cultivars may not describe the performance of this thrips when only one of

these hosts is present. It is possible that in a no-choice experiment, some cultivars would actually show a higher degree of damage or thrips abundance and density.

Acknowledgements

The researchers would like to thank the Conard-Pyle company for providing the Knock Out ® roses used in this study, and to thank Nelson's Roses of Florida for donating the other cultivars of rose tested.

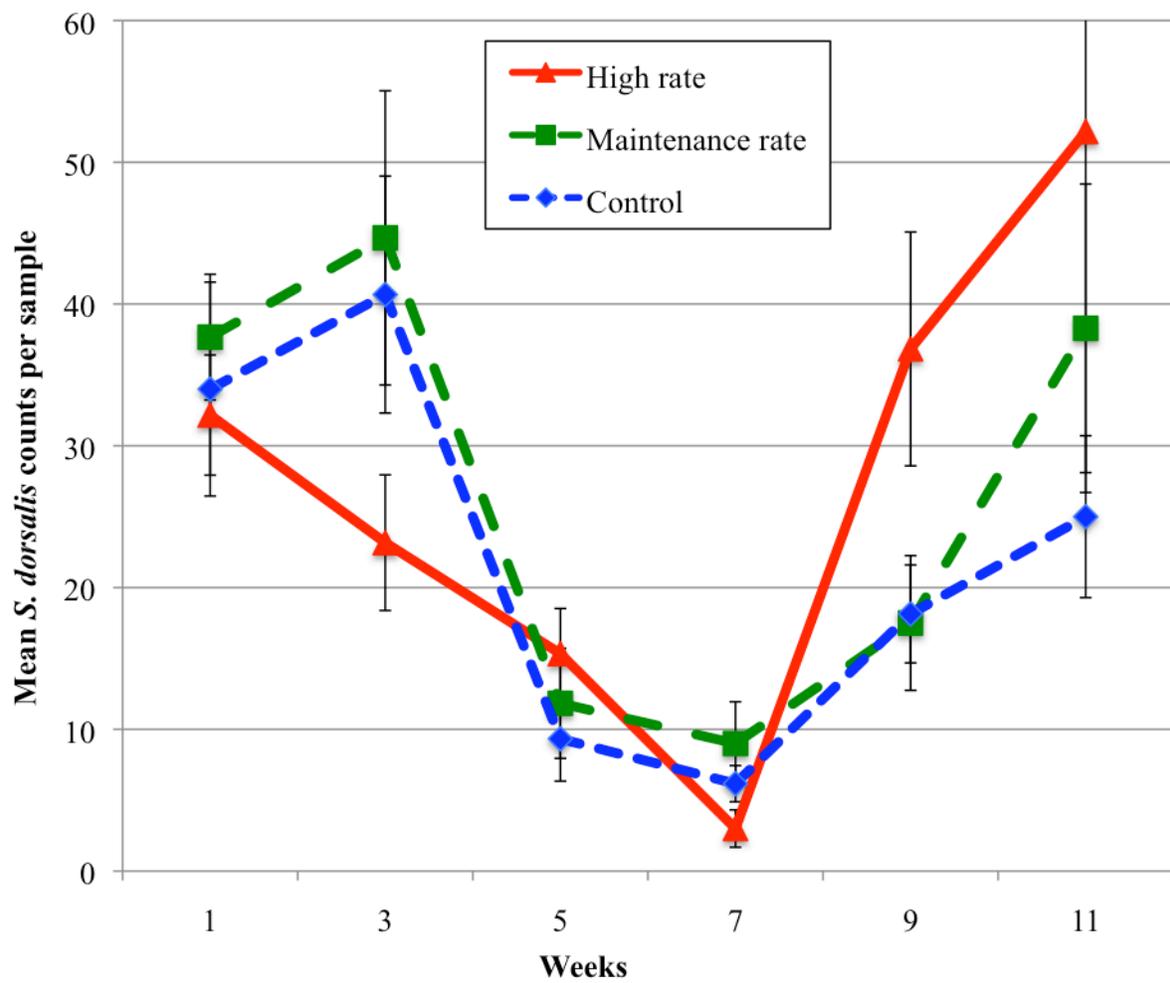


Figure 4-1. Weekly mean total number of thrips plus mean standard error for three fertilizer rates (no significant differences).

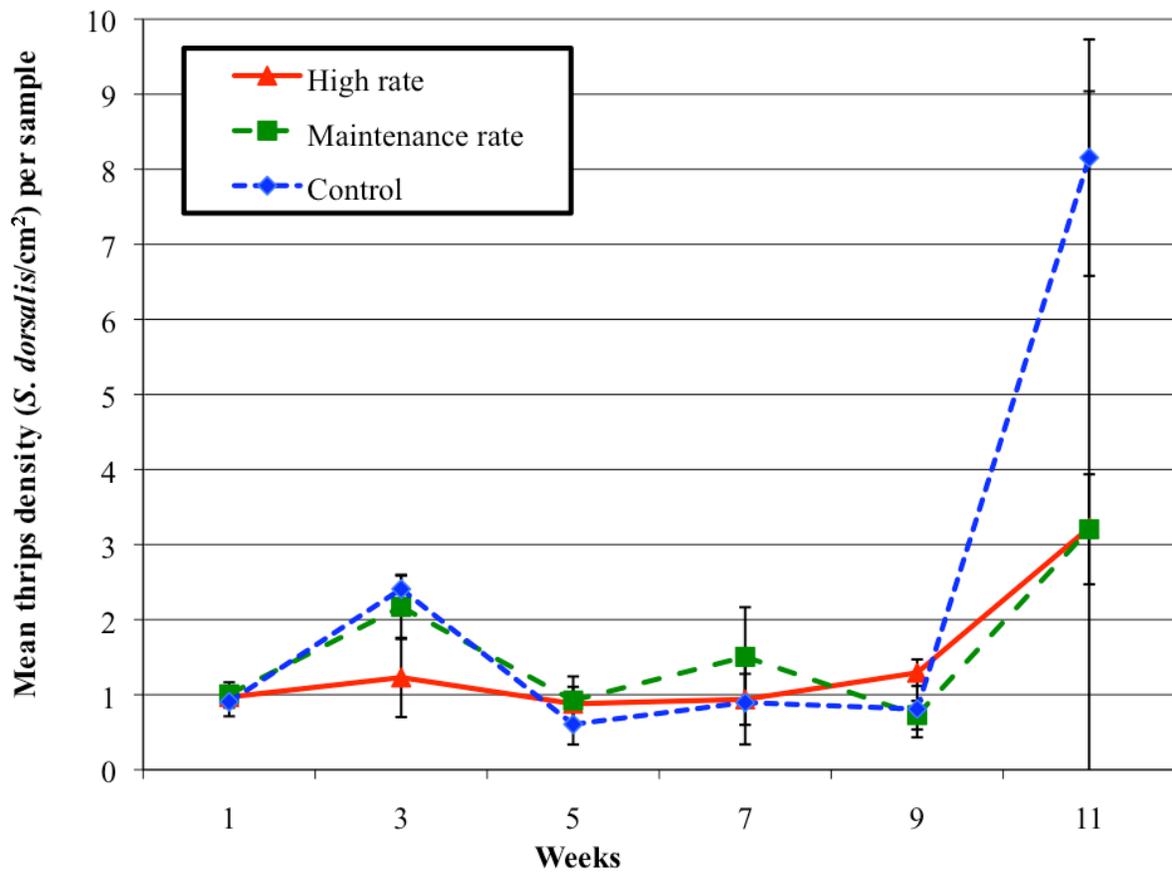


Figure 4-2. Weekly mean thrips density (*S. dorsalis*/cm²) plus mean standard error for three fertilizer rates (no significant difference).

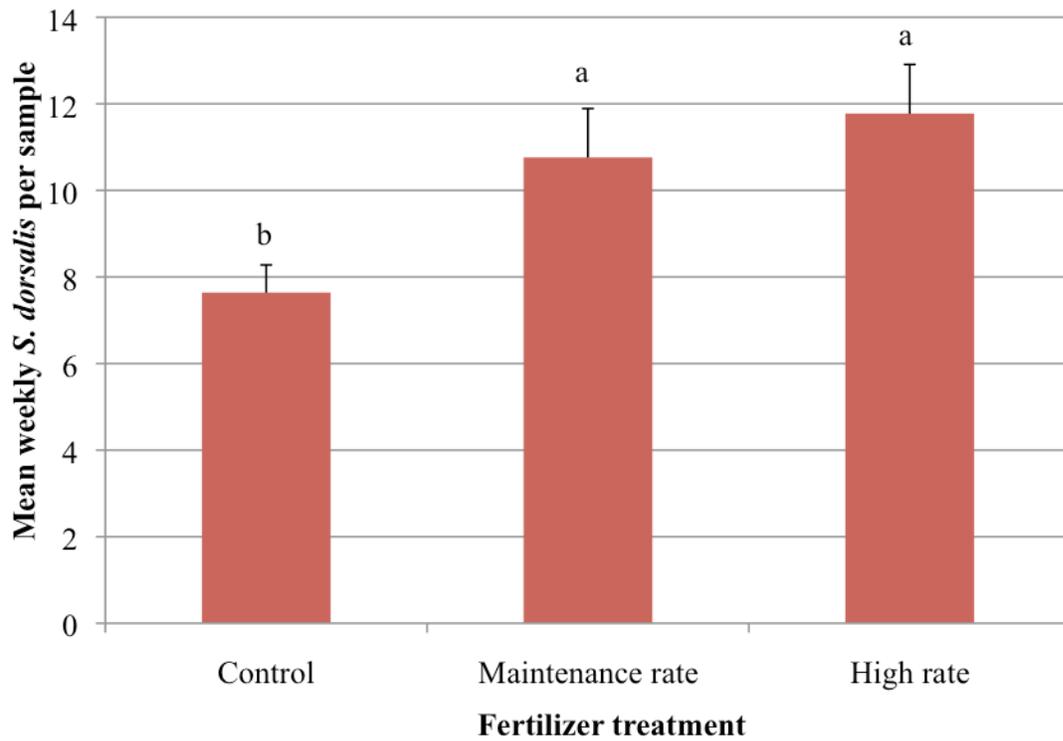


Figure 4-3. Mean total number of *Scirtothrips dorsalis* per floral sample for each fertilizer rate plus mean standard error (different letters among fertilizer treatments are significantly different by multiple pairwise *t*-test comparisons at $\alpha = 0.05$).

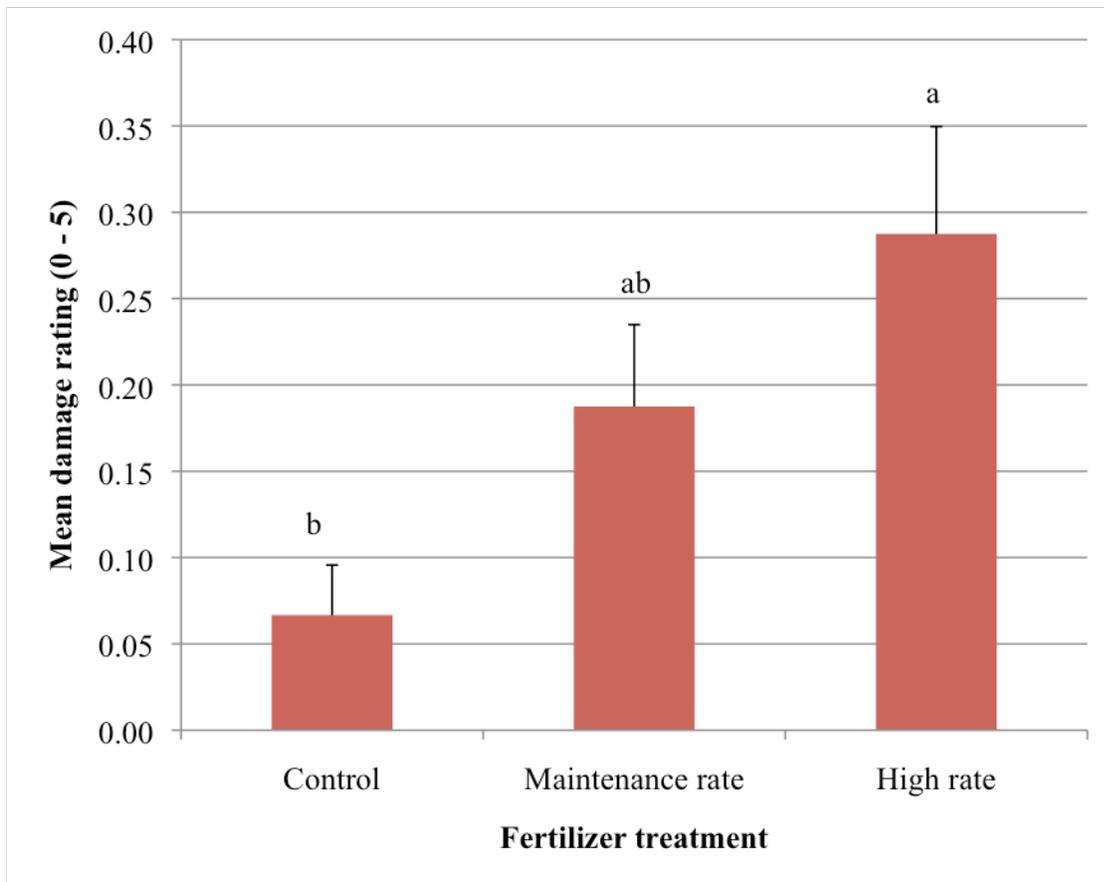


Figure 4-4. Mean damage rating recorded for each fertilizer treatment plus mean standard error (different letters among fertilizer treatments are significantly different by multiple pairwise *t*-test comparisons at $\alpha = 0.05$).

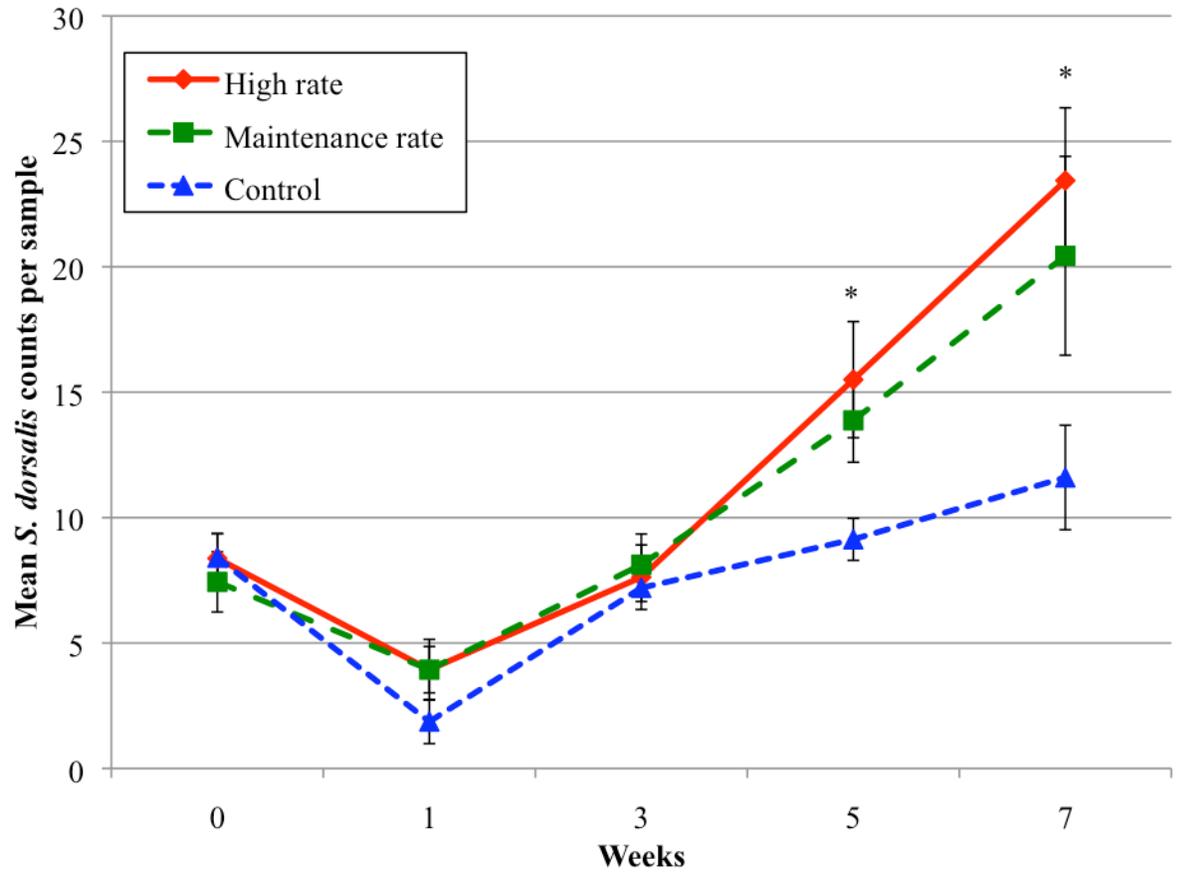


Figure 4-5. Weekly mean total number of thrips plus mean standard error for three fertilizer rates (* = high and maintenance rates are significantly different from control by multiple pairwise *t*-test comparisons at $\alpha = 0.05$).

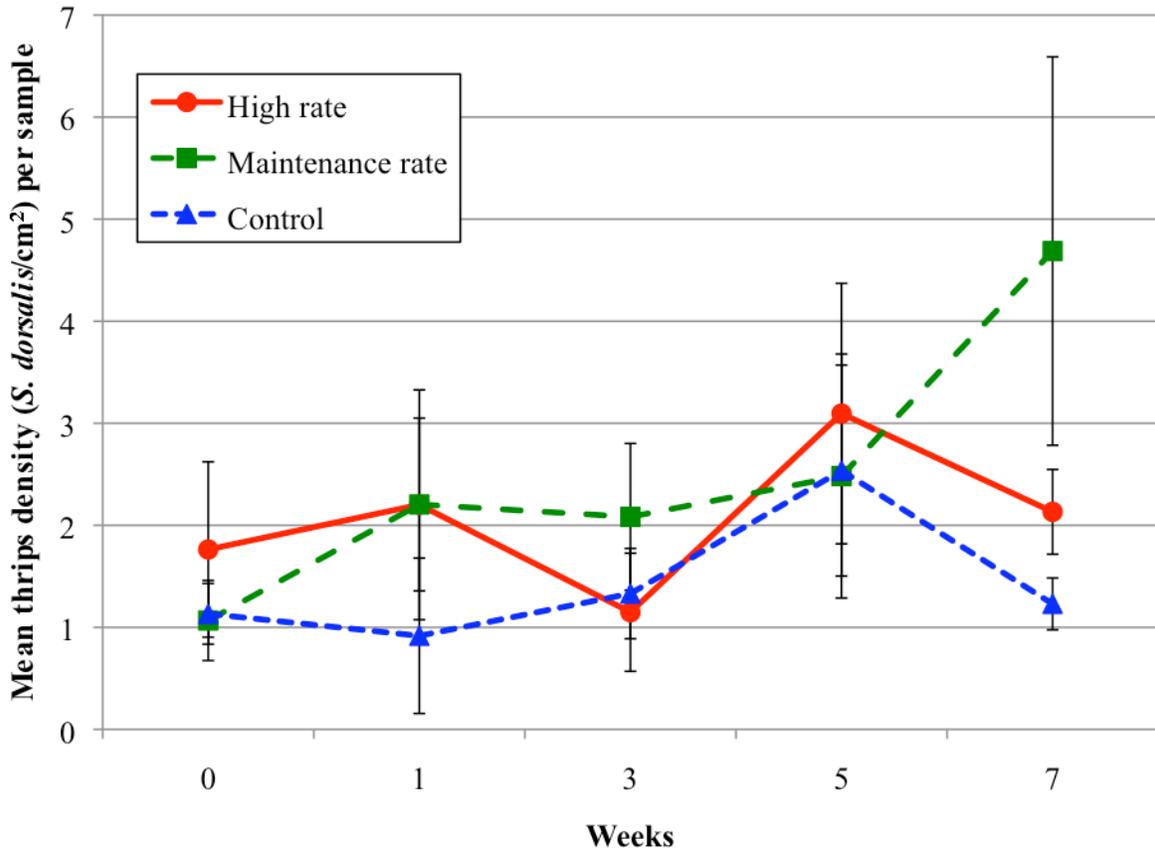


Figure 4-6. Weekly mean thrips density (*S. dorsalis*/cm²) plus mean standard error for three fertilizer rates (no significant differences detected using multiple pairwise *t*-tests, with $p > 0.25$).

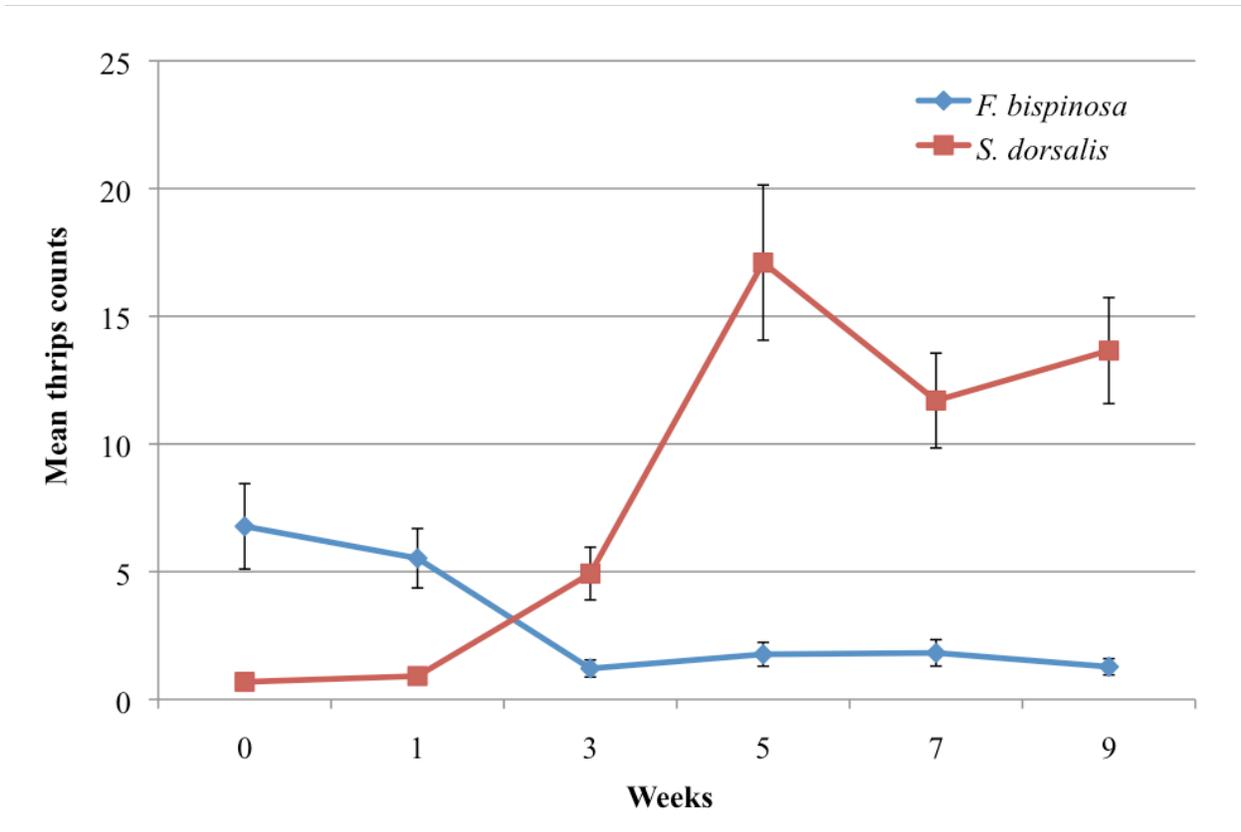


Figure 4-7. Mean weekly total number of thrips for *F. bispinosa* and *S. dorsalis* plus mean standard error over time.

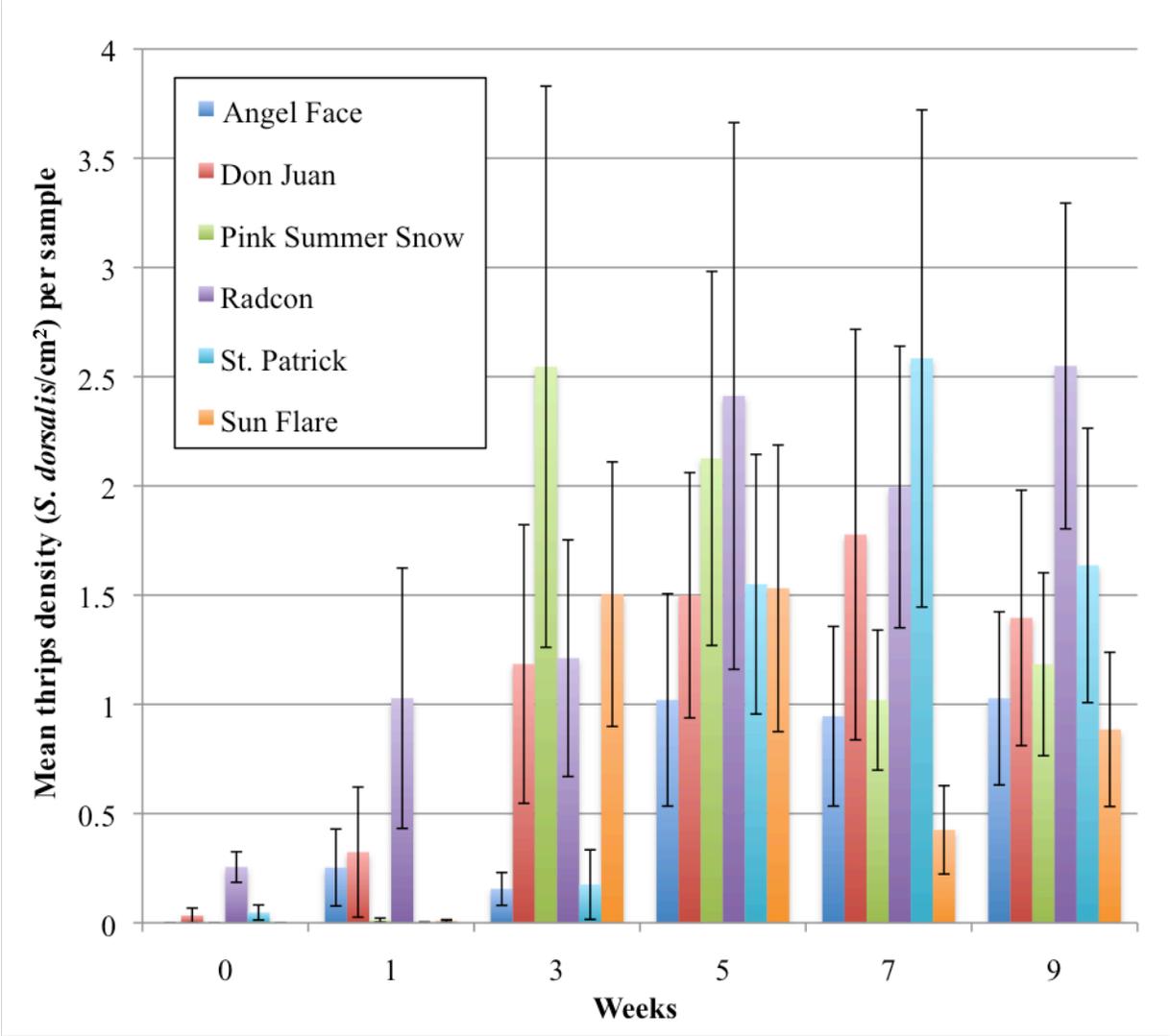


Figure 4-8. Weekly mean thrips density (*S. dorsalis*/cm²) plus mean standard error for each cultivar from mid-September to mid-November.

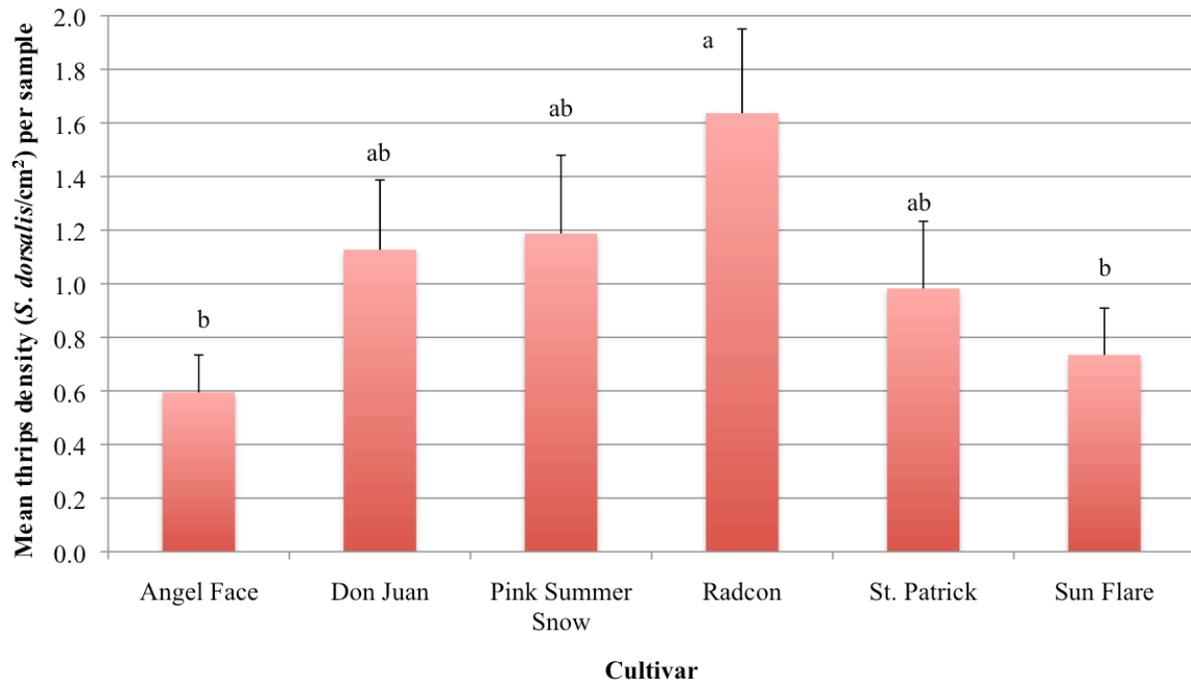


Figure 4-9. Mean thrips density (*S. dorsalis*/cm²) plus mean standard error on each cultivar (cultivars connected by the same letter are not significantly different by Tukey-Kramer HSD at $\alpha = 0.05$).

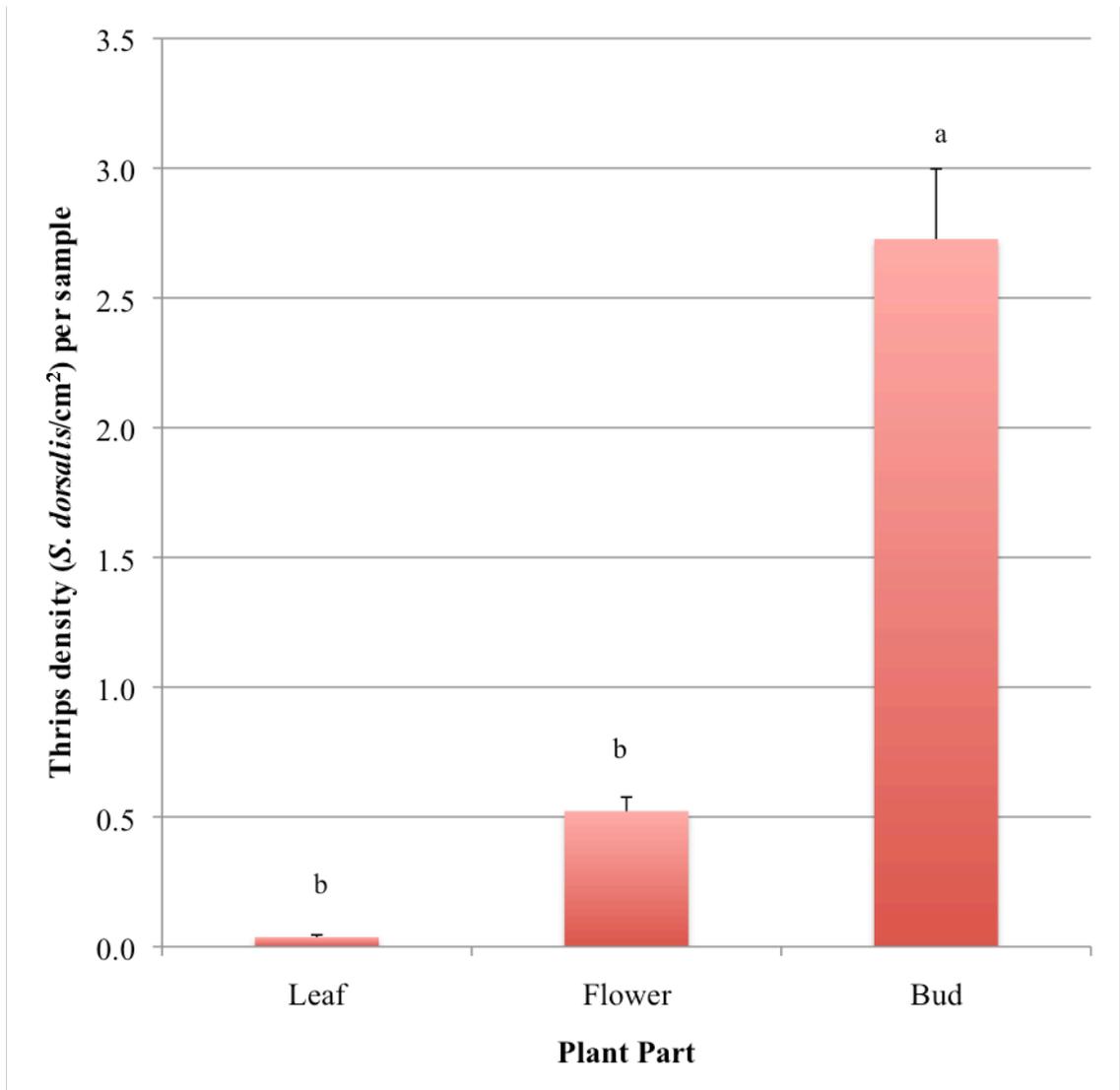


Figure 4-10. Mean thrips density (*S. dorsalis*/cm²) plus mean standard error on different plant organs sampled (organs connected by the same letter are not significantly different by Tukey-Kramer HSD at $\alpha = 0.05$).

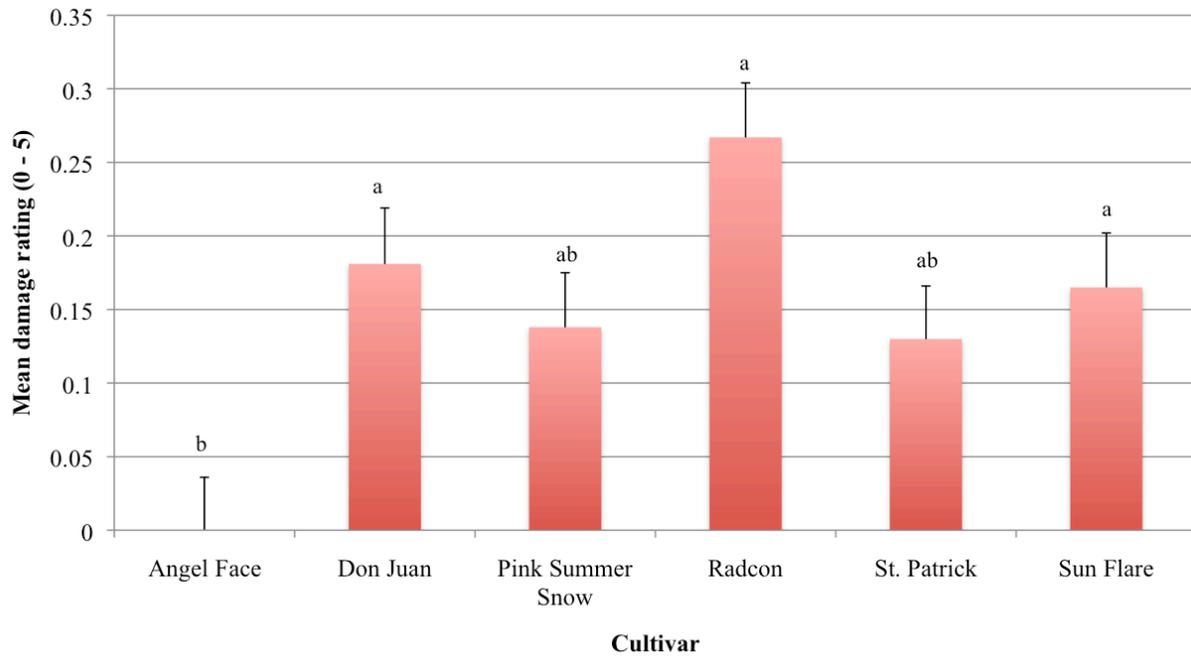


Figure 4-11. Mean damage rating plus mean standard error for each cultivar over nine weeks of exposure (cultivars connected by the same letter are not significantly different by Tukey-Kramer HSD at $\alpha = 0.05$).

CHAPTER 5 CONCLUSIONS

Scirtothrips dorsalis is an opportunistic generalist herbivore with parthenogenetic reproductive ability. These adaptations have allowed the insect to expand its range globally, and are important considerations when exploring the insect's potential impact upon the Florida landscape. The broad polyphagy of the organism permits its exploitation of a diverse group of potential hosts within its operational environment, but while this thrips is capable of subsisting upon many hosts, it is better able to complete development on some hosts than others under particular environmental conditions. This is most obvious when comparing the annual performance of this thrips upon rose to its performance upon buttonwood or schefflera. While all life stages were identified on the two alternative hosts, suggesting that reproduction was occurring, populations were significantly higher on rose. More importantly, the population demographics of *S. dorsalis* on rose showed a much smaller proportion of adults, suggesting a higher rate of growth.

These factors may be intrinsic to the plant, and I had hoped that by comparing different cultivars of rose, I might be able to tease out some of these factors. While there were some standouts in their responses to the thrips, most cultivars were infested in a similar fashion and suffered similar damage from the thrips. More importantly, the thrips appeared to infest all roses in a similar fashion. Total thrips numbers were much higher in flowers than on leaves, but the density of thrips exploiting these plant resources was very similar within the plant as well as between plants, with an overall trend moving the thrips towards areas of peak growth on the plant. As an opportunistic generalist, it will feed wherever it is most advantageous, or wherever it is not specifically excluded. The tightly packed foliage of flowers may serve as a refuge, protecting the thrips from exposure to the elements and predators.

It is also important not to forget that while the alternate hosts did not develop large populations, *S. dorsalis* were still a large proportion of the thrips fauna observed throughout this project. This implies that *S. dorsalis* has probably become established in the south Florida landscape, and with a large number of available ornamental, weed, and agricultural hosts to subsist upon, this pest will probably continue to persist in small population reservoirs somewhere in the environment no matter what control mechanisms are applied.

These reservoir populations will gradually recolonize lost territory from unmanaged areas, and a realistic management program should emphasize proactive measures that prevent or limit populations during crucial periods of peak growth. These measures may include factors not tested in these experiments, such as the efficacy of various insecticides as well as the development of long-term biological control, and should also consider the appropriate environmental conditions for the expansion of this thrips.

Modifying the nutritional content of these hosts will also play a significant role in the performance of this thrips. Fertilizing plant hosts appears to either make them more attractive to *S. dorsalis*, or provides more nutrients permitting a greater rate of population increase on a host. While higher rates of fertilization did not result in significantly larger numbers or sizes of flowers, there were trends suggesting that over time it would result in significantly larger populations of thrips.

This factor and the practice of “nutrient pushing” may explain some of sporadic explosions of previously unidentified infestations of *S. dorsalis* at nurseries. Small populations appear to cause relatively little damage, and may go unobserved – but when nursery growers fertilize, these populations can increase at a higher rate, thereby creating more observable damage.

Environmental factors extrinsic to the plant also play an important role in defining populations of *S. dorsalis*. As observed by other researchers, populations show a positive relationship with increasing temperature, and months with greater accumulated degree-days show larger thrips populations on all hosts tested. Increasing humidity and rainfall appear to be negatively correlated with this thrips' population growth – a trend common to the Thysanoptera as a whole.

Periods of peak population growth also appear to be periods of peak population dispersal. Thrips population density remained similar within a plot, suggesting that the thrips is capable of detecting population size through unknown means, possibly through volatile chemical communication or the number of interactions on a plant. When these cues increase in frequency, the thrips may disperse to reduce competition for resources. Thrips dispersal flight appears to be defined by environmental factors similar to those that regulate population growth. As the temperature rises and thrips accumulate degree hours, the number captured while dispersing increases until the majority of thrips who disperse will have flown. Humid conditions reduce these flights.

Based on these results, we should anticipate larger populations of this thrips towards late spring and mid fall in Florida, when our climate is at its warmest and driest. A period of growth and dispersal should also follow any unusually long droughts or months with unusually high minimum temperatures. Growers should prepare themselves accordingly, with regular trapping to observe population levels in the field, and then defend their crops with the appropriate control measures.

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BIOGRAPHICAL SKETCH

While born in Houston, Texas in 1977, Andrew Derksen was raised a citizen of the world sometime between the Permian and the late Mesozoic. He earned his undergraduate in biology and anthropology from Grinnell College in 2000. He misses the mountains, and would like to be working with molecular paleontology - but finds that life is full of unexpected turns and it is best to be prepared no matter where your path in life takes you. He received his Masters in Entomology from the University of Florida in the summer of 2009, and works for the state of Florida as a Pest Survey Specialist for the Cooperative Agricultural Pest Survey Program (CAPS) in Miami.