A NOVEL PUSH-PULL METHOD OF INTEGRATED PEST MANAGEMENT OF THRIPS AND TOSPOVIRUSES ON PEPPERS AND TOMATOES

By

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To Ramona Bunge, garden in peace.

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Abstract of Thesis Presented to the Graduate School
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A NOVEL PUSH-PULL METHOD OF INTEGRATED PEST MANAGEMENT OF
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The western flower thrips (*Frankliniella occidentalis*) presents a major problem to farmers of fruiting vegetables by injuring fruits and vectoring *Tomato spotted wilt virus*. Attempts at controlling this species using calendar applications of broad-spectrum insecticides were ineffective. In contrast, ultra-violet reflective mulches effectively repel thrips and reduce the incidence of Tomato spotted wilt on tomatoes. Furthermore, combining multiple management tactics into a push-pull strategy is effective in other crop systems with other pests. The current study tested various combinations of ultra-violet reflective or black mulch, a kaolin clay spray, and companion plantings of Spanish needle (*Bidens alba*) and sunflowers (*Helianthus annuus*) for thrips management in tomatoes and peppers in Florida. Kaolin clay and ultra-violet reflective mulch both reduced thrips numbers on both crops and had a synergistic effect. Additionally, the planting of sunflowers as a companion plant increased thrips numbers on pepper plants, while Spanish needle reduced thrips numbers on tomatoes. Sunflowers attracted higher numbers of an effective predator (minute pirate bug, *Orius insidiosus*) to the fields than the crops alone. Companion plants of *B. alba* and ultraviolet-reflective mulch increased

yield and decreased Tomato spotted wilt incidence on tomato. Ultraviolet-reflective mulch and kaolin increased yield of peppers. The results of the study show that these combinations can be successfully used as a push-pull method of thrips management in peppers and tomatoes.

CHAPTER 1
LITERATURE REVIEW

Agriculture is one of the most important facets of the economy in terms of monetary value and the value it serves by providing jobs and food. Florida specifically ranks second in value of vegetable production, producing 45% ($631 million) of fresh market tomatoes and 46% of total bell peppers ($296 million) in the United States (FDACS 2011). While growing crops to feed the world growers are forced to contend with many factors that challenge their ability to grow food in an efficient and profitable manner. Insect pests are a major force that threatens the livelihood of farmers and the health of the food industry. Thrips are one of the major pest groups affecting vegetable growers. There are over 6000 species of thrips (Order Thysanoptera) worldwide, and 87 are considered pests of commercial crops (Mound 1997). Injury to leaves, fruits, and flowers is caused during the feeding process, in which the adults and larvae pierce the plant with the mandible and extract the contents of ruptured cells. Additional injury to leaves, flowers, and fruits may occur during the oviposition process when the egg is inserted into the plant's tissue with the subsequent emergence of the larva (Childers, 1997). Numerous species also vector pathogens that cause disease in addition to the mechanical damage they inflict on the plants (OEPP/EPPO, 2004).

In Florida, the Western flower thrips (*Frankliniella occidentalis* Pergande) is an invasive species of thrips which injures leaves, fruits and flowers of multiple vegetable crops (Childers 1997) and vectors *Tomato Spotted Wilt Virus* (OEPP/EPPO 2004). The loss to farmers from this disease is estimated at $1 billion annually (Goldbach and Peters 1994). In the past and present, farmers have dealt with thrips and other pests using multiple applications of broad spectrum pesticides (Pimentel et al. 1991). While broad spectrum insecticides were originally successful there are negative effects which encourage new management strategies. These include: the development of resistance in insects to the pesticides (Roush and Tabashnik 1990); the unintentional decimation of other, potentially beneficial arthropods (Pimentel et al. 1991, Epstein et al. 2000); the resurgence of pests after pesticide applications (Hardin et al. 1995, Summers and Stapleton 2002a); secondary pest outbreaks of pests that previously were not problematic (Morse 1998); harmful effects on the environment and native wildlife (Davidson 2004); the endangerment of the health and lives of humans (Pimentel 2009). In addition to these disadvantages, pesticides do not always prevent disease transmission (Pinese et al. 1994, Summers and Stapleton 2002a, Summers et al. 2004) and despite the increase of pesticide use there has been an increase, rather than a decrease in pest damage (Pimentel et al. 1991). Pesticides cost an estimated $7.9 billion annually in public health effects, pesticide resistance, crop losses caused by pesticides, avian mortality due to pesticides and groundwater contamination (Pimentel 2009).

This misuse, overuse, and unnecessary use of pesticides resulted in the birth of integrated pest management in 1976 (Stern et al. 1959, Metcalf 1980). The spread of the western flower thrips and species of tospoviruses resulted in the world-wide destabilization of established integrated pest management programs for many crops (Morse and Hoddle 2006), and this included fruiting vegetables grown in Florida. One of the contributing factors to the problems produced by this pest is the propensity of the western flower thrips to quickly develop resistance to many classes of pesticides (Gao et al. 2012). Several technologies have been developed which circumvent these pesticide resistances. These technologies include, but are not limited to: spinosads and other new insecticides (Funderburk 2009); UV reflective mulch technologies (Stavisky et al. 2002, Reitz et al. 2003); companion plants (Kasina et al. 2006; Lopez and Shepard 2007); particle films such as kaolin clay (Glenn et al. 1999, Knight et al. 2000); and biocontrol using natural enemies (Funderburk et al. 2000). These methods can be used alone or in combination with other methods including the use of reduced risk insecticides as part of an integrated pest management plan. A recently developed technology combines both repellant and attractive plants in a field to repel pest insects from the crop and attract them to a non-crop plant on which they can be controlled (Khan et al. 2001). This method is effective in reducing damage to maize plants from stemborers in Kenya and may be promising for use with other crops and pests. The current study evaluates a new use of push pull technology combining ultraviolet reflective mulch (push), kaolin clay sprays (push) and companion plants (pull) to manage thrips on peppers and tomatoes.

Thrips and Tospoviruses

In Florida there are two common native species of thrips found in the flowers of crops. These are the eastern flower thrips (*Frankliniella tritici* Fitch) which is the common species in North Florida (Reitz 2002) and the Florida flower thrips (*Frankliniella bispinosa* Morgan) which is the common species in South and Central Florida (Hansen et al. 2003). Other species of thrips found on Florida vegetable crops in much lower numbers include the tobacco thrips (*Frankliniella fusca* Hinds) in Northern Florida, and *Frankliniella schultzei* (Trybom) in Central and Southern Florida (Hansen et al. 2003). In addition to these native species of thrips, there have been a few recent Thysanopteran invaders in Florida including the chili thrips, *Scirtothrips dorsalis* (Hood), *Megalurothrips mucunae* (Priesner) on legumes (Diffie et al. 2008) and the melon thrips, *Thrips palmi* Karny. Whereas these aforementioned thrips are not of major concern on tomato and pepper crops, one invasive species is present which poses a major threat to Florida farmers: the western flower thrips (*Frankliniella occidentalis* Pergande).

The western flower thrips is native to the Southwestern United States but was spread to other parts of the country and the world beginning in the 1980’s likely due to global trade in greenhouse plants (Kirk and Terry 2003). While *F. occidentalis* has been established in northern Florida since the early 1980s, it did not become an economic problem in central and southern Florida until 2005 (Frantz and Mellinger 2009). The potential damage posed by the western flower thrips is twofold: aesthetic damage caused by excessive levels of injury due to feeding and oviposition, and plant disease caused by Tospovirus spread by the western flower thrips. Worldwide the western flower thrips is the major vector of *Tomato spotted wilt virus* and *Impatiens necrotic spot virus* and it is also a vector of *Chrysanthemum stem necrosis virus*, *Groundnut ringspot virus* and *Tomato chlorotic spot virus* (Pappu et al. 2009, Webster et al. 2011).

Frankliniella bispinosa, F. tritici, and *F. occidentalis* all exhibit thigmotactic behavior. For this reason they are found aggregating in flowers as adults and as larvae are found in flowers and on fruits, often choosing to hide under the calyx on the fruit or in places of contact between fruits and stems or leaves (Kirk 1997). These polyphagous species feed and reproduce on many species of cultivated and uncultivated plants. The adults feed on the pollen and flower tissues and the female lays individual eggs in the small developing fruit of some crops such as tomato. After the egg hatches a small dimple often remains on the developing fruit which may or may not be surrounded by a halo. This dimple will remain on the developing fruit long after the egg hatches (Salguero Navas et al. 1991). In addition to this initial oviposition injury, the larvae will continue to feed on the fruit causing an additional injury known as “flecking” (Ghidiu et al.2006).

Although the injury to the fruits by the *F. occidentalis* can be aesthetically damaging causing cullout and downgrading (Funderburk 2009), a more serious threat is the vectoring capability of *F. occidentalis* of various tospoviruses. For Florida vegetable growers the most serious and widespread disease vectored by *F. occidentalis* is *Tomato spotted wilt virus*, estimated to cost farmers US$1 billion in crop losses annually (Goldbach and Peters 1994). Eight species of thrips are capable of transmitting Tomato spotted wilt virus: *F. bispinosa, F. cephalica, F. fusca*, *Frankliniella intonsa* (Trybom), *F. occidentalis*, *F. schultzei, Thrips setosus* Moulton, and *Thrips tabaci* Lindeman, and *S. dorsalis.* (Pappu et al. 2009). There are 19 species of tospovirus, of which *Tomato spotted wilt virus* is the type species. All of the tospoviruses are spread exclusively by thrips. Tomato spotted wilt infects 900 species of plants, cultivated and uncultivated. The virus manifests as necrotic spots, streaks or rings on the leaves or fruits. The severity of the symptoms can range from flecks on the fruit to necrotic lesions. Tomato spotted wilt has a mutual relationship with *F. occidentalis*: thrips larvae have a higher survival rate and develop more quickly on infected plants (Stumpf and Kennedy 2007). Additionally, plants infected with the virus are more attractive to thrips which preferentially feed and oviposit on the infected plants over uninfected plants (Maris et al. 2004).

Tospoviruses are spread by the thrips in two stages: Primary infection and secondary infection. Tospoviruses are first acquired by the larvae while feeding on an infected plant. Upon becoming adults, these infected thrips can transmit tospoviruses to uninfected plants within seconds of feeding on them. The adults persistently transmit once they have acquired the tospovirus as larvae. Primary infection refers to infection that occurs when a viruliferous adult capable of transmitting a tospovirus arrives in a new field, and begins to feed on the plants thereby infecting them with the disease. Secondary spread occurs when the adults reproduce on the infected plants, and the larvae acquire the tospovirus. After developing to adult, the thrips transmit the virus to other uninfected plants within the same field (Momol et al. 2004). Pesticides do not effectively reduce primary spread due to the small amount of feeding time required for infection to occur (Momol et al. 2004). Thrips are able to feed and transmit the disease faster than they are killed by the pesticide. Therefore repellant strategies are needed to prevent the adults from feeding. The most effective way to reduce secondary spread is by controlling larvae. The majority of infections in northern Florida tomatoes are caused by primary infection (Momol et al. 2004).

Control Methods

The population attributes of reproduction on numerous plant species in many plant families, high fecundity, rapid generation time, and high dispersal capability provide for an extraordinary ability for *F. occidentalis* to exploit ephemeral crop resources. Populations are able to continue rapid population buildup despite the attempts to control with repeated application of conventional insecticides (Funderburk et al. 2000). Farmers worldwide commonly employ calendar applications of broad-spectrum insecticides in an effort to control thrips. Unfortunately, this method is not successful and, in addition to economic damage from the cost of overusing pesticides, farmers suffer losses of crops to disease epidemics and direct damage from high populations (Funderburk 2009). This results in a “3-R” situation for *F. occidentalis* resistance to numerous insecticides; resurgence of *F. occidentalis* populations as a result of natural predators and native competitor thrips being eliminated; and replacement by various other pests (Reitz and Funderburk 2012).

Frankliniella occidentalis have a propensity for developing resistance to many classes of insecticides. The means by which *F. occidentalis* develops pesticide resistances are reviewed by Gao et al. (2012). The polyphagous nature of thrips likely resulted in their predisposition to evolve resistances through several metabolic detoxification pathways. These pathways allowed the insect to develop an array of resistances when traveling from host to host and encountering unknown defensive chemicals (Rosenheim et al. 1996). This adaptation continues to benefit *F. occidentalis* as it enables them to efficiently develop resistances through these same pathways to numerous classes of insecticides (Zhao et al.1995, Broadbent and Pree 1997) including organophosphate, carbamate, pyrethroid, and organochlorine insecticides (Immaraju et al. 1992). The resistance to pyrethroids through these metabolic detoxification pathways has occurred worldwide and occurs rapidly (Immaraju et al. 1992, Zhao et al. 1995, Broadbent and Pree 1997, Seaton et al. 1997, Herron and Gullick 2001, Espinosa et al. 2002, Thalavaisundaram et al. 2008, Frantz and Mellinger 2009). Resistance to insecticides can derive from more than one trait, can develop from more than one pathway and multiple pathways can combine to contribute to each pesticide resistance

(Jensen 1998). These many factors have led to a large number of modes by which *F. occidentalis* has developed resistances to many pesticides and combinations thereof. Additionally, *F. occidentalis* maintain these resistances for long periods of times in the absence of pesticides without any obvious fitness disadvantages (Robb 1989, Brødsgaard 1994, Kontsedalov et al. 1998, Bielza et al. 2008). Other characteristics of thrips which render foliar sprays of pesticides ineffective are their cryptic behaviors and their ability to pupate in the soil (Berndt et al. 2004).

Many factors render pesticides ineffective in the short or long term in controlling thrips and tospoviruses. Furthermore, control approaches affect the lives of other non-target organisms. For these reasons, alternative methods of managing thrips are desirable. These methods should be safe for beneficial insects, efficacious for thrips and other pests, economical, and utilize the behaviors of the thrips and their natural enemies all within the scope of integrated pest management (Stern et al. 1959).

The adults of the two native thrips, *F. tritici* and *F. bispinosa*, species do not damage the fruiting vegetables and these native species also contribute to the control of *F. occidentalis* by out-competing *F. occidentalis*. Even densities of 20-25 adults per flower of the two native species do not result in damage to tomato, pepper, or eggplant (Funderburk 2009); however, the economic threshold of *F. occidentalis* adults is one adult per tomato flower or six adults per pepper or eggplant flower due to the damage they cause and their vectoring capabilites(Funderburk et al. 2011a, Funderburk et al. 2011b). Using these thresholds to decide when to take action can preserve native species of thrips which can act as a natural barrier against *F. occidentalis* in the field.

Most broad-spectrum synthetic insecticides, including pyrethroids, neonicotinoids, organophosphates, and carbamates kill the native species of thrips that outcompete *F. occidentalis* (Hansen et al. 2003, Reitz et al. 2003, Srivistava et al. 2008), thereby leading to dramatic large scale shifts in thrips demographics (Frantz and Mellinger 2009). Broad-spectrum insecticides can directly enhance the rate of increase of *F. occidentalis* populations. The pyrethroid acrinathrin increases the fecundity of resistant *F. occidentalis* females, and survivorship, developmental rates, and longevity of progeny is as great, or greater, than for progeny of susceptible females (Bielza et al. 2008). Synthetic broad-spectrum insecticides not only disrupt *F. occidentalis* management, they also disrupt management of other pests including spider mites, whiteflies, and leafminers, by eliminating natural enemies of those pests (Armenta et al. 2003, Gonzalez-Zamora et al. 2004).

In recent years, due to the harmful unintended side-effects of broad-spectrum pesticides, growers have begun using natural and reduced-risk insecticides. The spinosyn class is the most efficacious of these insecticides providing a greater level of control of *F. occidentalis* than all other currently available reduced-risk and broad-spectrum insecticides (Funderburk 2009). Due to the high vagility of *F. tritici* and *F. bispinosa*, spinosyns are effective against *F. occidentalis* while affecting the two native species of thrips to a lesser degree which can assist in preserving natural competition (Reitz et al. 2003). Unfortunately *F. occidentalis* has developed some level of resistance to spinosyns in pockets in Florida (Weiss et al. 2009)

A biologically based integrated pest management program is fundamental in preventing the development of insecticide resistance, resurgence of *F. occidentalis* populations, and replacement with nontarget pest damage (Weiss et al. 2009). Evidence suggests that the conservation biological control component of the integrated pest management program is the most effective way to manage thrips in pepper and eggplant (Funderburk et al. 2000, Reitz et al. 2003, Funderburk 2009). Many predaceous arthropod groups help to suppress thrips populations. Species of Anthocoridae are the most important worldwide predators of thrips. Within this family are minute pirate bugs with two species in Florida, *Orius pumilio* (Champion) and *Orius insidiosus* (Say), the key natural enemies of thrips in eggplant and pepper (Funderburk et al. 2000). Although the minute pirate bugs are not present in high numbers in tomato fields, they are the only predatory heteropteran consistently found in tomato fields, in low numbers (Kiman and Yeargan 1985).

The minute pirate bugs feed on all three species of thrips, but they prey preferentially on the adults of the *F. occidentalis* over the adults of the non-damaging native thrips species (Reitz et al. 2006). This aspect of feeding makes the minute pirate bugs a valuable tool for managing *F. occidentalis*. *Frankliniella tritici* and *F. bispinosa* are smaller and move around more frequently and at a faster pace than *F. occidentalis*. This may be the reason for the preferential feeding behavior (Baez et al. 2004, Reitz et al. 2006). The thrips larvae are the preferred life stage for predation (Baez et al. 2004). Approximately one adult minute pirate bug for every 180 thrips is sufficient for suppression of the populations of thrips. At a ratio of about one predator to 40 thrips, thrips populations are controlled (Funderburk et al. 2000). Natural populations of minute pirate bugs are highly vagile (Ramachandran et al. 2001). The adults rapidly invade pepper and eggplant fields in Florida in sufficient numbers to control *F. occidentalis* adults and larvae, but they must be conserved with cautious insecticide use (Funderburk 2009). Usually, natural populations are not sufficient in tomato to provide control of *F. occidentalis* (Baez et al. 2011).

Other thrips predators include the big-eyed bugs (Family Lygaeidae), damsel bugs (Family Nabidae), lacewings (Family Chrysopidae), predatory thrips (primarily in the family Aeolothripidae), and predatory mites (Family Phytoseiidae). Natural populations of these predatory groups do not typically invade fields of fruiting vegetables in sufficient numbers to suppress thrips populations.

There is potential to attract minute pirate bugs into these fields using habitat management strategies such as companion plantings. Minute pirate bugs are known to supplement their diet with plant materials such as pollen and can develop and reproduce on a diet of pollen and nectar alone for up to six months (van den Meiracker and Ramakers 1991). Their survival rate, life span and reproduction rate are higher, and the developmental time is shorter on a diet of thrips and pollen than on a diet of thrips alone (Kiman and Yeargan 1985). Minute pirate bugs are also more abundant where pollen is present and will migrate in the absence of pollen (Malais and Ravensburg 1992).

In a study by Lundgren et al. 2009 the addition of plants with suitable oviposition sites and refuges from natural enemies was associated with lower herbivore densities and higher predator densities on the target plant. The densities of minute pirate bugs in this study were higher on the target plants in polycultures than in monocultures. Minute pirate bug nymphs also experienced higher fitness in diverse fields (Lundgren et al. 2009). Minute pirate bugs have the ability to rapidly recolonize plots treated with insecticides (Ramachandran et al. 2001) and this ability could be enhanced with the addition of companion plantings in which the minute pirate bugs could take shelter to avoid insecticides and then later recolonize the sprayed plots.

Companion Plantings And Conservation Biological Control

Conservation biological control involves the use of methods which act to conserve natural enemies of pests in the environment. One of these methods is habitat management. Habitat management is the alteration of farmland or the general landscape in such a way as to provide resources for natural enemies such as food, alternative prey or hosts, and shelter from adverse conditions (Landis et al. 2000). The diversification of agricultural systems using native plants can benefit both integrated pest management programs and the conservation of arthropods in a region (Kogan and Lattin 1993). There are many methods of diversifying agricultural systems to enhance natural enemies. These include companion, refugia, or banker plantings, intercrops, strip crops, conservation strips, beetle banks and polycultures in general. These different types of structural diversification are beneficial in different crop and pest situations, but overall increased habitat structure diversification is associated with a significant increase in natural enemy abundance (Langellotto and Denno 2004).

In an early study on enhancing natural enemies in cotton in Oklahoma, sorghum strip crops in cotton fields increased predator numbers in the cotton and were associated with an increased yield of cotton (Robinson et al. 1972). In a later study, strip cropping of Lucerne (*Medicago sativa*) with cotton also increased the numbers of predators of *Helicoverpa spp.* (Mensah 1999). Habitat diversification and the presence of flowering weeds successfully increased the numbers of natural enemies and decreased numbers of aphids, whiteflies, and leafhoppers in cotton (Showler and Greenburg 2002, Ghodani et al. 2009). The suppression of these pests and the injury they cause using habitat diversification was superior to suppression using insecticides (endosulfan and monocrotophos). The diversification also led to increased yield of cotton (Ghodani et al. 2009).

Strip crops of corn and weeds also increased the numbers of natural predators and parasitoids of the African bollworm (*Heliothis armigera*) on haricot bean (Abate 1991). This effect is variable depending upon the strip crop used and the natural enemy concerned. In this case, corn and weed strip crops both increased the numbers of tachinid parasitoids, whereas only weed strip crops increased the numbers of the *Tiphia spp.* predatory wasps (Abate 1991).

Intercropping, planting two different crops or a crop and noncrop alternating in the same row has also been a successful form of habitat management (Tonhasca 1993, Ponti et al. 2007). Intercropping soybean and corn increased the numbers of natural enemies compared to planting these crops in monocultures. In a similar study, intercropping buckwheat and mustard with broccoli decreased cabbage aphid (*Brevicoryne brassicae* L.) pressure and increased the numbers of natural enemies (Ponti et al. 2007).

Habitat diversification also effectively reduces numbers of pests and increases numbers of natural enemies in non-crop agricultural systems. Conservation strips (beetle banks and flowering insectory strips) successfully increased predator, parasitoid and alternative prey abundance in golf course fairways. Predation on *Agrotis ipsilon* Hufnagel was greater in fairways with conservation strips (Frank and Shrewsbury 2004).

Planting flowering forbs around ornamental shrubs in urban environments increased parasitism rates on bagworm by 71% (Ellis et al. 2005). Plantings of flowering plants around ornamental plants *Euonymus fortunei* also increased numbers of natural enemies (Rebeck et al. 2005).

Various plant species offer habitat for important natural enemies of thrips and other insects (Landis et al. 2000). Numerous plant species attract enough enemies to control *F. occidentalis* populations on green beans and medicinal plants (Kasina et al. 2006, Lopez and Shepard 2007). Intercrops of baby corn, Irish potato and sunflowers with French beans in Kenya reduced populations of *F. occidentalis* and increased populations of *Orius spp.* compared with a monocrop (Nyasani et al. 2012). In Florida, *Bidens alba*, sunflowers, *Wedelia trilobata*, and two species of clover are hosts for minute pirate bug and other natural enemies (Bottenberg et al. 1999), and plantings near crops of fruiting vegetables increase biological control of thrips (Frantz and Mellinger 2009). Queen Anne's lace, *Daucus carota*, and false Queen Anne's lace, *Ammi majus*, are good hosts for *Orius* species (Shirk et al. 2011). Additionally, these and other wild plant species around fields host the non-damaging native thrips species (Northfield et al. 2008) that are competitors of *F. occidentalis* (Paini et al. 2008). Companion plantings of these species are not sources for damaging populations of *F. occidentalis* as they are outcompeted by the native thrips species and they suffer preferential predation by minute pirate bugs. These plant species can be effective companion plants, intercrops or strip crops in fields to increase natural predators of thrips and reduce thrips numbers.

Ultraviolet-Reflective Technologies

Thrips, like other insects, locate host plants primarily through a combination of visual cues, with anthophilous thrips attracted to colors of flowers. *Frankliniella occidentalis* are attracted to spectral radiation in the ultraviolet range (~365 nm) and in the yellow-green range (~540 nm) (Matteson et al. 1992). The yellow-green sensitivity plays a role in long distance orientation to plants, and the ultraviolet sensitivity assists with distinguishing flowers. Consequently, increasing the reflectivity in the ultraviolet range of the spectrum repels thrips. The ultraviolet-reflective mulches available for the raised-bed plastic mulch production system effectively repel colonizing adults of *F. occidentalis*, and this repellency reduces the primary and secondary spread of Tomato spotted wilt. The use of ultraviolet-reflective mulch also reduces the influx of the native thrips, but not disproportionately to reductions in *F. occidentalis* (Reitz et al. 2003, Momol et al. 2004).

Ultraviolet-reflective mulches are used in many crops. These mulches are used on both organic and conventional farms as part of an integrated past management program. The ultraviolet-reflective mulches work by reflecting as much as 86% of incoming short-wave light (Summers et al. 2004) which repels incoming insects and reduces the number of insects alighting on plants (Kring and Schuster 1992). Ultraviolet-reflective mulches are successful in different crops including corn (Summers and Stapleton 2002a), zucchini (Pinese et al. 1994), cantaloupe (Stapleton and Summers 2002), cucumber (Summers and Stapleton 2002b, Rapando et al. 2009) summer squash (Brown et al. 1996, Murphy et al. 2008), watermelon (Farios-Larios and Orozco-Santos 1997, Simmons et al. 2010), pumpkins (Brust 2000, Summers and

Stapleton 2002b), peppers (Reitz et al. 2003, Kring and Schuster 1992), and tomatoes (Momol et al. 2002, Riley and Pappu 2004) to name a few.

In addition to thrips, many other key pests of these crops are controlled successfully by ultraviolet-reflective mulches including whiteflies (Summers et al. 2004, Simmons et al. 2010), aphids (Pinese et al. 1994, Stapleton and Summers 2002, Summers et al. 2010), leafhoppers (Summers and Stapleton 2002a), plant bugs (Rhainds et al. 2001) and beetles (Andino and Motsenbocker 2004). The broad range of pests repelled by the mulch make ultraviolet-reflective mulch ideal for crop systems that are infested by numerous pest species. In addition to repelling insects the mulch also reduces incidence of disease (Kring and Schuster 1992, Brust 2000, Stapleton and Summers 2002, Murphy et al. 2008, Rapando et al. 2009), increases yield (Farios-Larios and Orozco-Santos 1997, Pinese et al. 1994, Reitz et al. 2003, Murphy et al. 2008), improves crop growth (Pinese et al. 1994, Andino and Motsenbocker 2004, Summers et al. 2004) provides monetary savings from reduced crop losses, labor and insecticides (Pinese et al. 1994, Brust 2000, Riley and Pappu 2004), and can be used in combination with other management strategies such as insecticides (Momol et al. 2002, Reitz et al. 2003, Riley and Pappu 2004, Nyoike et al. 2010) and disease resistant plants (Riley and Pappu 2004, Rapando et al. 2009, Simmons et al. 2000).

Ultraviolet-reflective mulches are most effective early in the crop season before the plant canopy begins to cover the mulch, thereby reducing the surface area available for reflectance (Reitz et al. 2003, Momol et al. 2004). Application of certain fungicides and other pesticides reduces the ultraviolet reflectance and hence the efficacy of the mulch. A single application of copper and mancozeb fungicide can reduce the reflectance by approximately 49% (Reitz, unpublished).

Kaolin Particle Films

Kaolin clay is a particle film composed of aluminosilicate mineral that can be applied to plants as a form of protection. The clay leaves a white residue that can be washed from the fruits and the plant. Kaolin films are compatible with organic methods and can suppress pests while benefiting the plant in other ways. Particle film treatments control arthropod pests through numerous processes including: reducing the longevity of the pest (Knight et al. 2000); reducing mating success (Knight et al. 2000), oviposition rate (Knight et al. 2000; Larentzaki et al. 2008) and hatch rate (Larentzaki et al. 2008); increasing development time (Larentzaki et al. 2008); interfering with the insects' ability to grasp plant surfaces (Puterka et al. 2005, Hall et al. 2007) and to recognize host plants (Puterka et al. 2003); and even increasing mortality (Larentzaki et al. 2008).

Foliar applications of kaolin clay reduce populations of various pests and the damage they cause including obliquebanded leafrollers on fruit trees (Knight et al. 2000); fruit flies on fruit trees (Mazor and Erez 2004, Saour and Makee 2004); boll weevils on cotton (Showler 2002); silverleaf whiteflies on melons (Liang and Liu 2002); pear psylla (Puterka et al. 2005); citrus psyllids (Hall et al. 2007); glassy-winged sharpshooters on grapes (Puterka et al. 2003); weevils, leafhoppers, sawflies, scale insects, moths, and aphids on apples (Marko et al. 2008); and moths, Japanese beetles, plant bugs and stink bugs on peach trees (Lalancette et al. 2005).

Applications of kaolin clay can also be used to control thrips. Laboratory studies revealed numerous mechanisms by which the kaolin suppresses populations of *T.tabaci* on onions including reducing feeding, increasing mortality, reducing hatch rate, and increasing development time (Larentzaki et al. 2008). Kaolin clay applications also reduce populations of *Frankliniella* thrips within the canopy of rabbiteye blueberry plants while also increasing yield (Spiers et al. 2004).

In addition to suppressing pests, kaolin clay reduces the number of plants infected with disease (Glenn et al. 2001, Tubajika et al. 2007, Reitz et al. 2008), increases yield (Spiers et al. 2004, Lalancette et al. 2005, Reitz et al. 2008), and reduces heat stress and sunburn damage in fruit trees (Glenn et al. 2001, Glenn et al. 2002). Despite all of these benefits, kaolin clay has a few weaknesses. It is degraded by rain and must be reapplied throughout the season in order to remain effective (Showler 2002, Hall et al. 2007). It can also reduce numbers of natural enemies thus causing an increase in some pest numbers (Marko et al. 2008). The hydrophobicity and deposit density of the clay are important factors for disease management and some deposit densities do not prevent disease effectively which must be taken into account (Lalancette et al. 2005).

Push-Pull Method

A novel approach to pest management is the push-pull or stimulo-deterrent method. This method was developed in Kenya for use on subsistence farms. The method is based on behavioral manipulations involving an unattractive stimulus (push) to repel insects from crops and an attractive (pull) stimulus to attract the pests to an alternate source from which they can be removed or controlled (Cook et al. 2007). This method is successful in Kenya in a maize crop system. Stemborers are pushed from the maize using repellant molasses grass and desmodium and pulled to the attractive

Napier grass. This particular combination significantly increased yield, increased parasitism of stemborers by parasitoids attracted to the molasses grass, and reduced damage to maize by the competitive weed Striga (Khan et al. 2001, Khan et al. 2008a). This system is estimated to be profitable for small farms in Africa (Khan et al. 2008b).

While this example involved the use of companion plants as the push and the pull, other potential methods that have been used are chemical odors for thrips on onions (Van Tol et al. 2007) and light traps for wood-boring beetles (Pawson and Watt 2009). Apart from these studies and despite the success in the maize systems in Kenya, very little research has been done using push pull methods to control pests.

Primary Research Objectives

The primary objectives of the current study were to (1) evaluate the effects of a push-pull method of thrips management on thrips, *Orius spp.*, and yield in bell peppers; (2) evaluate the effects of a push-pull method of thrips management on thrips, *Orius spp.*, and yield in tomatoes; (3) evaluate the effects of a push-pull method of thrips management on the incidence of Tomato spotted wilt on tomatoes. Each of these push-pull methods involved ultraviolet-reflective mulch and foliar applications of kaolin clay as the push with *Bidens alba* companion plants acting as the pull in tomatoes and *Helianthus annuus* as the pull in bell peppers.

CHAPTER 2
EVALUATION OF A PUSH-PULL STRATEGY FOR THE MANAGEMENT OF *FRANKLINIELLA BISPINOSA* (THYSANOPTERA: THRIPIDAE) IN BELL PEPPERS

Introduction

The invasive western flower thrips (*Frankliniella occidentalis* Pergande) and the native *F. bispinosa* (Morgan) are pests of numerous crops in Florida, including bell pepper (*Capsicum annuum* L). Attempts to control these pests with applications of broad-spectrum insecticides were unsuccessful, in part because these insecticides suppress populations of the important natural predator of thrips *Orius insidiosus* (Say) (Funderburk et al. 2000, Frantz and Mellinger 2009). Additionally, *F. occidentalis* developed resistance to insecticides from numerous chemical classes with different modes of action (Gao et al. 2012). Both *F. bispinosa* and *F. occidentalis* are competent vectors of *Tomato spotted wilt virus*, the type species of an important group of plant viruses in the genus *Tospovirus* (Avila et al. 2006). Demirozer et al. (2012) reviewed integrated pest management programs for thrips in fruiting vegetables that are effective, economical, and ecologically sound. The components included the following: define pest status (economic thresholds), increase biotic resistance (natural enemies and competition), integrate preventive and therapeutic tactics (scouting, ultraviolet (UV)-reflective mulch technologies, biological control, compatible insecticides, companion plants, and fertility), and vertically integrate the programs with other pests. These programs have been widely implemented in Florida, and they have significantly improved management of *Frankliniella* thrips and thrips-transmitted tospoviruses.

Natural populations of *O. insidiosus* rapidly invade pepper fields in Florida in numbers sufficient to suppress thrips populations (Funderburk et al. 2000, Ramachandran et al. 2001). This predator successfully preys on all the common species of flower thrips and their larvae (Baez et al. 2004, Reitz et al. 2006). Funderburk et al. (2000) reported that its ability to suppress populations of *Frankliniella* species exceeded the suppressive effects of weekly applications of insecticides. Thrips locate their host plants using visual cues in the ultraviolet-light range (Terry 1997). The light reflected by ultraviolet-reflective mulches disrupts this natural mechanism thereby reducing the numbers of thrips landing on plants (Stavisky et al. 2002, Reitz et al. 2003, Momol et al.2004, Riley and Pappu 2004). In addition to disrupting host-finding by thrips and other insects, ultraviolet-reflective mulch decreases incidence of insect-vectored diseases, including Tomato spotted wilt, and increases yields (Greenough et al. 1990, Stavisky et al. 2002, Greer and Dole 2003, Reitz et al. 2003, Hutton and Handley 2007, Diaz-Perez 2010, Riley et al. 2012). Reitz et al. (2003) reported that populations of *O. insidiosus* were reduced by ultraviolet-reflective mulches, thereby resulting in effects on predator-prey dynamics (Reitz et al. 2003).

Kaolin, an aluminosilicate particle film, is an organic method of managing pests on crops (Bar-Joseph and Frenkel 1983). This film acts through multiple modes of action to reduce pests and diseases on crops. Modes of action include interfering with feeding behavior and oviposition, increasing mortality, concealing the host plant visually or chemically, reducing survival rate, and lengthening developmental time (Lapointe 2000, Wilson et al. 2004, Barker et al. 2006, Peng et al. 2010). Applying kaolin effectively decreased populations of psyllids (Daniel et al. 2005, Peng et al. 2010), aphids (Bar-Joseph and Frenkel 1983, Marko et al. 2008), thrips (Spiers et al. 2004, Reitz et al. 2008), weevils (Lapointe 2000, Marko et al. 2008), lepidoptera (Barker et al.

2006), and others (Marko et al. 2008). Incidence of insect-vectored disease was lowered on plants coated in kaolin (Creamer et al. 2005, Reitz et al. 2008).

Some studies indicated that kaolin applications increased yield (Spiers et al. 2004, Reitz et al. 2008, Cantore et al. 2009) while other studies indicated decreased yield or no difference (Wilson et al. 2004, Creamer et al. 2005, Kahn et al. 2008, Larentzaki et al. 2008). In tomatoes kaolin reduced fruit temperature and sunburn damage, and increased lycopene content and red coloration of the fruit (Cantore et al. 2009). On chile peppers kaolin reduced water stress, increased levels of chlorophyll, and increased light reflectance of leaves (Creamer et al. 2005).

Different species of thrips or their damage were reduced on crops by applying kaolin. Application of kaolin reduced populations of *F. tritici* on tomatoes (Reitz et al. 2008), thrips foliar injury on peanuts (Wilson et al. 2004), populations of *Frankliniella* spp. on blueberries (Spiers et al. 2004), and populations of *T. tabaci* on onion (Larentzaki et al. 2008). Porcel et al. (2011) reported that populations of most natural enemies were not affected on plants treated by kaolin, although *Chrysoperla carnea* preferred them for oviposition. Bengochea et al. (2013) reported that application of kaolin increased the mortality of *Anthocoris nemoralis* a predator of olive psyllids and thrips.

Plant species diversification of agricultural landscapes is a method of habitat manipulation that allows for a number of ecosystem services, including biological control (Kogan and Lattin 1993). Plants provide resources for natural enemies including food, alternative prey or hosts, and shelter from adverse conditions (Landis et al. 2000). Certain plant host species or cultivars can be deliberately planted to conserve and augment populations of natural enemies. A diverse diet of pollen and thrips prey offered by the pepper cultivar 'Black Pearl' increased longevity of *O. insidiosus*, decreased nymphal development time, and produced larger females than a diet of thrips alone (Wong and Frank 2013). Numerous studies have shown that companion plant species that are hosts for *Orius* spp. resulted in reduced numbers of *Frankliniella* spp. thrips in the main crop. Kasina et al. (2006) and Lopez & Shepard (2007) reported that *Tagetes erecta* L., *Daucus carota* L., *Coriandrum sativum* L., *Brassica oleracea* L., *Capsicum annuum* L., *Zea mays* L., and *Tanacetum parthenium* (L.) Sch. Bip. attracted enough *O. insidiosus* to reduce *F. occidentalis* populations on *Phaseolus vulgaris* L. and medicinal plant species. Nyasani et al. (2012) reported that intercrops of *Solanum tuberosum* L. and *Helianthus annuus* L. reduced populations of *F. occidentalis* and increased populations of *Orius* spp. in *P. vulgaris*. In Florida *Bidens alba*, sunflowers (*Helianthus annuus*), *Wedelia trilobata*, and two species of clover are hosts for minute pirate bug and other natural enemies (Bottenberg et al., 1999, Legaspi and Baez 2008), and plantings near crops of fruiting vegetables increase biological control of thrips from *O. insidiosus* (Frantz and Mellinger 2009). The above-mentioned studies supposed that predation from *O. insidiosus* was the mechanism responsible, at least in part, for the reduced numbers of thrips in the main crop.

Companion plants can reduce insect pests on the crop by serving as a sink for the pests or by serving as habitat for natural enemies that feed on the pest either in the companion plant or on the crop. Plants that serve as hosts for natural enemies and traps for crop pests are important components of push-pull strategies (Cook et al. 2007). In such a system, the herbivore is pushed away from the crop and pulled toward a companion plant where they are removed by the natural enemy. Behavior of the natural enemy can be manipulated using appropriate stimuli to increase biological control of the herbivore either in the companion plant, the crop, or both the companion plant and the crop. The purpose of this research was to evaluate a push-pull system for managing flower thrips on peppers. Push components under evaluation were UV-reflective mulch and foliar applications of kaolin, and the pull component was the companion plant sunflower *H. annuus*. The objectives were to determine the separate and interactive effects of each component on the abundance and population dynamics of *Frankliniella* species, *O. insidiosus*, and the yield and quality of pepper.

Methods

Plot Establishment And Maintenance

Experiments of 'Aristotle' bell pepper were conducted in 2011 and 2012 at the Glades Crop Care, Inc., farm located at 18674 131st Trail, Jupiter, FL 33458. Plots were fertilized with 148, 59, and 148 kg/ha of N, P, and K, respectively, by broadcasting and roto-tilling prior to shaping the beds. Six-week-old pepper seedlings were transplanted in raised beds covered in plastic mulch (Berry Plastics Corp., Evansville, IN 47706) with trickle-tube irrigation according to typical commercial practices for Florida. The beds were 20.3 cm in height and 81.4 cm in width, with 1.52 m row spacing. Liquid fertilizer 8-0-8 was injected through the drip irrigation system as needed to maintain crop growth of peppers.

In 2011 the experiment was a completely randomized design with three replications Treatments were black mulch, black mulch plus 'Pro-cut Gold' and 'Zebulon' sunflower companion plants, UV-reflective mulch, UV-reflective mulch plus sunflower companion plants, black mulch plus foliar applications of kaolin, black mulch plus foliar applications of kaolin plus sunflower companion plants. Peppers were transplanted on 16 and 17 February 2011. Kaolin (Surround® WP Engelhard Corp., Iselin, NJ 08830) was applied weekly on 9, 11, 18, 25 of March and 1, 15, 20, and 28 of April 2011 at the rate of 7.0 kg/ha with a CO_2-powered backpack sprayer equipped with three nozzles applying 65 g/a. Each of the 18 plots consisted of 4 beds by 14.6 m with each bed consisting of two linear rows of peppers with a 30-cm-spacing between and within rows for a total of 257 pepper plants per plot. Spacing between beds was 1.8 m. 'Pro-cut Gold' and 'Zebulon' sunflowers were planted into the soil along the outer beds of each plot of each treatment. Sunflowers also were planted at both ends of each bed of each plot of each treatment containing companion plants.

In 2012 the experiment was a split-split-plot randomized complete block design with three replicates. Whole plot treatments were UV-reflective and black mulch, subplot treatments were kaolin and a control of no kaolin, and sub-subplot treatments were sunflower companion plants and a control of no sunflower. Sub-sub-plot size was 6 beds by 9.1 m with the four inner beds of each sub-subplot consisting of two linear rows of pepper with a 30-cm-spacing between and within rows for a total of 384 pepper plants. Spacing between beds was 1.8 m. Peppers were transplanted into the field on 21 February 2012. The two outer beds of each sub-subplot consisted of black mulch with 'F30008', 'Big Smile', and 'Zebulon' sunflower planted in sub-subplots of treatments with companion plants and thinned after emergence to 364 plants per plot. Sunflowers also were planted at both ends of each bed of each plot of each treatment containing companion plants. Kaolin was applied once per week on 16, 26, 27 of March and 3, 10 of April and 2 May 2012 at the same rate and method as described previously for 2011.

Insect Sampling

Frankliniella and *Orius* are anthophilous and highly aggregated in the flowers of pepper plants; consequently, flowers were sampled to estimate density (Hansen et al. 2003). Sampling for insects began within a few days of first flowering. Two samples of ten pepper flowers were randomly collected from the inner four beds of each plot once per week for six weeks in 2011. In 2012 the samples were collected twice per week for the first two weeks and once per week for the next three weeks. Two random samples of three sunflower inflorescences also were collected from each plot with companion plants on the same dates. Flowers were placed immediately into vials or bags of 70% ethanol. Thrips and other insects were extracted from the flowers in each sample and identified to species, life stage, and gender under a stereoscope with 40 X magnification. The number of adult *O. insidiosus*, adult *O. pumilio* and nymphal *Orius* spp. in each sample was determined.

Tomato Spotted Wilt Incidence

Each pepper plant in each plot was examined weekly for visual symptoms of *Tomato spotted wilt virus* infection. Leaf samples were taken from any plant showing visual symptoms, and they were tested for the presence of *Tomato spotted wilt virus* using ImmunoStrips® (Agdia, Elkhart, IN 46514).

Yield

Peppers were harvested on 03 and 17 May in 2011 and on 27 April and 10 May in 2012. Peppers of marketable size were picked from 6.1 m lengths of row located on the two center rows of each plot. Harvested fruits were counted, weighed, and graded for marketability according to USDA standards (USDA 2007).

Data Analysis

The number of thrips larvae per adult *F. bispinosa* was determined on each sample date for each treatment and plant. Ratios of < 1, 1, and > 1 were considered indicative of a declining, stable, and increasing population, respectively (Northfield et al. 2008). The ratio of total thrips (adults and larvae) per *O. insidiosus* was determined for each treatment and plant on each sample date. The predator is capable of suppressing a thrips population at a ratio of 1 predator per 217 thrips (Sabelis and van Rijn 1997).

Differences between treatments in numbers of male and female *F. bispinosa*, thrips larvae, and *O. insidiosus* and *pumilio* adults and *Orius* species nymphs on tomatoes and sunflowers separately were analyzed using analysis of variance for a completely randomized design in 2011 and for a randomized complete block design for a split-split-plot treatment arrangement in 2012 (PROC GLIMMIX, SAS Institute 2008). When the main effect of treatment was significant ($P < 0.05$) in 2011, the sums of squares were further partitioned into orthogonal contrasts. Type 3 tests of the main and interactive effects and the orthogonal contrasts comparing treatments were made using the remaining residual in the ANOVA model.

Response variables were transformed as needed and each analysis performed using a specified distribution for best fit. In 2011, data for the *F.bispinosa* females, thrips larvae and adult *O. insidiosus* were analyzed using the original counts on a negative binomial distribution, data for the adult male *F.bispinosa* and for adult *O. pumilio* were transformed using square root (x + 0.5) on a normal distribution, and data for *Orius* nymphs were analyzed using the original counts on a poisson distribution. In 2012, the Poisson distribution was used to analyze the original counts for *F.bispinosa* males and females and for *Orius* nymphs. Original counts of thrips larvae were fitted to the negative binomial distribution for analysis. The counts for *O. pumilio* and *O. insidiosus* were log-10 transformed (x + 0.1) to normalize these variables and analyzed on a normal distribution. Differences in yield between treatments were analyzed with ANOVA using the GLIMMIX procedure. The distributions for each yield variable were normal, so the analyses were conducted on the original data. The distributions of insects on sunflowers were normal, and these analyses were conducted on the original data.

Results

The predominant thrips species in the sunflower and pepper flowers was *F. bispinosa*. Other species accounted for only 0.4 and 0.2% of the adult thrips in the pepper flowers in 2011 and 2012, respectively. Other species in the samples were *F. occidentalis*, *F. schultzei*, and *F. fusca*. Overall the mean number (±SEM) of adult and larval *F. bispinosa* in pepper was greater in 2012 (83.6 ± 5.9 per 10 flowers) than in 2011 (46.7 ± 4.7 per 10 flowers). Seasonal trends in population abundance of *F. bispinosa* during 2011 and 2012 in plots with and without sunflower companion plants are shown in Figures 2-1 and 2-2, respectively. The numbers of *F. bispinosa* male and female adults were greatest during the first or second week of sampling each year, and the larvae were greatest during the second week of sampling. The adults and larvae declined on later sample dates until reaching very low numbers during the fourth week of sampling each year.

The mean ratios of thrips larvae to adult *F. bispinosa* on peppers and sunflowers for each different treatment in 2011 are shown in Table 2-1. Thrips populations were increasing at the beginning of the season in all treatments on sunflowers, followed by declining populations towards the end of the season. Thrips populations were always decreasing on peppers over black mulch with or without sunflower companion plants, but were increasing in the reflective mulch and kaolin conditions until the end of the season at which time the populations were decreasing. The mean ratios of thrips larvae to *F. bispinosa* adults on peppers and sunflowers in each condition in the 2012 experiment are shown in Table 2-2. Thrips populations were very rarely increasing during 2012, but were rather decreasing in most conditions for most of the season in 2012.

Two species of *Orius* were collected. The mean number ($\pm$SEM) over all samples in pepper in 2011 and 2012 was greater for *O. insidiosus* (0.76 ± 0.07 and 2.67 $\pm$ 0.18 per ten pepper flowers, respectively) than for *O. pumilio* (0.41 ± 0.05 and 0.39 $\pm$ 0.05 per ten pepper flowers, respectively). The numbers of *Orius* species adults were small (approximately 1 per 100 flowers) during the first week of sampling in 2011 and 2012 (Figs. 2-3 and 2-4, respectively). Nymphs of *Orius* were first detected in pepper during the second week of flowering. The numbers of adults and nymphs increased and were greatest during the fifth through seventh weeks of flowering.

The mean ratios of thrips to *Orius* in peppers and sunflowers in each treatment are shown for 2011 in Table 2-3 and for 2012 in Table 2-4. In 2011 prey to predator ratios were always at the level appropriate for suppression with the exception of the black mulch treatment in peppers on the first sample date. In 2012 the prey to predator ratios were always at the level sufficient for suppression with the exception of the ratios in the pepper flowers of three conditions on March 29.

There were six treatments in 2011. These included black mulch with and without companion plants, black mulch and kaolin clay with and without companion plants, and ultraviolet-reflective mulch with and without companion plants. The results of the ANOVA's evaluating the effects of companion plants, the other treatments, and the interaction of companion plants and the other treatments on numbers of adult and immature *F. bispinosa* species in pepper flowers for individual sample dates in 2011 are shown in Table 2-5. Companion plants resulted in a significant increase in the number of adult male, adult female, and larval *F. bispinosa* in the pepper flowers during the first week of sampling on 26 Mar in 2011 (Fig. 2-1). The effect of companion plant was not significant on later 2011 sample dates, except for adult males during the fifth week of sampling on 29 Apr.

The other treatments significantly affected the number of female, male, and larval *F. bispinosa* in 2011 (Table 2-5). During the first week of sampling on 31 Mar, the number of adult males (F=38.55; df=1,12; P<0.0001) and females (F=5.91; df=1,12; P=0.0317) in the treatments of black mulch plus kaolin and ultraviolet-reflective mulch were significantly less than in the treatment of black mulch alone (Fig. 2-5). There were no significant differences between treatments of black mulch, black mulch plus kaolin, and ultraviolet-reflective mulch in the numbers of adult females on later 2011 sample dates. There were no significant differences in 2011 between treatments of black mulch, black mulch plus kaolin, and ultraviolet-reflective mulch in the numbers of adult males on 6 Apr, 22 Apr, and 6 May or in the numbers of larvae on 31 Mar, 6 Apr, 22 Apr, 29 Apr, and 6 May. Numbers of adult males of *F. bisinosa* were greater in treatments of black mulch plus kaolin and ultraviolet-reflective mulch than in the treatment of black mulch alone on 14 (F=12.35; df=1,2; P=0.0043) and 29 Apr (F=12.47; df=1,12; P=0.0041) in 2011. Numbers of larval *F. bispinosa* were greater in treatments of black mulch plus kaolin and ultraviolet-reflective mulch than in the treatment of black mulch alone on 14 Apr (F=41.20; df=1,12; P<0.0001) in 2011. There were no significant interactive effects of companion plants with these other treatments on the number of *F. bispinosa* in 2011 (Table 2-5).

There were eight treatments in 2012. These were a factorial of the two mulches, companion plants/no companion plants, and kaolin/no kaolin. The results of the ANOVA's evaluating the main and interactive treatment effects of mulch, companion plants, and kaolin on numbers of adult and larval *F. bispinosa* species in pepper flowers for individual sample dates in 2012 are shown in Table 2-6. As in 2011, companion plants resulted in significant increases in the number of adult male, adult female, and larval *F. bispinosa* in the pepper flowers during the first week of sampling on 26 and 29 Mar in 2012 (Fig. 2-2). Unlike 2011, companion plants resulted in significant decreases during the next two weeks of sampling in the number of adult females in the pepper flowers. Further, there were significant decreases in the number of adult males in the pepper flowers in the companion plant treatments during the second week of sampling. The effect of companion plant was not significant for adult females on 19 and 26 Apr; for adult males on 5, 12, and 19 Apr; and for larvae on 2, 5, 12, 19, and 26 Apr.

There were no significant effects of mulch on the numbers of adult female, adult male, and larval *F. bispinosa* on any sample date in 2012 (Fig. 2-6, Table 2-6). The numbers of adult female and larval *F. bispinosa* were significantly reduced by kaolin application on the first three sample dates in 2012 while the numbers of adult male *F. bispinosa* were significantly reduced by the application of kaolin on the first four sample dates in 2012 (Fig. 2-7, Table 2-6). Conversely, the numbers of adult females were significantly increased by the application of kaolin on 12, 19, and 26 Apr 2012 and the numbers of adult males were significantly increased on 19 Apr. There were no significant differences for adult females on 5 Apr, adult males on 12 and 26 Apr, and larvae on 5, 12, 19, and 26 Apr in 2012. The interactive effect of companion plant*kaolin was not significant for adult *F. bispinosa* on any sample date except 2 Apr when it was significant for males. This interaction was due to a larger increase in thrips numbers on pepper plants when kaolin was not used in the peppers that were planted without sunflowers compared to the difference in peppers planted with sunflowers. There were significant interactions of companion plant*mulch for larvae in 2012 on 2 and 5 Apr. This interaction indicated a larger effect of mulch on thrips larvae numbers in peppers planted alone than in peppers planted with sunflowers. More thrips larvae were found on plants in the reflective mulch and peppers planted alone condition. The interactive effect of mulch*kaolin was not significant for adults or larval thrips on any sample date in 2012. The interactive effect of companion plant*mulch*kaolin was not significant for adult or larval *F. bispinosa* except for females on 26 Mar. This interaction indicates that on the first date of the season sunflowers decrease the thrips numbers on pepper plants in the two kaolin conditions, but increase the numbers of thrips on companion plants when no kaolin is used and when black mulch is used in place of reflective mulch.

Effects of treatments on *Orius* in pepper flowers. The mean numbers (±SEM) of adult *O. insidiosus*, adult *O. pumilio*, and *Orius* nymphs in treatments of pepper with and without sunflower companion plants in 2011 and 2012 are shown in Figures 2-3 and 2-4, respectively. There was little effect of the companion plants on the numbers of *Orius* in the pepper flowers. There were no significant effects on the numbers of adult *O. pumilio* in 2011 (Table 2-5). The effects on numbers of adult *O. insidiosus* and *Orius* nymphs were significant on only one sample date in 2011. There were no significant effects of companion plants in the numbers of *O. pumilio* adults, *O. insidiosus* adults, or *Orius* nymphs on any sample date in 2012 (Table 2-6).

The mean numbers (±SEM) of adult *O. insidiosus*, adult *O*. *pumilio*, and *Orius* nymphs in the black mulch, black mulch plus kaolin, and ultraviolet-reflective mulch treatments of pepper in 2011 are shown in Figure 2-8. The numbers of adult *O. insidiosus* were significantly less in pepper flowers of the ultraviolet-reflective mulch and black mulch plus kaolin treatments compared to the black mulch treatment on the 22 Apr sample date in 2011 (F=12.34; df=1,12; P=0.0043) (Table 2-6). The numbers of adult *O. pumilio* in pepper flowers of the ultraviolet-reflective mulch and black mulch plus kaolin treatments were significantly less compared to the black mulch treatment on 6 (F=8.49; df=1,12; P=0.013) and 22 Apr (F=9.53; df=1,12; P=0.0094) in 2011 (Table 2-5). There were no other significant differences between mulch and kaolin treatments in the numbers of adult *O. insidiosus* in 2011. The numbers of adult *O. pumilio* in pepper flowers of the ultraviolet-reflective mulch treatment were significantly greater than the black mulch and black mulch plus kaolin treatments on the 6 May sample date in 2011 (F=9.59; df=1,12; P=0.0093). The numbers of *Orius* nymphs in the pepper flowers of the ultraviolet-reflective mulch treatment were significantly less than black mulch on the 14 Apr sample date in 2011 (F=8.83; df=1,12; P=0.0117). They were significantly greater in ultraviolet-reflective treatment than the black mulch and black mulch plus kaolin treatments on the 29 Apr sample date in 2011 (F=11.91; df=1, 12; P=0.0048).

The mean numbers (±SEM) of adult *O. insidiosus*, adult *O. pumilio*, and *Orius* nymphs in the black mulch and ultraviolet-reflective mulch treatments of pepper in 2012 are shown in Figure 2-9. There were no significant effects of mulch treatment on the numbers of adult *O. pumilio* or the numbers of *Orius* nymphs in 2012 (Table 2-6). The effect of mulch was significant for adult *O. insidiosus* only on the 12 Apr date in 2012, in which the numbers were significantly less in the ultraviolet-reflective versus the black mulch treatment.

The effects of kaolin clay on *Orius* in 2012 were more consistent than those of mulch (Fig. 2-10). Adults of both species and *Orius* nymphs were more abundant on plants that were not coated in kaolin clay than on plants that had been sprayed with kaolin clay. This effect was significant on the third collection date for adults of both species and at the end of the season for nymphs.

The ANOVA results for the effects of the treatments on the numbers of thrips and *Orius* found on sunflowers are shown in Table 2-7. Ultraviolet-reflective mulch under peppers significantly increased numbers of thrips larvae found on sunflowers in those plots compared to black mulch or kaolin treatments on Mar 31 2011 (Fig.2-11) as revealed by orthogonal contrasts (F=199.20; df=1,2; P=0.0050). On 22 Apr 2011 thrips larvae numbers were greatest in sunflowers in pepper plots planted with black mulch when compared to ultraviolet-reflective mulch and kaolin treatments (Fig. 2-11) as revealed by orthogonal contrasts (F=648; df=1,2; P=0.0015). Black mulch also significantly increased the numbers of adult male *F. bispinosa* found on sunflowers compared to kaolin and ultraviolet-reflective mulch treatments on 29 April 2011 (F=204.45; df=1,2; P=0.0049). Treatments did not have any other significant effects in 2011.

The ANOVA results for the effects of kaolin and mulch on insect numbers found in sunflowers in the 2012 experiment are shown in Table 2-8. There were no significant treatment or interaction effects on the numbers of female *F. bispinosa*. Numbers of male *F. bispinosa* were significantly reduced by kaolin and also by ultraviolet-reflective mulch (Table 2-8, Fig. 2-12). There was a significant interaction effect of mulch and kaolin on the numbers of thrips larvae on 26 April, however the difference was too small to be practically important (Table 2-8, Fig. 2-12). Applications of kaolin significantly reduced numbers of adult *O. insidiosus* on 26 March (Table 2-8, Fig. 2-12). A significant interaction effect of kaolin and mulch on *O. pumilio* was found on two dates (Table 2-8). On 26 March the interaction was such that kaolin decreased the population of *O. pumilio* on sunflowers in the ultraviolet-reflective mulch condition, but increased their numbers in the black mulch condition (Fig. 2-12). On the April 12 kaolin did not affect populations on sunflowers in the ultraviolet-reflective mulch condition but decreased populations in the black mulch condition (Fig. 2-12). There were no significant effects on *Orius spp.* nymph populations (Table 2-8).

The mean number and weights (±SEM) of the peppers harvested by each size as well as the results of the ANOVAs of the effects on yield in 2011 are shown for the first harvest on 3 May, the second harvest on 17 May, and the total both harvests in Table 2-9. There were very few extra-large fruits in 2011 and these were combined with the large fruits for analysis. Unmarketable fruits in 2011 were not due to thrips damage, but rather were the result of damage from Heteropterans.

Companion plants had a significant effect on the number and weight of medium marketable fruits harvested on the second harvest date, which were also the total medium fruits harvested as none were harvested on the first date. Highest yield in pounds and number of medium marketable fruits was obtained from plots grown without sunflowers. Sunflowers also significantly decreased the number of marketable large and extra-large peppers harvested on the second date.

Mulch and kaolin treatments did not affect medium peppers in 2011 but significantly affected the weight of large and extra-large peppers harvested on the first date. Ultraviolet-reflective mulch significantly increased yield of large and extra-large tomatoes on the first date compared to black mulch and kaolin (F=11.95; df=1,12; P=0.0047). Treatments of ultraviolet-reflective mulch and kaolin both increased the yield of large and extra-large peppers significantly compared to black mulch for the season total by weight (F=9.62; df=1,12; P=0.0092) and number (F=6.92; df=1,12; P=0.0275).

The mean number and weights (±SEM) of medium, large, and extra-large fruits on the 27 Apr harvest, the 10 May harvest, and the total of both harvests in the 2012 experiment are shown in Table 2-10. There were few unmarketable fruit in 2012, so the data were not included. Harvested fruits were mostly extra-large on the first harvest date, while medium, large, and extra-large fruits were harvested on the second harvest date. There were no significant effects of companion plant or mulch on the number and weights of fruits of any size on the first or second harvest dates. Application of kaolin significantly increased the number and weights of extra-large fruits on the first and second harvests. Application of kaolin significantly increased the weights of large fruits on the second harvest date. Only the number and weights of extra-large fruits were significantly increased by application of kaolin when the number and weights of fruit were combined over both harvests. The interactive effect of mulch*kaolin on the number and weights of extra-large fruits was significant for the second harvest and for the total of both harvests. This was due to a greater number and weight of fruits by application of kaolin on black compared to ultraviolet-reflective mulch.

Discussion

In both years of the experiments the native *F. bispinosa* was the only species of thrips found in considerable numbers. In this region of Florida, when broad-spectrum insecticides are not used as they were not in this experiment, *F. occidentalis* is outcompeted by this native species and consumed by preferentially by *Orius spp.* (Funderburk et al. 2000, Reitz et al. 2006, Frantz and Mellinger 2009, Funderburk 2009). Due to the lack of this capable vector of Tomato spotted wilt, and due also to the lack of competency of *F. bispinosa* to vector the disease in the field (Avila et al. 2006), the infection was not present in the fields in either year. The population abundance of *F. bispinosa* followed a very distinct pattern in both years. The adults are present in the flowers at the end of March and beginning of April, followed by a peak in larval populations a weak later. Once the predator *Orius* begins to arrive in the fields, even in numbers as small as one or two adults per 10 pepper flowers, the thrips populations immediately decrease at an accelerated pace reaching near extinction only one week after *Orius* numbers begin to increase. This clear relationship between the predator and its prey illustrates how effective this natural control is when pesticides are excluded from a field (Funderburk et al. 2000, Ramachandran et al. 2001, Frantz and Mellinger 2009).

In 2011 the thrips populations were always decreasing on peppers in the black mulch condition. This indicates that either the plants were not suitable for reproduction due to some antibiotic or antixenotic factor, or that the predators were able to control thrips populations on these plants. Thrips larvae to adult ratios were higher on sunflowers than on peppers which could indicate a reproductive host preference. Predation is also a viable explanation. *Orius* numbers were higher in the black mulch condition than in the other two mulch conditions due to the repellency of the kaolin clay and ultraviolet-reflective mulch. In 2012 a similar pattern was observed with thrips populations never increasing in the black mulch condition, but with a few increasing populations in the kaolin clay and ultraviolet-reflective mulch conditions. Again, in 2012 *Orius* numbers were higher on black mulch than reflective mulch and higher in plots without kaolin than in those where kaolin was used. This evidence strongly supports the explanation of predation as the force contributing to decreasing populations of thrips.

Prey to predator ratios were always high enough for suppression of thrips populations on peppers in 2011 and were only below this threshold in the black mulch and ultraviolet-reflective mulch conditions without kaolin in 2012 for three sample points. These prey to predator ratios demonstrate the superior ability of native *Orius* predators to be present in pepper fields in South Florida in high enough numbers to suppress thrips when pesticides are not used. In 2012 the addition of kaolin further reduced these ratios. Despite also reducing predator numbers on pepper plants, kaolin may also reduce thrips numbers enough to contribute to thrips suppression rather than impede it.

In 2011, though not always significant, thrips followed a similar distribution pattern across the different mulch conditions to those found in a previous study (Reitz et al. 2003). As in that study, higher numbers of thrips were present on the peppers growing over black mulch early in the season followed by a reversal later in the season when numbers were higher on ultraviolet-reflective mulch. The distribution of thrips larvae in our study and the study by Reitz et al. (2003) were similar with higher numbers of larvae found in plots with ultraviolet-reflective mulch. One possible explanation for this response, presented by Reitz et al. (2003) and with which these results are in agreement, is an effect of the arrestment and repellant qualities of the ultraviolet-reflective mulch. Although most thrips are repelled by the reflectance, the few that do land are arrested and will oviposit on the plants. Those eggs will have a higher survival rate than those on black mulch due to protection from natural enemies that are repelled by the mulch (Reitz et al. 2003). This explanation is relevant as *Orius* were repelled by ultraviolet-reflective mulch in the current study and the previous study (Reitz et al. 2003). Thrips larvae are more vulnerable to predation by *Orius* than thrips adults (Baez et al. 2004), which is why this effect is apparent for the larvae but not the adults. This also explains why adult numbers are higher or the same on ultraviolet-reflective mulch later in the season.

Another potential mechanism for the higher number of larvae on ultraviolet-reflective mulch is the physiology of the plants grown over the different mulches.

Females may oviposit more on plants grown over ultraviolet-reflective mulch and/or larvae may have higher survival rates due to the physical condition of the plants. The ultraviolet-reflective mulch modifies temperatures and humidity of the soil and plant canopy (Hutton and Handley 2007), and these different conditions may be beneficial for larvae and eggs. Additionally, by the end of the season plants have grown over the mulch obscuring its reflectance.

In 2012 the distribution of thrips adults across the different mulches was different from that observed in 2011 and in the Reitz et al. (2003) study. In this case adult thrips were higher on black mulch (not significant) for the entire collection period. This difference may have occurred due to the higher abundance of *O. pumilio* in ultraviolet-reflective mulch towards the end of this period when thrips adults would normally have been higher on ultraviolet-reflective mulch. Thrips larvae were higher on ultraviolet-reflective mulch in 2012 as they were in 2011, though the difference was not as great as in 2011 and this can again be attributed to predation by higher numbers of *O. pumilio* in ultraviolet-reflective mulch plots which could compensate for the lower number of *O. insidiosus*.

The use of kaolin clay resulted in lower populations of thrips on peppers at the beginning of both seasons and was stronger than any other effect. Thrips numbers were higher on kaolin clay, however, in the middle of the season in 2011 and the end of the season in 2012. These results are contrary to previous reports of the effects of kaolin clay on thrips, which did not find any effect of kaolin clay on thrips populations and concluded that kaolin clay works by interfering with feeding behavior and disease transmission (Wilson et al. 2004, Reitz et al. 2008). The lower number of thrips in plots that received applications of kaolin clay in this study suggests that the clay does indeed repel *F. bispinosa*, although the mechanism is unknown. A few mechanisms have been found in previous studies to cause this reduction in thrips populations, including reflective properties, reduced oviposition, and increased mortality (Larentzaki et al. 2008). Studies with other insect species suggest additional mechanisms which may also be valid in this context. Some of these other mechanisms include reduced ability to perceive the plant through mechanoreception (Peng et al. 2010), vision (Bar-Joseph and Frenkel 1983), and olfaction (Barker et al. 2006). A combination of mechanisms is likely responsible for the drastic reduction in thrips populations on plants sprayed with kaolin clay. Further laboratory experiments will need to be conducted to determine any physiological effects the clay may have on *F. bispinosa*.

The later season reversal of this effect on thrips is likely due to the lower numbers of *Orius* on these plants, as was the case for the ultraviolet-reflective mulch. Fewer numbers of predators on these plants allowed thrips to avoid predation. This may have been a result of more thrips surviving on these plants and/or more adults immigrating to these plants from the control plants to avoid predation. Females of *F. tritici* and *F. occidentalis* will disperse from flowers in the presence of *O. insidiosus* (Baez et al. 2004). This suggests that thrips attempt to flee from predators and may flee to other plots with fewer predators. Additionally, the lower number of thrips found in plots without kaolin clay at the end of the season may have been due not to fewer thrips on the plants, but fewer in the flowers. More thrips may have fled the flowers to seek refuge on the leaves, away from predators resulting in fewer thrips in those samples of flowers.

Thrips numbers were higher on peppers planted with sunflower companion plants than on those planted alone on the first collection date, and this was followed by a reversal in this pattern for adults in 2012 and adult females in 2011. The initial higher numbers of thrips may be due to more thrips being attracted to those fields with sunflowers. After the first date, populations of *Orius* began to increase in all plots and were higher in plots with sunflowers. These more abundant predators reduced thrips in these plots compared to plots without sunflowers. Some of this later number dilution may also have resulted from thrips being attracted away from the peppers and to the sunflowers in the plots with sunflowers, which has been suggested (Legaspi and Baez 2008). Future experiments involving the exclusion of predators will help to uncover the mechanism for this and the other effects.

In 2011 there were no interaction effects on thrips distributions, indicating that sunflowers had the same effect on thrips with each mulch and kaolin treatment. In 2012, there were a few significant interactions on only a few dates, which renders the practical significance of these results questionable. There was a significant interaction effect of companion plant and mulch type on female thrips numbers on one date. Sunflowers decreased thrips numbers with both mulches, but resulted in a greater difference on black mulch. The same effect was observed with males, however, this effect was significant for two dates and was inconsistent between the dates. Thrips larvae also experienced significant interaction, although a different interaction. The interaction was on two dates between companion plants and kaolin. Kaolin clay does not reduce thrips numbers as effectively in plots with sunflowers as it does in plots without sunflowers. This suggests that the sunflowers interfere with the activity of the kaolin clay in some way, perhaps by shading the pepper plants and interfering with the reflective quality of the clay and providing a source of adult thrips that can move easily between the rows of sunflowers and peppers to oviposit.

While not a significant interaction, kaolin clay decreases thrips larvae on ultraviolet-reflective mulch to a greater degree than on black mulch, suggesting a synergistic reduction in thrips numbers when the two are used together. Thrips larvae are more abundant on ultraviolet-reflective mulch than on black mulch when kaolin clay is not used, due to protection from *Orius*. However, when kaolin clay is used the larvae likely suffer higher mortality which is stronger than the protection from predation. No other interactions were significant in the experiment. The best combination for reduction in thrips numbers at the beginning of the season is a combination of ultraviolet-reflective mulch and kaolin clay with no companion plants. Later in the season companion plantings become effective and kaolin clay increases thrips numbers. Sunflowers may act as a source for thrips at the beginning of the season and later in the season may begin to act as a sink (Legaspi and Baez 2008). To avoid the problem of sunflowers acting as a source for thrips pests they can be planted later in the season so the flowers will bloom just after the pepper flowers and attract the thrips away. Planting sunflowers to bloom later in the season and discontinuing kaolin clay applications once predators have reached high enough numbers to suppress thrips will likely increase the efficacy of this method.

The two different species of *Orius* responded differently to different mulches. Higher numbers of *O. insidiosus* were always found on black mulch, demonstrating an obvious aversion to ultraviolet-reflective mulch. The same was not true for *O. pumilio* which was variable throughout the season, on some dates appearing in higher numbers on black mulch and on other dates appearing in higher numbers on ultraviolet-reflective mulch. The reason for this is unclear. On the first two dates the distribution of *O. pumilio* appears to be tracking the thrips, but after this date no relationship can be seen. This species might also be tracking other species of prey that were not recorded in this study.

Nymphs of *Orius* displayed another pattern entirely, initially appearing in higher densities on the black mulch until the end of the season at which point they were significantly more abundant on ultraviolet-reflective mulch. Higher numbers of *Orius* nymphs on peppers grown on ultraviolet-reflective mulch could be the result of a number of factors. The potential explanations fall into a few categories: plant canopy conditions, intraguild predation, and prey availability. Different canopy conditions in peppers grown on reflective mulch could be conducive to the survival of eggs and nymphs of *Orius* that were oviposited by the few females to land on these plants. This higher survival rate would then lead to higher numbers on ultraviolet-reflective mulch compared to black mulch.

Another possibility is intraguild predation. Other potential predators of thrips, *Chrysoperla* and to a greater extent *Geocoris,* also feed on *Orius* spp. (Rosenheim 2005). Intraguild predation by *Geocoris* exerts a substantial influence on the survival rate and density of *Orius tristicolor* in cotton and this *Geocoris* feeds more successfully on *Orius* nymphs than the vagile adults (Rosenheim 2005). Both *Chrysoperla* and *Geocoris* decrease densities of *Orius* through intraguild predation (Rosenheim 2005). If *Geocoris* is repelled by ultraviolet-reflective mulch as are thrips and *Orius*, the lower densities of *Geocoris* in this treatment would allow higher survival rates and higher densities of *Orius*, specifically nymphs, to occur. Additionally, *Orius* nymphs may be higher in these plots due to the higher densities of thrips larvae in these plots allowing more nymphs to feed with lower intraspecific competition. Nymphs were not identified to species and as such a third explanation arises: the nymphs could be nymphs of *O. pumilio* which was more abundant on ultraviolet-reflective mulch towards the end of the season. This could have resulted in higher numbers of eggs and therefore nymphs of this species on plants in the ultraviolet-reflective mulch plots. A combination of these factors is also possible and further experiments involving exclusion of intraguild predators and other species is needed to elucidate the mechanism responsible.

Similar to the ultraviolet-reflective mulch, kaolin clay resulted in a significant reduction in the abundance of *Orius* on peppers, consistently for both species and all life stages. This reduction may have resulted in part from the repellant nature of the clay and also in part from direct mortality. No studies have been conducted to determine the effects of kaolin clay on *Orius* spp., but a similar predator from the same family, *Anthocoris memoralis* suffers increased mortality when it is coated with kaolin clay (Bengochea et al. 2013). Using that information and the information gained from this study it is likely that in addition to being repelled by kaolin clay, *Orius spp.* suffer direct mortality from kaolin clay applications. Laboratory assays are needed to determine if this is so. This negative effect of kaolin clay on natural predators of thrips can be alleviated by terminating applications of kaolin clay once *Orius* begin to appear in fields in high enough numbers for suppression of thrips populations. This will likely not change the benefits received when using kaolin clay as indicated by previous studies which found that later applications were not beneficial and that the kaolin clay is most effective when thrips populations are high (Spiers et al. 2004). Additionally, predaceous heteropterans are able to rebound in fields once kaolin clay treatments are terminated (Marko et al. 2008) and cessation of these treatments can allow *Orius* to move into those fields and continue suppression of thrips populations.

The effect of companion plants on *Orius* populations was not consistent and is not conclusive. For the different species and life stages the sunflowers had different effects at different times during each season. These differences were only rarely significant. Legaspi and Baez (2008) also did not find differences in the densities of *O. insidiosus* on peppers in the two conditions, and suggest that sunflowers act as a sink for O*. insidiosus* and thrips, rather than a source. Sunflowers, they propose, may serve better as a trap crop for thrips than as an attractant for *O. insidiosus* and our results are in agreement. Interaction effects on *Orius* populations were sporadic and inconsistent and are not considered any further.

As ultraviolet-reflective mulch repels both thrips and their natural enemies, it must be used cautiously to ensure that the thrips numbers do not build up on this mulch in the absence of predators. Reitz et al. 2003 reported that *Orius* are arrested by ultraviolet-reflective mulch if they are released onto plants grown on this mulch and may lay eggs before dispersing. Growers can overcome the problem of natural enemies being repelled by the ultraviolet-reflective mulch by releasing adults directly onto these plants early in the season (Reitz et al. 2003). Additionally, the presence of sunflower companion plantings increased the number of *Orius* adults and nymphs on pepper plants in the ultraviolet-reflective mulch plots compared to reflective mulch plots without sunflowers in both years (data not shown). Planting companion plants with reflective mulch may decrease the repellency of ultraviolet-reflective mulch or allow *Orius* to move into these pepper fields more easily.

Effects of mulch and kaolin on the numbers of thrips on sunflowers in 2011 were few and inconsistent. The practical significance of these effects is dubious. In 2012 kaolin and reflective mulch separately reduced numbers of male *F.bispinosa* on sunflowers and kaolin reduced numbers of adult *Orius* on sunflowers. These effects only occurred for one date each indicating that this effect may not be practically significant, however the consistency of the effect increasing insect numbers on sunflowers for both predator and prey indicates a potentially valid effect. More research is needed to elucidate the practical significance.

Ultraviolet-reflective mulch increased yield of extra-large fruits in 2011 and large in 2012, although this increase was only significant for extra-large fruits in 2011. Increases in yield when ultraviolet-reflective mulch is used have been found previously (Greer and Dole 2003, Reitz et al. 2003, Hutton and Handley 2007, Diaz-Perez 2010). This difference in yield may have been more apparent if the experiments had been conducted in the fall as one study found higher yield from ultraviolet-reflective mulch in the fall growing season but no differences in the spring growing season (Diaz-Perez 2010). Higher yield from ultraviolet-reflective mulch is likely due to several factors including reduced pest damage, reduced disease incidence and cooler soil temperatures. However, this difference was only significant for extra-large fruits in one year, and if growers are more concerned about medium or large fruits they should consider this before choosing to use this mulch as it may reduce yield of those fruits.

Kaolin clay significantly increased yield of extra-large fruits in 2012 and non-significantly increased yield of peppers in 2011. The significant interaction effect of mulch and kaolin indicates that kaolin increases yield of peppers on black mulch to a greater extent than the yield of ultraviolet-reflective mulch. When kaolin clay is not used, higher yield is produced by plants grown on reflective mulch, but when kaolin clay was used the black mulch yielded more marketable extra-large fruits than the ultraviolet-reflective mulch. Considering these results, if growers are only using the mulch and not the kaolin clay, reflective mulch is superior for yield. However, if a grower will use mulch and kaolin clay or if a grower does not use plastic mulch at all, applications of kaolin clay will increase yield substantially. Although the effects of kaolin clay on the yield of various crops are mixed, our results are in agreement with those studies that found an increase in yield when kaolin clay was used (Spiers et al. 2004, Reitz et al. 2008, Cantore et al. 2009). Possible explanations for this increase in yield, in addition to reduced insect damage, include: lower disease incidence (Creamer et al. 2005, Reitz et al. 2008), less water and heat stress (Spiers et al. 2004, Creamer et al. 2005), higher levels of chlorophyll in the plants (Creamer et al. 2005), or decreased damage from sunburn (Cantore et al. 2009).

Companion plants significantly increased yield of extra-large fruits in 2011, but did not have a significant effect on yield in 2012. However, a significant interaction with the other treatments indicates that companion plants increase yield in ultraviolet-reflective mulch and kaolin clay conditions, while causing a decrease in yield in the black mulch conditions. It may be that in the black mulch conditions the sunflowers acted as a source for thrips to immigrate to the peppers, resulting in more damage and lower yield. As this interaction effect was not observed for any other fruit sizes or in 2012 it does not seem to be a consistent effect.

In order to reduce thrips populations, increase populations of natural predators and increase yield, this study provides several effective combinations. A combination of reflective mulch with applications of kaolin clay early in the season and sunflower companion plants that begin blooming after the peppers may provide the best control of thrips and greatest yield. However, growers with limited space can still receive reductions in thrips numbers without the sunflowers. This study indicates that kaolin clay is a very effective “push” stimulus for thrips, as is reflective mulch and a combination of the two. Kaolin clay is also applicable for growers that do not use plastic mulch. The results of the sunflowers as a pull stimulus are not conclusive and a different plant or timing may need to be tested in future research to increase the efficacy of this program. All components of this method can be used in different combinations in organic as well as in conventional farming systems and are compatible with other methods of pest management for other species of pests.

Table 2-1. The ratio of the total number of larval *Frankliniella* species to the total number of *Frankliniella bispinosa* adults in the flowers of peppers planted without sunflowers, peppers planted with sunflowers, and sunflowers on each sample date in the experiment conducted in 2011 in Palm Beach County, Florida.

Treatment	31-Mar.	6-April	14-Aprill	22-April	29-April	6-May
	Peppers without sunflowers					
B[a]	0.41	0.88	0.64	0.42	0.2	0
B/K	1.35	1.05	1.46	0	0.33	0.05
R	0.98	0.79	1.21	1.5	0.33	0.33
	Peppers with sunflowers					
B	0.43	0.92	0.91	0.05	0.16	0.47
B/K	0.25	1.15	2.22	1.67	0.75	0.08
R	0.7	1.47	1.91	0.05	0	0.33
	Sunflowers					
B	1.66	7.71	1.30	0.11	0.16	1.14
B/K	1.98	3.08	1.73	0.02	0.03	0.01
R	2.50	15.77	0.33	0.04	0.05	0.34

[a] B indicates plants planted on black mulch, K indicates kaolin clay and R indicates pepper plants planted on reflective mulch

Table 2-2. The ratio of the total number of larval *Frankliniella* species to the total number of *Frankliniella bispinosa* adults in the flowers of peppers planted without sunflowers, peppers planted with sunflowers, and sunflowers on each sample date in the experiment conducted in 2012 in Palm Beach County, Florida.

Treatment	26-Mar.	29-Mar.	2-April	5-April	12-April	19-April	26-April
	Peppers without sunflowers						
B[a]	0.06	0.1	0.23	0.76	0.18	0.15	0
B/K	0.01	0.16	0.34	0.44	0.3	0.1	1.07
R	0.11	0.19	0.75	1.4	0.6	0	0
R/K	0.04	0.19	0.31	0.54	0.27	0.32	0.24
	Peppers with sunflowers						
B	0.04	0.22	0.77	0.78	0.19	0.04	0
B/K	0.03	0.16	1.2	1.34	0.48	0.08	0.28
R	0.07	0.38	0.55	0.79	0.56	0	0.13
R/K	0.04	0.2	0.73	0.85	0.53	0.12	0.4
	Sunflowers						
B	0.15	0.99	0.29	0.63	0.55	0.74	0.64
B/K	0.14	1.02	0.83	2.54	0.41	1.48	0.84
R	0.32	0.34	0.5	0.5	0.55	1.13	0.18
R/K	0.35	0.28	0.33	1.86	1.86	0.4	0.32

[a] B indicates plants planted on black mulch, K indicates kaolin clay and R indicates pepper plants planted on reflective mulch

Table 2-3. The ratio of the total number of adult and larval *Frankliniella* species to the total number of *Orius insidiosus* and *O. pumilio* adults and nymphs in the flowers of peppers planted without sunflowers, peppers planted with sunflowers, and sunflowers on each sample date in the experiment conducted in 2011 in Palm Beach County, Florida.

Treatment	*F*-value of treatment effect					
	31-Mar.	6-Apr	14-Apr	22-Apr	29-Apr	6-May
	Peppers without sunflowers					
B[a]	146.25*	87.38*	8*	0.21*	0.17*	0.27*
B/K	152*	65.73*	19.19*	0.26*	0.15*	0.41*
R	---	61.5*	19.75*	0.6*	0.15*	0.19*
	Peppers with sunflowers					
B	218.67	63.51*	1.95*	0.29*	0.64*	0.7*
B/K	110*	88.19*	10.55*	0.49*	0.48*	0.84*
R	---	114.04*	38.46*	0.26*	0.03*	0.13*
	Sunflowers					
B	69.55*	42.13*	0.73*	6.47*	9.72*	2.46*
B/K	173.67*	51.61*	1.52*	8.16*	8.57*	5.19*
R	187.96*	128.17*	6.58*	6.75*	6.24*	3.43*

[a] B indicates plants planted on black mulch, K indicates kaolin clay and R indicates pepper plants planted on reflective mulch

[b]--- indicates no *Orius* on that date (undefined)

*, indicates the number of *Orius* was sufficient for suppression of the thrips population

Table 2-4. The ratio of the total number of adult and larval *Frankliniella* species to the total number of *Orius insidiosus* and *O. pumilio* adults and nymphs in the flowers of peppers planted without sunflowers, peppers planted with sunflowers, and sunflowers on each sample date in the experiment conducted in 2012 in Palm Beach County, Florida.

Treatment	26-Mar.	29-Mar.	2-Apr	5-Apr	12-Apr	19-Apr	26-Apr
	Peppers without sunflowers						
B[a]	68*	154.75*	161.08*	41.82*	8.63*	0.66*	0.26*
B/K	36*	39*	---[b]	61*	29.08*	31.49*	4.45*
R	---	361	125.25*	146.75*	13.61*	0.53*	0.16*
R/K	---	---	28*	54.5*	25.1*	23.55*	4.18*
	Peppers with sunflowers						
B	169.75*	252.38	103.82*	19.63*	2.79*	0.73*	0.18*
B/K	40*	47*	78*	20.92*	23.33*	29.6*	1.08*
R	154*	257.11	159.97*	40.41*	9.63*	0.41*	0.14*
R/K	---	60.5*	66.17*	56.67*	16.89*	10.36*	1.33*
	Sunflowers						
B	54.73*	53.23*	10.21*	9.3*	3.69*	2.51*	1.79*
B/K	55.36*	52.25*	22.74*	7.85*	4.2*	1.75*	3.62*
R	53.26*	42.33*	20.21*	13.55*	4.19*	2.48*	5.7*
R/K	58.23*	40.28*	21.97*	15.31*	3.99*	2.08*	0.59*

[a] B indicates plants planted on black mulch, K indicates kaolin clay and R indicates pepper plants planted on reflective mulch
[b]--- indicates no *Orius* on that date (undefined)
*, indicates the number of *Orius* was sufficient for suppression of the thrips population

Table 2-5. *F*-values for treatment effects in the ANOVAs conducted for individual 2011 sample dates to determine the effects of companion plants, mulch and kaolin on the numbers of adults and immatures of *F. bispinosa* and *Orius* species in the experiment conducted in Palm Beach County, Florida.

ANOVA treatment effect	d.f.	*F*-value					
		31-Mar.	6-April	14-April	22-April	29-April	6-May
F. bispinosa adult females							
C[a]	1, 12	16.0**	0.2	0.4	2.4	0.6	0.3
T	2, 12	4.0*	2.1	2.7	0	3	3.6
C x T	2, 12	0.1	2.2	0.3	0.3	2.2	0.1
F. bispinosa adult males							
C	1, 12	9.0**	3.2	0.7	0.5	5.3*	0.3
T	2, 12	23.6***	3.6	7.6**	0.9	6.4**	1
C x T	2, 12	0.3	3.1	2.4	1.1	2.9	0
F. bispinosa larvae							
C	1, 12	5.7*	1.5	1.3	0.5	1	n/a
T	2, 12	3.3	2.2	20.6***	0.2	0	n/a
C x T	2, 12	0.2	5.3*	2	2.7	2.6	n/a
O. insidiosus adult males and females							
C	1, 12	n/a	1.9	0.5	0.1	4.4	5.5*
T	2, 12	n/a	1.4	1.7	6.7**	0.3	1.5
C x T	2, 12	n/a	0.8	0.4	1.9	0.9	1.5
O. pumilio adult males and females							
C	1, 12	0.2	0.3	0.1	0	0.1	3
T	2, 12	1.8	4.3*	0	4.9*	1.2	4.8*
C x T	2, 12	0.2	0.3	0.4	0.9	1.4	4.5*
Orius species nymphs							
C	1, 12	n/a	n/a	0.1	0.1	10.4**	0.9
T	2, 12	n/a	n/a	4.5*	1.4	6.0**	0.2
C x T	2, 12	n/a	n/a	2.6	0.4	0.4	1.4

[a]C indicates companion plant effects, T indicates treatment (mulch type, kaolin clay) effects.

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

Table 2-6. *F*-values for treatment effects in the ANOVAs conducted for individual 2012 sample dates to determine the effects of companion plants, mulch and kaolin on the numbers of adults and immatures of *F. bispinosa* and *Orius* species in the experiment conducted in Palm Beach County, Florida.

ANOVA treatment effect	d.f.	*F*-value						
		26-Mar.	29-Mar.	2-April	5-April	12-April	19-April	26-April
F. bispinosa adult females								
C[a]	1, 8	16.4**	0.5	14.7**	7.4*	5.4*	3.0	0.2
M	1, 2	0.8	1.5	0.2	0.0	1.1	8.8	0.2
C x M	1, 8	0.8	0.0	17.0**	1.5	0.5	0.9	0.0
K	1, 4	42.1**	67.8***	62.5***	0.0	34.7**	83.3***	9.7*
C x K	1, 8	0.0	1.0	9.47*	0.9	3.7	0.1	0.1
M x K	1, 4	0.2	1.3	1.7	2.8	1.3	0.0	0.2
C x M x K	1, 8	5.2*	0.0	3.3	0.0	2.2	0.4	0.5
F. bispinosa adult males								
C	1, 8	18.7**	12.6**	5.2*	0.9	0.0	2.3	5.6*
M	1, 2	1.2	2.0	0.8	0.0	0.0	8.2	1.1
C x M	1, 8	1.0	7.2*	8.6*	0.7	0.1	0.0	0.0
K	1, 4	61.2**	201.3***	180.2***	11.5*	0.0	119.2***	3.1
C x K	1, 8	0.0	5.0	1.0	4.9	0.0	2.3	1.9
M x K	1, 4	0.4	0.0	3.5	0.7	0.7	1.1	0.0
C x M x K	1, 8	4.3	5.0	0.2	1.9	0.2	0.3	0.9
F. bispinosa larvae								
C	1, 8	9.7**	7.8*	3.7	0.6	0.0	n/a	n/a
M	1, 2	0.6	0.1	0.1	0.0	1.8	n/a	n/a
C x M	1, 8	0.1	0.9	0.0	1.5	0.3	n/a	n/a
K	1, 4	37.6**	43.8**	20.7**	2.4	6.0	n/a	n/a
C x K	1, 8	2.1	0.2	7.6*	13.9**	0.3	n/a	n/a
M x K	1, 4	1.0	3.0	2.5	2.7	6.1	n/a	n/a
C x M x K	1, 8	0.1	2.6	1.4	1.8	0.4	n/a	n/a

Table 2-6. Continued

ANOVA treatment effect	d.f.	*F*-value							
		26-Mar.	29-Mar.	2-April	5-April	12-April	19-April	26-April	26-April
O. insidiosus adult males and females									
C	1, 8	0.1	0.1	0.6	3.6	0.8	2.8	0.3	
M	1, 2	3.6	3.2	0.9	1.1	25.6*	5.6	7.9	
C x M	1, 8	0.1	1.4	0.8	6.3*	0.4	0.2	0.0	
K	1, 4	0.1	1.0	20.6**	3.6	7.1	12.1*	1.0	
C x K	1, 8	0.1	1.4	0.4	0.2	3.1	2.4	0.9	
M x K	1, 4	0.1	3.2	3.3	1.7	8.7*	2.5	0.1	
C x M x K	1, 8	0.1	0.1	1.4	2.5	0.1	0.0	2.2	
O. pumilio adult males and females									
C	1, 8	0.4	0.5	0.1	0.1	0.9	0.5	0.6	
M	1, 2	0.3	0.2	0.3	0.2	0.7	0.2	2.1	
C x M	1, 8	0.4	0.5	0.0	0.4	0.4	9.7*	9.6*	
K	1, 4	2.5	6.2	15.9*	5.0	4.8	1.5	3.5	
C x K	1, 8	0.4	0.5	1.0	0.1	0.1	1.5	0.6	
M x K	1, 4	0.3	0.2	0.0	0.2	0.8	1.5	0.0	
C x M x K	1, 8	0.4	0.5	0.4	0.3	0.0	1.0	4.0	
Orius species nymphs									
C	1, 8	n/a	n/a	n/a	1.7	0.9	1.5	4.1	
M	1, 2	n/a	n/a	n/a	0.3	0.0	2.2	7.7	
C x M	1, 8	n/a	n/a	n/a	0.3	2.1	0.0	0.3	
K	1, 4	n/a	n/a	n/a	7.1	7.5*	34.3**	24.4**	
C x K	1, 8	n/a	n/a	n/a	0.0	0.2	0.9	1.7	
M x K	1, 4	n/a	n/a	n/a	3.0	0.2	0.1	1.0	
C x M x K	1, 8	n/a	n/a	n/a	0.8	0.0	0.3	0.7	

[a]C indicates effect of companion plants, M indicates mulch effects, K indicates kaolin clay effects.
*, *P* < 0.05; **, *P* < 0.01; ***, *P* < 0.001

Table 2-7. *F*-values for treatment effects in the ANOVAs conducted for individual 2011 sample dates to determine the effects of mulch and kaolin on the numbers of adults and immatures of *F. bispinosa* and *Orius* species on sunflowers in the experiment conducted in Palm Beach County, Florida.

Variable	d.f.	*F*-value of treatment effect						
		31-Mar.	6-April	14-April	22-April	29-April	6-May	26-Apr
F. bispinosa adult females	2,2	7.8	1.8	1.8	2.9	12.5	2.6	0.2
F. bispinosa adult males	2,2	3.4	3.3	1.2	0.7	102.4**	3.8	0.2
F. bispinosa larvae	2,2	101.8**	2.5	0.5	327.0**	0.9	3.0	0.0
O. insidiosus adult males and females	2,2	2.6	4.0	0.4	0.6	0.7	0.0	0.1
O. pumilio adult males and females	2,2	0.1	0.3	0.5	3.7	1.6	0.1	0.1
Orius species nymphs	2,2	na	3.8	0.3	0.6	0.9	1.5	0.2

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

Table 2-8. *F*-values for treatment effects of mulch type, and kaolin in the ANOVA's conducted for individual 2012 sample dates on the numbers of adults and immatures of *F. bispinosa* and *Orius* species on sunflowers in the experiment conducted in Palm Beach County, Florida.

ANOVA treatment effect	d.f.	*F*-value						
		26-Mar.	29-Mar.	2-April	5-April	12-April	19-April	26-Apr
F. bispinosa adult females								
M[a]	1, 2	0.4	3.5	0.1	0.0	3.7	0.4	0.4
K	1, 4	2.2	1.1	0.0	1.3	0.3	0.9	0.0
M x K	1, 4	4.9	0.0	3.5	0.1	1.3	2.6	3.4
F. bispinosa adult males								
M	1, 2	1.8	17.3*	5.1	1.0	0.0	1.5	0.6
K	1, 4	0.9	10.6*	0.0	1.8	0.1	0.3	0.1
M x K	1, 4	1.0	6.6	0.5	0.5	1.1	2.1	2.5
F. bispinosa larvae								
M	1, 2	0.0	1.1	0.4	0.1	1.0	0.9	1.9
K	1, 4	0.0	0.8	0.5	7.2	0.6	2.8	7.1
M x K	1, 4	0.1	0.7	6.0	0.4	3.3	0.2	10.1*
O. insidiosus adult males and females								
M	1, 2	2.0	1.7	0.0	0.1	0.0	2.9	2.0
K	1, 4	11.4*	0.0	0.5	0.8	0.0	0.1	2.1
M x K	1, 4	1.0	0.4	1.5	0.0	1.9	1.1	3.8
O. pumilio adult males and females								
M	1, 2	0.0	0.1	0.3	0.0	0.0	1.0	0.3
K	1, 4	0.1	1.6	0.3	1.8	2.7	0.1	1.2
M x K	1, 4	13.1*	1.6	0.1	24.2**	0.4	0.3	0.5
Orius species nymphs								
M	1, 2	0.9	0.1	0.6	0.2	0.2	5.6	0.1
K	1, 4	0.4	0.4	3.0	0.4	0.5	0.6	0.1
M x K	1, 4	0.9	0.1	2.2	3.6	1.1	0.3	2.4

[a]M indicates mulch effects, K indicates kaolin clay effects.

*, $P < 0.05$; **, $P < 0.01$

Table 2-9. Mean (± SEM) number and weight per plot of medium, large, and extra-large fruits harvested on 3 and 17 May 2011 in the push-pull experiment conducted in Palm Beach County, Florida.

Treatment	Mean number (no.) and weight (kgs) per plot (SEM)							
	Medium fruits				Large and Extra-large fruits			
	Marketable		Unmarketable		Marketable		Unmarketable	
	no.	kgs	no.	kgs	no.	kgs	no.	kgs
3-May-11								
B[a]	0	0	0	0	91 ± 8	22 ± 2	24 ± 16	7 ± 5
B/C	0	0	0	0	81 ± 11	21 ± 3	44 ± 7	11 ± 2
B/K	0	0	0	0	97 ± 5	24 ± 1	20 ± 9	5 ± 2
B/K/C	0	0	0	0	95 ± 14	25 ± 4	29 ± 10	7 ± 3
R	0	0	0	0	112 ± 22	28 ± 6	13 ± 4	3 ± 1
R/C	0	0	0	0	122 ± 8	38 ± 2	27 ± 5	8 ± 2
ANOVA F-value								
C (1,12 d.f.)	---	---	---	---	0	1.7	3.6	2.8
Other trts (2,12 d.f.)	---	---	---		3.3	6.4*	1.2	0.9
C*other trts (2, 12 d.f.)	---	---	---	---	0.3	1.7	0.2	0.1
17-May-11								
B	70 ± 16	11 ± 2	69 ± 30	13 ± 6	36 ± 4	9 ± 1	0	0
B/C	37 ± 7	6 ± 1	84 ± 13	15 ± 3	11 ± 4	3 ± 1	0	0
B/K	76 ± 27	13 ± 5	70 ± 28	14 ± 6	50 ± 9	12 ± 2	0	0
B/K/C	32 ± 4	5 ± 1	46 ± 9	12 ± 2	27 ± 9	7 ± 2	0	0
R	56 ± 16	9 ± 3	37 ± 13	7 ± 3	39 ± 15	9 ± 3	0	0
R/C	39 ± 0	7 ± 0	96 ± 3	21 ± 0	40 ± 4	11 ± 1	0	0
ANOVA F-value								
C (1,12 d.f.)	6.9*	7.2*	1.2	2.4	5.3*	3.6	---	---
Other trts (2,12 d.f.)	0.1	0.1	0.5	0.1	2.4	2.7	---	---
C*other trts (2, 12 d.f.)	0.4	0.8	2.5	2.1	1.5	2.5	---	---

Table 2-9. Continued.

	Mean number (no.) and weight (kgs) per plot (SEM)							
	Medium fruits				Large and Extra-large fruits			
	Marketable		Unmarketable		Marketable		Unmarketable	
Treatment	no.	kgs	no.	kgs	no.	kgs	no.	kgs
Total 3-May and 17-May 2011								
B	70 ± 16	11 ± 2	69 ± 30	13 ± 6	126 ± 12	31 ± 3	24 ± 16	7 ± 5
B/C	37 ± 7	6 ± 1	84 ± 13	15 ± 3	91 ± 14	23 ± 4	44 ± 7	11 ± 2
B/K	76 ± 27	13 ± 5	70 ± 28	14 ± 6	147 ± 14	35 ± 3	20 ± 9	5 ± 2
B/K/C	32 ± 4	5 ± 1	46 ± 9	12 ± 2	122 ± 19	32 ± 5	29 ± 10	7 ± 3
R	56 ± 16	9 ± 3	37 ± 13	7 ± 3	151 ± 28	37 ± 7	13 ± 4	3 ± 1
R/C	39 ± 0	7 ± 0	96 ± 3	21 ± 0	162 ± 5	49 ± 2	27 ± 5	8 ± 2
ANOVA F-value								
C (1,12 d.f.)	6.9*	7.2*	1.2	2.4	1.5	0	3.6	2.8
Other trts (2,12 d.f.)	0.1	0.1	0.5	0.1	4.0*	7.3**	1.2	0.9
C*other trts (2, 12 d.f.)	0.4	0.8	2.5	2.1	1	3.2	0.2	0.1

[a] B indicates plants planted on black mulch, C indicates companion plants, K indicates kaolin clay and R plants planted on reflective mulch.

[b] C indicates companion plant effect, T indicates mulch and kaolin treatment effects.

*, *P* < 0.05; **, *P* < 0.01; ***, *P* < 0.001;

Table 2-10. Mean (± SEM) number and weight per plot of medium, large, and extra-large fruits harvested on 27 April and 10 May 2012 in the push-pull experiment conducted in Palm Beach County, Florida.

Treatment	Mean number (no.) and weight (kgs) per plot (SEM)					
	Medium fruits		Large fruits		Extra-large fruits	
	no.	kgs	no.	kgs	no.	kgs
	27-Apr-12					
B[a]	0 ± 0	0 ± 0	5 ± 4	1 ± 1	56 ± 16	16 ± 5
B/C	0 ± 0	0 ± 0	4 ± 1	1 ± 0	56 ± 12	15 ± 3
B/K	0 ± 0	0 ± 0	3 ± 2	1 ± 0	74 ± 22	20 ± 6
B/C/K	0 ± 0	0 ± 0	11 ± 3	2 ± 1	88 ± 22	23 ± 6
R	0 ± 0	0 ± 0	12 ± 4	2 ± 1	35 ± 7	8 ± 2
R/C	0 ± 0	0 ± 0	10 ± 1	2 ± 0	40 ± 11	10 ± 2
R/K	0 ± 0	0 ± 0	20 ± 11	4 ± 2	43 ± 10	10 ± 2
R/C/K	0 ± 0	0 ± 0	5 ± 1	1 ± 0	46 ± 13	11 ± 3
ANOVA F-value						
C (1, 8 d.f.)	n/a	n/a	0.7	0.9	1.3	0.9
Mulch (1, 2 d.f.)	n/a	n/a	3	2.1	6	8.2
C x Mulch (1, 8 d.f.)	n/a	n/a	3.9	4	0.1	0
K (1, 4 d.f.)	n/a	n/a	0.4	0.3	11.2*	9.0*
C x K (1, 8 d.f.)	n/a	n/a	0.1	0	0.4	0.6
Mulch x K (1, 4 d.f.)	n/a	n/a	0	0.1	3.8	4
Mulch x C x K (1, 8 d.f.)	n/a	n/a	3.6	3.7	0.7	0.7

Table 2-10. Continued.

Treatment	Mean number (no.) and weight (kgs) per plot (SEM)					
	Medium fruits		Large fruits		Extra-large fruits	
	no.	kgs	no.	kgs	no.	kgs
	10-May-12					
B	30 ± 10	5 ± 2	47 ± 2	9 ± 0	37 ± 9	10 ± 3
B/C	33 ± 10	5 ± 2	60 ± 12	12 ± 2	35 ± 7	10 ± 2
B/K	42 ± 24	8 ± 5	78 ± 5	16 ± 1	85 ± 9	25 ± 3
B/C/K	41 ± 20	7 ± 4	78 ± 13	17 ± 3	77 ± 10	22 ± 3
R	29 ± 5	4 ± 1	99 ± 26	19 ± 5	49 ± 13	12 ± 3
R/C	38 ± 12	6 ± 2	95 ± 14	19 ± 3	51 ± 6	13 ± 2
R/K	31 ± 5	5 ± 1	110 ± 19	23 ± 5	67 ± 12	17 ± 3
R/C/K	30 ± 12	4 ± 2	104 ± 18	22 ± 4	62 ± 7	17 ± 2
ANOVA F-value						
C	0.2	0.1	0	0.1	0.3	0.2
Mulch (1, 2 d.f.)	0.1	0.1	3.8	3.3	0.1	0.9
C x Mulch (1, 8 d.f.)	0.1	0.2	0.8	0.5	0.1	0.4
K (1, 4 d.f.)	0.3	0.4	7.1	10.2*	30.1**	34.6**
C x K (1, 8 d.f.)	0.5	0.8	0.4	0.4	0.4	0.4
Mulch x K (1, 4 d.f.)	1.1	1.3	1.3	0.9	8.1*	8.3*
Mulch x C x K (1, 8 d.f.)	0.1	0	0.1	0	0	0

Table 2-10. Continued.

Treatment	Mean number (no.) and weight (kgs) per plot (SEM)					
	Medium fruits		Large fruits		Extra-large fruits	
	no.	kgs	no.	kgs	no.	kgs
	Season Total 27-April-2012 and 10-May-2012					
B	30 ± 10	5 ± 2	52 ± 3	10 ± 1	93 ± 25	26 ± 7
B/C	33 ± 10	5 ± 2	64 ± 12	12 ± 2	91 ± 19	25 ± 5
B/K	42 ± 24	8 ± 5	81 ± 4	17 ± 1	159 ± 31	44 ± 8
B/C/K	41 ± 20	7 ± 4	90 ± 16	19 ± 4	165 ± 32	45 ± 8
R	29 ± 5	4 ± 1	110 ± 29	21 ± 6	84 ± 18	20 ± 5
R/C	38 ± 12	6 ± 2	105 ± 14	21 ± 3	92 ± 13	23 ± 3
R/K	31 ± 5	5 ± 1	130 ± 29	27 ± 6	109 ± 15	27 ± 4
R/C/K	30 ± 12	4 ± 2	108 ± 19	22 ± 4	108 ± 20	28 ± 5
ANOVA F-value						
C (1, 8 d.f.)	0.2	0.1	0.1	0	0.1	0
Mulch (1, 2 d.f.)	0.1	0.1	4	3.3	4.1	6.1
C x Mulch (1, 8 d.f.)	0.1	0.2	1.8	1.3	0	0.2
K (1, 4 d.f.)	0.3	0.4	5.1	7.1	26.4**	27.2**
C x K (1, 8 d.f.)	0.5	0.8	0.3	0.3	0	0
Mulch x K (1, 4 d.f.)	1.1	1.3	0.9	0.7	7.8*	7.9*
Mulch x C x K (1, 8 d.f.)	0.1	0	0.2	0.2	0.2	0.1

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; [a] B indicates plants planted on black mulch, C indicates companion plants, K indicates kaolin clay and R indicates plants planted on reflective mulch.

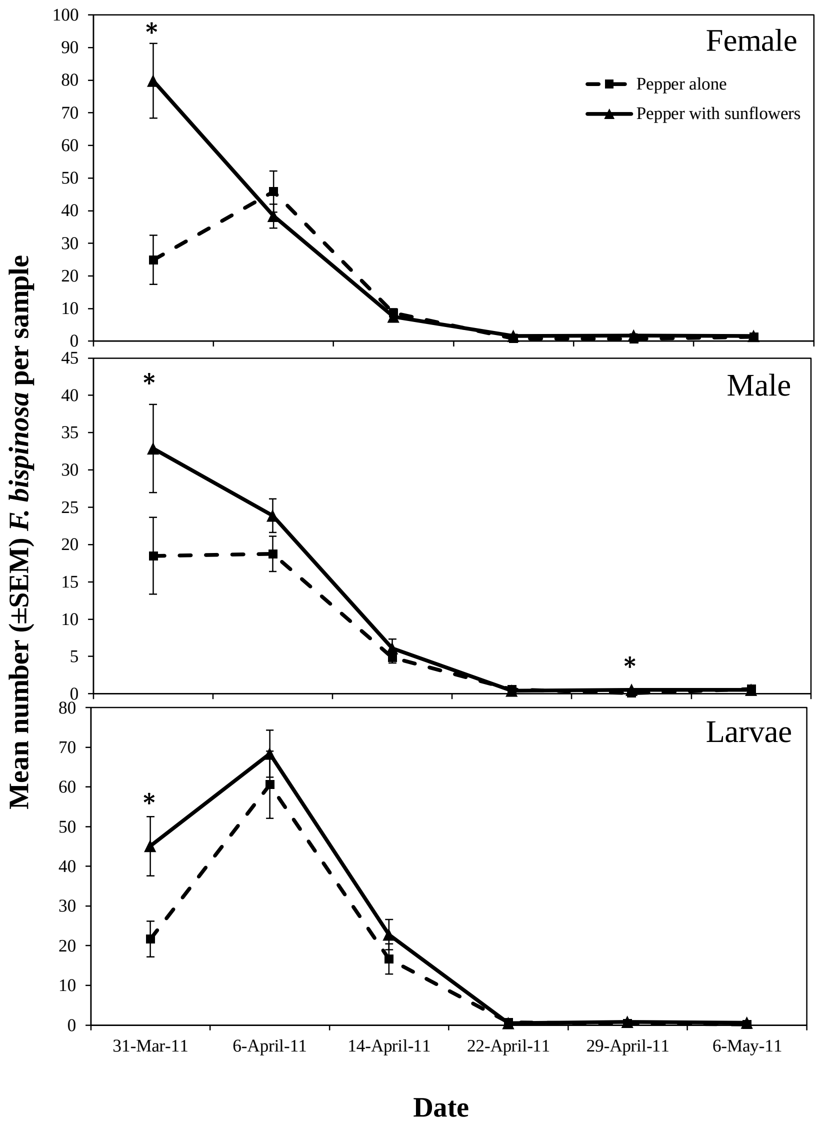


Figure 2-1. The mean number per 10 pepper flowers (± SEM) of *F. bispinosa* adult females, adult males, and larvae in plots with and without companion plantings of sunflowers in the experiment conducted in Palm Beach County, Florida in 2011 (data pooled over mulch and kaolin treatments).

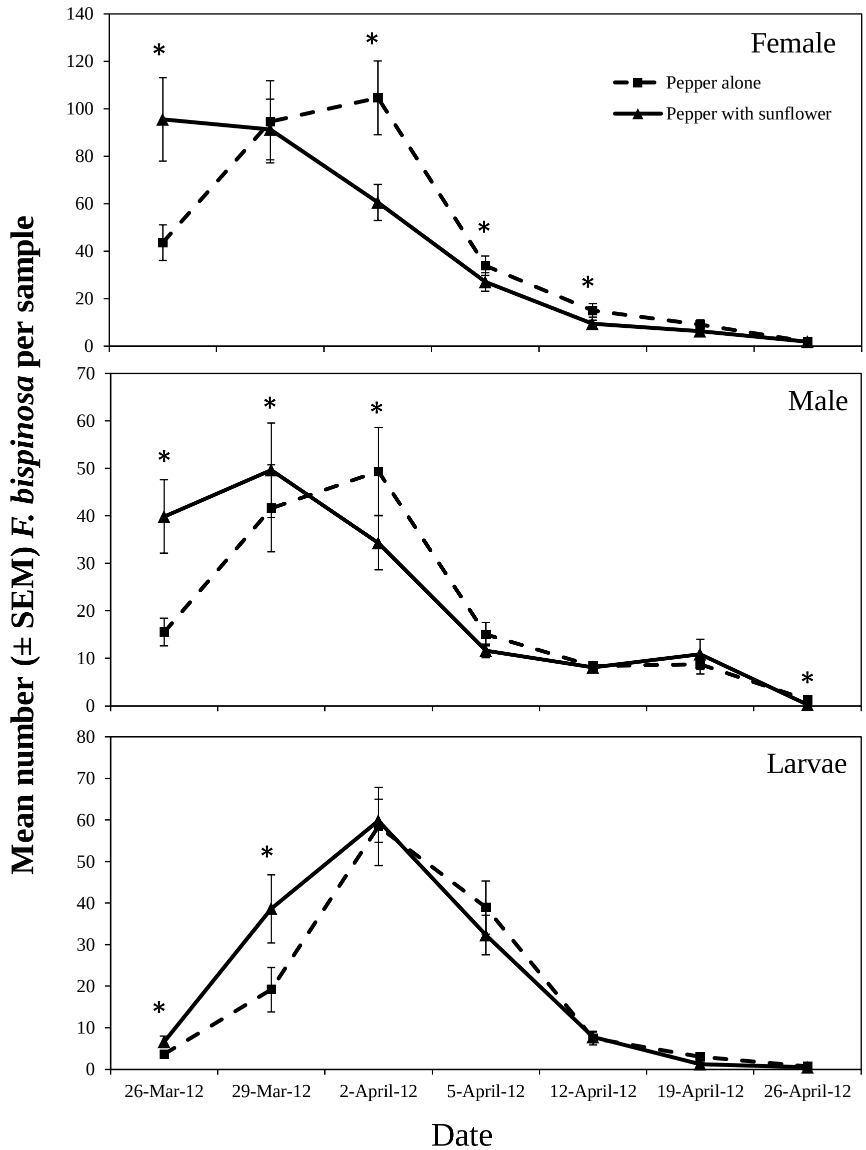


Figure 2-2. The mean number per 10 pepper flowers (± SEM) of *F. bispinosa* adult females, adult males, and larvae in plots with and without applications of kaolin clay in the experiment conducted in Palm Beach County, Florida in 2012 (data pooled over mulch and companion plant treatments).

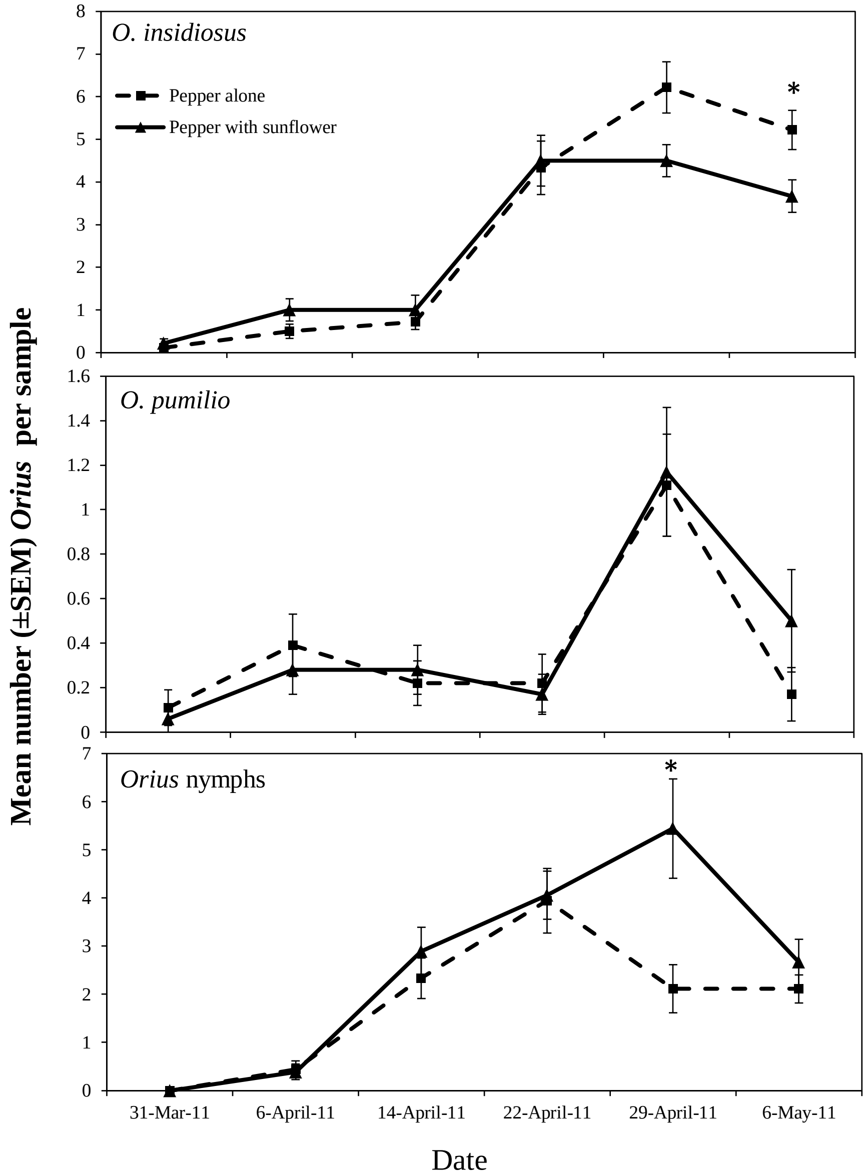


Figure 2-3. The mean number per 10 pepper flowers (± SEM) of *O. insidiosus* adults, *O. pumilio* adults, and *Orius* spp. nymphs in plots with and without companion plantings of sunflowers in the experiment conducted in Palm Beach County, Florida in 2011 (data pooled over mulch and kaolin treatments).

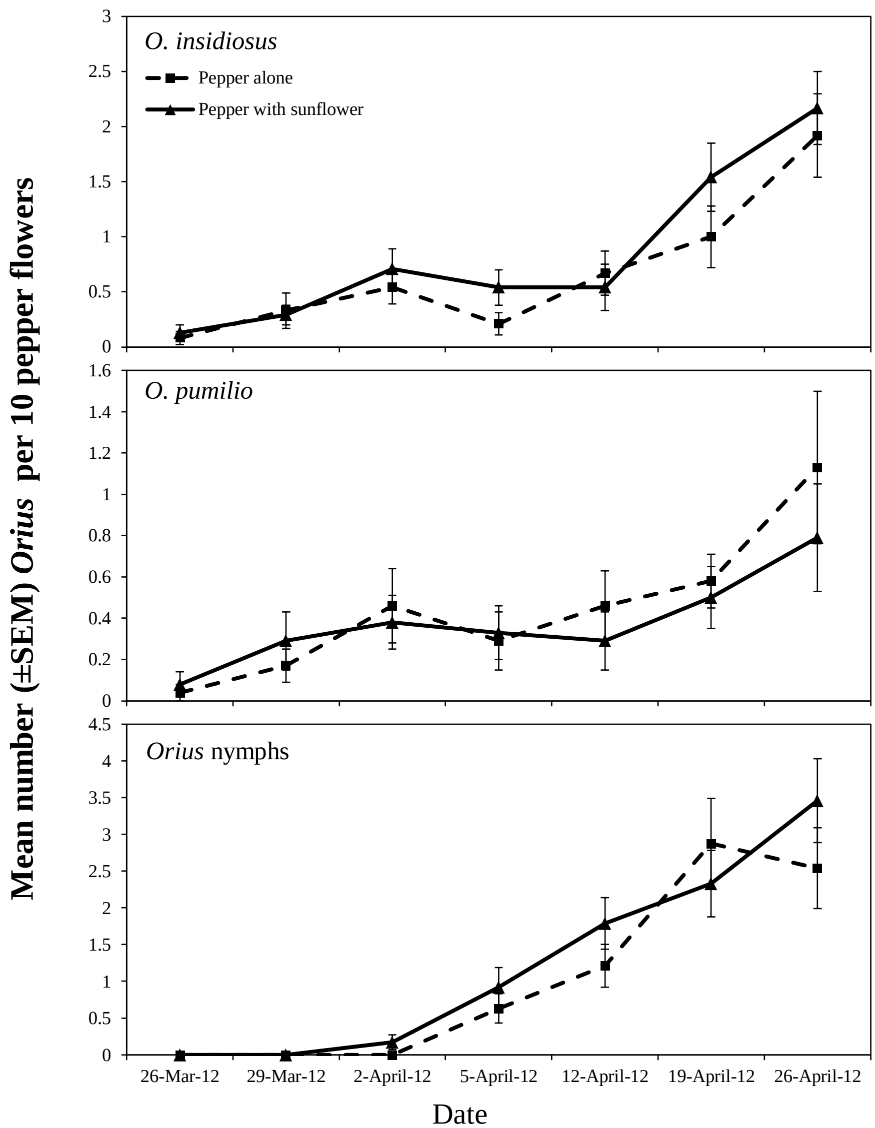


Figure 2-4. The mean number per 10 pepper flowers (± SEM) of *O. insidiosus* adults, *O. pumilio* adults, and *Orius* spp. nymphs in plots with and without applications of companion plantings of sunflower in the experiment conducted in Palm Beach County, Florida in 2012 (data pooled over mulch and kaolin clay treatments).

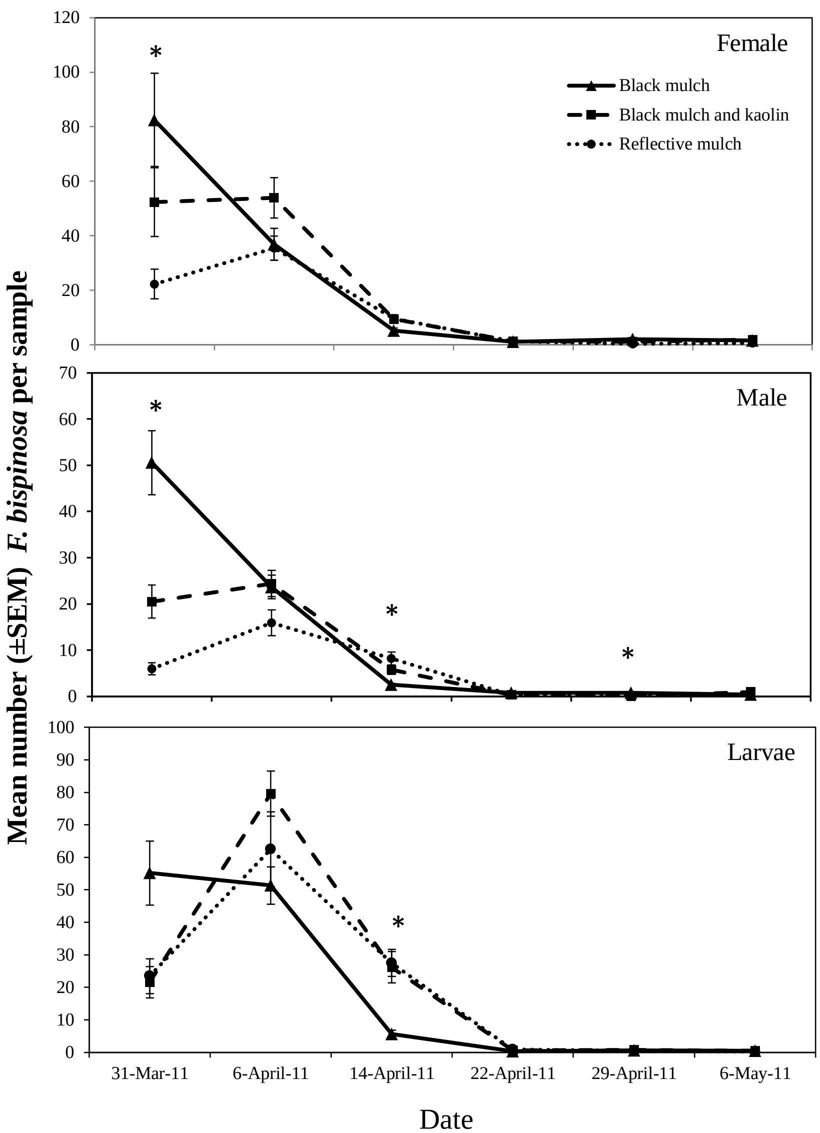


Figure 2-5. The mean number per 10 pepper flowers (± SEM) of *F. bispinosa* adult females, adult males, and larvae in plots with black mulch, black mulch and kaolin clay applications, and reflective mulch in the experiment conducted in Palm Beach County, Florida in 2011 (data pooled over companion plant treatments).

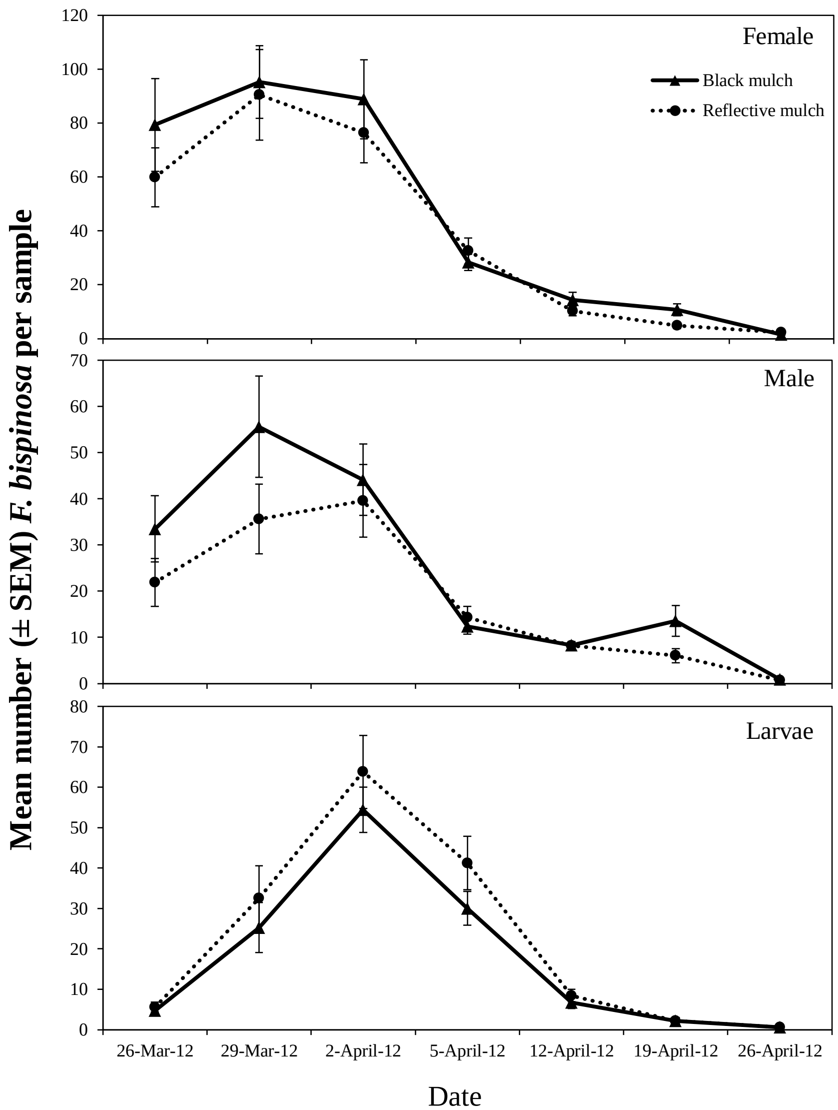


Figure 2-6. The mean number per 10 pepper flowers (± SEM) of *F. bispinosa* adult females, adult males, and larvae in plots with black or reflective mulch in the experiment conducted in Palm Beach County, Florida in 2012 (data pooled over companion plant and kaolin clay treatments).

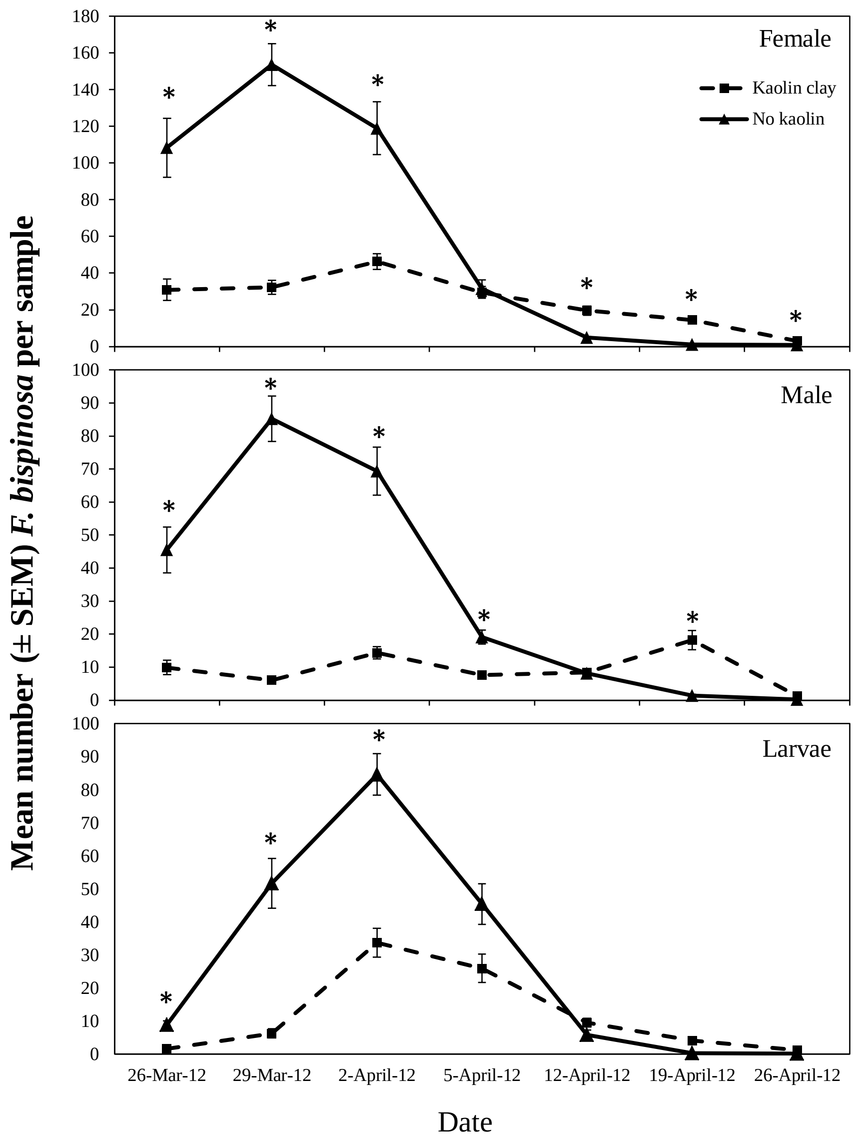


Figure 2-7. The mean number per 10 pepper flowers (± SEM) of *F. bispinosa* adult females, adult males, and larvae in plots with and without applications of kaolin in the experiment conducted in Palm Beach County, Florida in 2012 (data pooled over mulch and kaolin clay treatments).

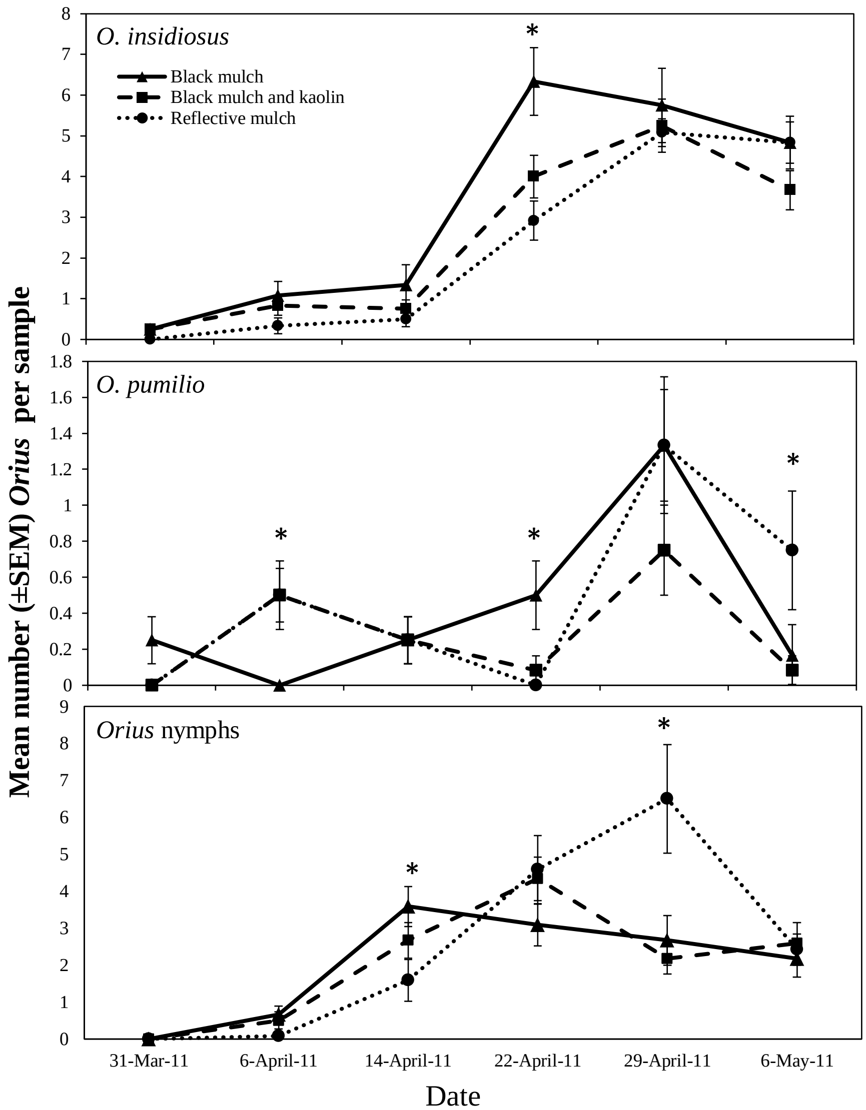


Figure 2-8. The mean number per 10 pepper flowers (± SEM) of *O. insidiosus* adults, *O. pumilio* adults, and *Orius* spp. nymphs in plots with black mulch, black mulch and kaolin clay applications, and reflective mulch in the experiment conducted in Palm Beach County, Florida in 2011 (data pooled over companion plant treatments).

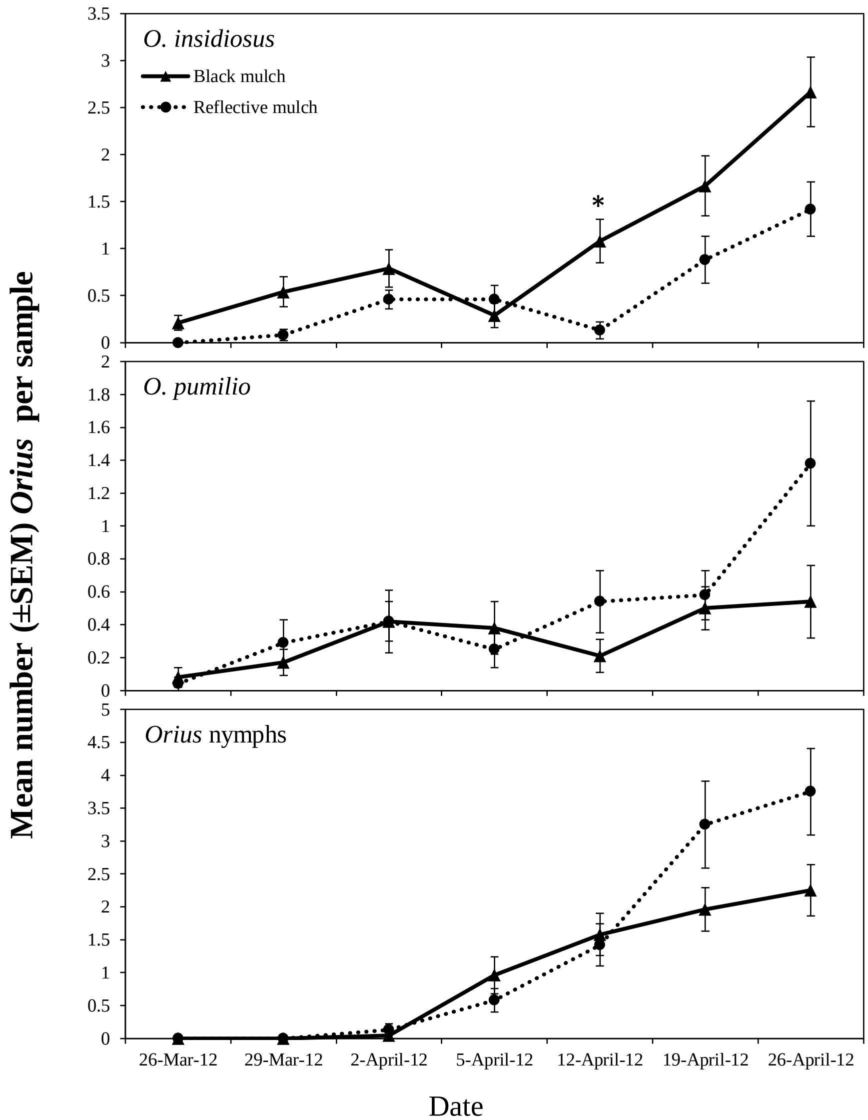


Figure 2-9. The mean number per 10 pepper flowers (± SEM) of *O. insidiosus* adults, *O. pumilio* adults, and *Orius* spp. nymphs in plots with black or reflective mulch in the experiment conducted in Palm Beach County, Florida in 2012 (data pooled over companion plant and kaolin clay treatments).

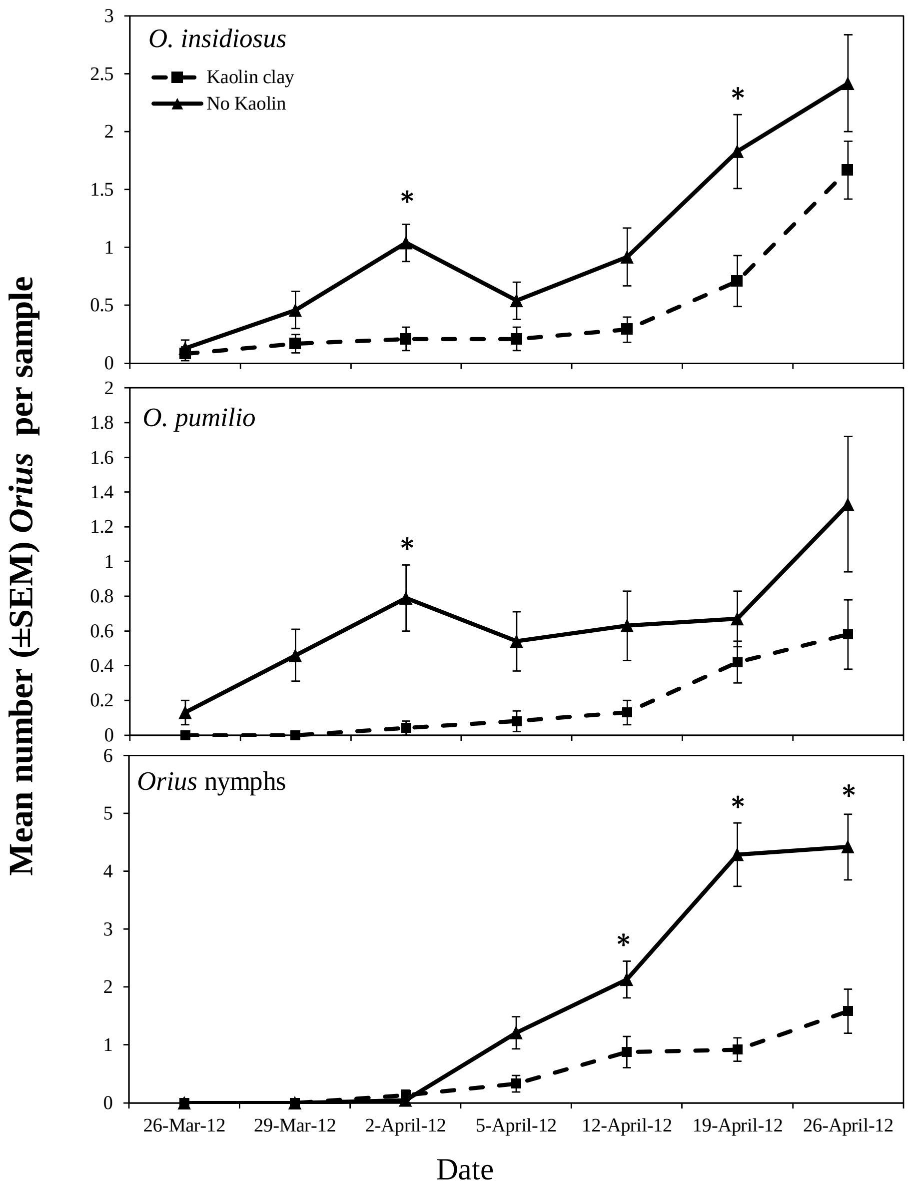


Figure 2-10. The mean number per 10 pepper flowers (± SEM) of *O. insidiosus* adults, *O. pumilio* adults, and *Orius* spp. nymphs in plots with and without applications of kaolin clay in the experiment conducted in Palm Beach County, Florida in 2012 (data pooled over mulch and companion plant treatments).

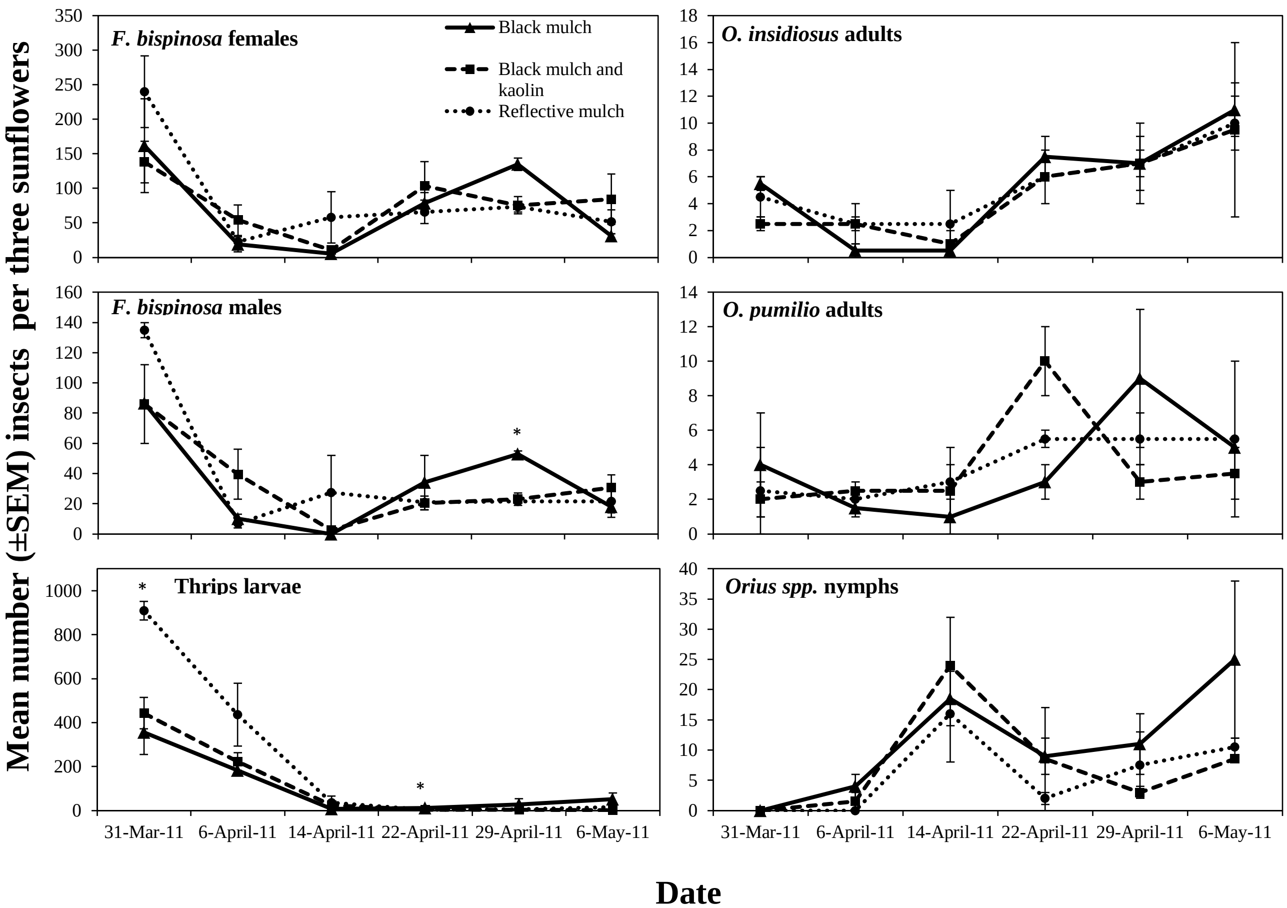


Figure 2-11. The mean number per three sunflower inflorescences (± SEM) of *F. bispinosa* adult females, *F. bispinosa* adult males, thrips larvae, *O. insidiosus* adults, *O. pumilio* adults, and *Orius* spp. nymphs in plots with black mulch, reflective mulch, or black mulch with kaolin applications in the experiment conducted in Palm Beach County, Florida in 2011

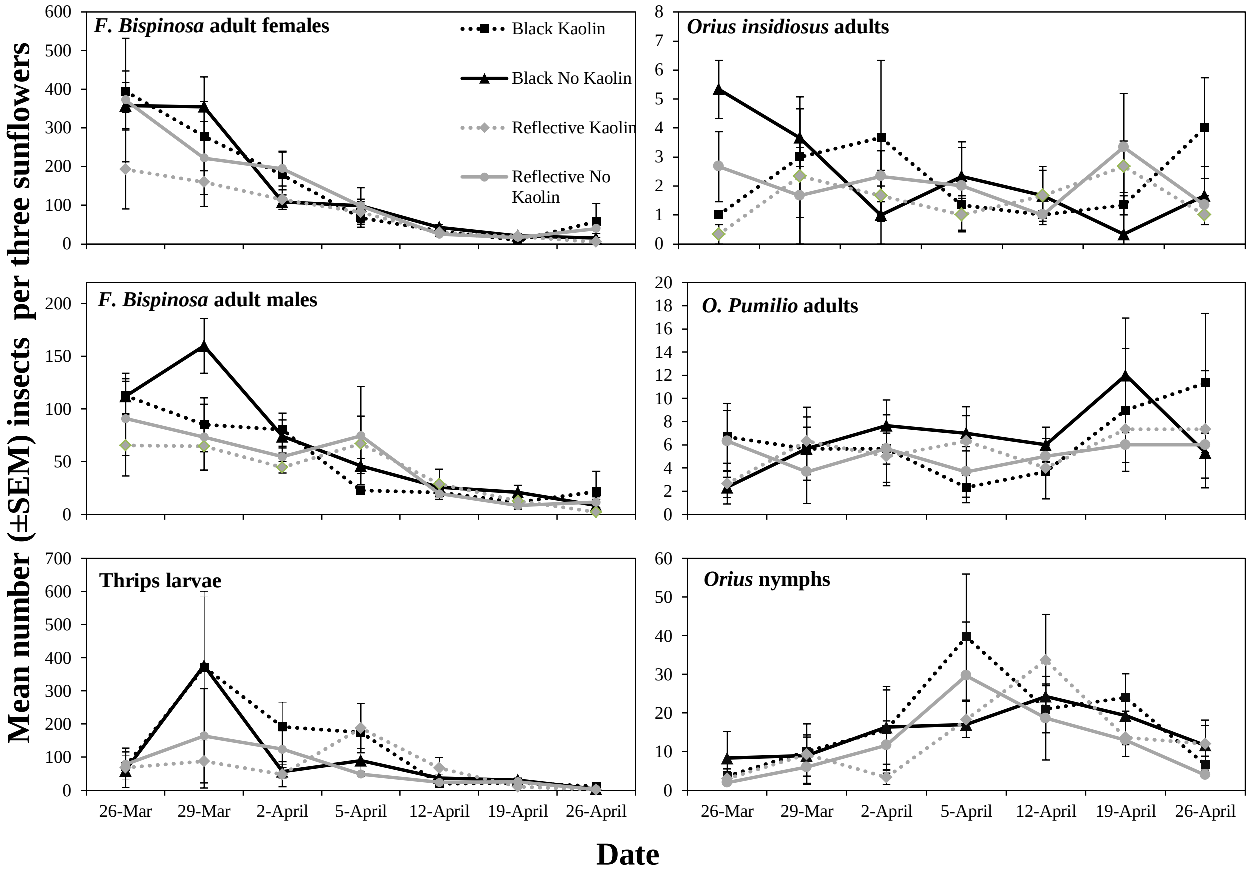


Figure 2-12. The mean number per three sunflower inflorescences (± SEM) of *F. bispinosa* adult females, *F. bispinosa* adult males, thrips larvae, *O. insidiosus* adults, *O. pumilio* adults, and *Orius* spp. nymphs in plots with black mulch, black mulch and kaolin, reflective mulch and reflective mulch with kaolin in the experiment conducted in Palm Beach County, Florida in 2012.

CHAPTER 3

EVALUATION OF A NOVEL PUSH-PULL METHOD FOR THE MANAGEMENT OF THRIPS AND TOSPOVIRUSES IN TOMATOES IN NORTH FLORIDA

Introduction

Native to southwestern United States, *F. occidentalis* is now a common pest thrips found on tomatoes and other crops in Florida. It became a serious economic problem for growers in 2005 (Frantz and Mellinger 2009). This species of thrips causes crop losses due to direct physical damage produced from the thrips feeding and ovipositing on the flowers resulting in unmarketable fruits (Salguero Navas et al. 1991, Ghidiu et al.2006). Additional crop losses from *F. occidentalis* result from indirect damage when the thrips vectors *Tomato spotted wilt virus* to the plants leading to reduced yield and unmarketable fruits. Crop losses from tomato spotted wilt have been estimated to reach a cost of US $1 billion (Goldbach and Peters, 1994). This thrips is capable of vectoring additional viruses including *Impatiens necrotic spot virus*, *Chrysanthemum stem necrosis virus*, *Groundnut ringspot virus* and *Tomato chlorotic spot virus* (Pappu et al. 2009, Webster et al. 2011).

In addition to *F. occidentalis*, tomato spotted wilt is vectored by seven other species of thrips (Pappu et al. 2009). Of these species, *F. bispinosa* Morgan is a native thrips also found on tomatoes in North Florida, but its ability to transmit the virus in the field is not supported by research findings (Avila et al. 2006, Funderburk et al. 2011). A third species of thrips is commonly found in tomatoes in North Florida, the native *F. tritici* Fitch. Both of these native species can produce direct physical damage on tomato fruits while feeding and ovipositing on fruits, but they do not vector diseases to the tomatoes and so are not as serious of a threat to tomato growers. These two species also have the ability to outcompete *F. occidentalis* if allowed to persist in a field (Paini et al. 2008).

Another natural control of *F. occidentalis* and other thrips species is natural predation by the native predator *Orius insidiosus* (Say). Where these insects are not eliminated by pesticides, they can effectively suppress thrips populations at very high prey to predator ratios (Funderburk et al. 2000).The minute pirate bugs feed on all three species of thrips, but they prey preferentially on thrips larvae and the adults of the *F. occidentalis* over the adults of the non-damaging native thrips species (Baez et al. 2004, Reitz et al. 2006). This aspect of feeding makes the minute pirate bugs a valuable tool for managing *F. occidentalis.* The native thrips species are smaller and move around more frequently and at a faster pace than *F. occidentalis*, and may be the reason for the preferential feeding behavior (Baez et al. 2004, Reitz et al. 2006). Approximately one adult minute pirate bug for every 180 thrips is sufficient for suppression of the populations of thrips with thrips populations being under complete control at a ratio of about one predator to 40 thrips (Funderburk et al. 2000). Usually, natural populations are not sufficient in tomato to provide control of thrips (Baez et al. 2011), and a lower attack coefficient is achieved by *O. insidiosus* on tomato (Coll and Ridgway 1995).

Calendar applications of broad spectrum insecticides, such as pyrethroids, have been a popular method for controlling thrips in fields. These applications were initially successful with their effects dwindling and reversing with increased use (Funderburk et al. 2000, Funderburk 2009). These chemicals eliminate the natural predators and the native species of thrips which would otherwise prevent *F. occidentalis* from attaining damaging levels in the field (Funderburk 2009, Reitz and Funderburk 2012). Applications of insecticides to control adult thrips in blossoms do not prevent the virus transmission in fields (Reitz et al. 2003). Furthermore, the life history and genetic adaptations of *F. occidentalis* lead to the rapid development of resistant populations (Gao et al. 2012). Resistant populations of *F. occidentalis* combined with a lack of natural predators and competition create a situation in which damaging thrips populations are present in a field and cannot be controlled.

The ineffectiveness of pesticides for controlling thrips, as well as increasing consumer demand for organic produce and the struggle of organic growers to keep pace with demand (Dimitri and Oberholtzer 2009) indicate a need for more sustainable and organic methods of managing pests in food crops. Many techniques are currently in use which can effectively reduce thrips populations and are compatible in conventional and organic production systems. These include ultraviolet-reflective mulch, companion plantings, and kaolin clay. Moreover, a new pest management system has recently been developed for certain cropping systems. This “push-pull” or stimulo-deterrent pest management system involves the use of both repellant and attractive stimuli in crop fields to repel pest insect from the crop while attracting them away from the crop to a non-crop plant (Khan et al. 2001).

Ultraviolet-reflective mulch is an effective pest management tool for numerous insect pests on numerous crops (Greenough et al. 1990, Greer and Dole 2003, Reitz et al. 2003). The mulch reflects ultraviolet light which disrupts the ability of certain insects, including thrips, to find the host plant grown on the mulch (Terry 1997). Ultraviolet-reflective mulch repels thrips, significantly reduces incidence of Tomato spotted wilt on tomatoes, and increases yield when compared to insecticides and controls (Greenough et al. 1990, Stavisky et al. 2002, Reitz et al. 2003, Riley and Pappu 2004, Riley et al. 2012). The use of this mulch also results in increased yield when compared to black mulch and insecticides (Reitz et al. 2003). When combined with the judicious use of insecticides the mulch leads to even greater control, and combining it with other non-chemical methods of pest management may also have a synergistic effect.

Kaolin clay is an alternative pesticide which is economical, ecological, and easily washed off plants (Bar-Joseph and Frenkel 1983, Reitz et al. 2008). This aluminosilicate mineral is used on plants both for pest control and to protect plants from sun damage (Cantore et al. 2009). The material reduces numbers of insects on plants through various modes of action including repelling light, impeding the ability of insects to grasp the plant surface, deterring feeding and oviposition, impeding development and direct mortality (Bar-Joseph and Frenkel 1983, Lapointe 2000, Barker et al. 2006, Larentzaki et al. 2008, Peng et al. 2010). Kaolin clay effectively repels thrips from blueberries, onions, and tomatoes (Spiers et al. 2004, Larentzaki et al. 2008, Reitz et al. 2008). Kaolin clay also reduces pest numbers (Marko et al. 2008), damage caused by pests (Wilson et al. 2004) and disease incidence (Wilson et al. 2004, Creamer et al. 2005) on crops. Use of this kaolin clay on tomatoes resulted in reduced thrips numbers, reduced incidence of Tomato spotted wilt, and increased yield (Reitz et al. 2008). The reduction in disease incidence and increased yield from the use of kaolin clay and essential oils was as effective as standard broad-spectrum insecticides (Reitz et al. 2008). Its use in pears significantly reduced numbers of *Cacopsylla pyri* comparably or slightly better than IPM or organic control (Daniel et al. 2005). Lacewings prefer to oviposit on kaolin-treated surfaces (Porcel et al. 2011). One potential negative effect associated with the use of kaolin clay is possible repellence and mortality to natural enemies (Marko et al. 2008, Bengochea et al. 2013). However, once the applications are stopped, the predators that were repelled can rebound (Marko et al. 2008).

Although natural populations of minute pirate bugs are too low in tomato fields to provide control of thrips (Baez et al. 2011), there is potential to attract minute pirate bugs into these fields using habitat management strategies such as companion plantings. Minute pirate bugs are known to supplement their diet with plant materials such as pollen and can develop and reproduce on a diet of pollen and nectar alone for up to six months (van den Meiracker and Ramakers 1991). Their survival rate, life span and reproduction rate, and adult female size are higher, and the developmental time is shorter on a diet of thrips and pollen than on a diet of thrips alone (Kiman and Yeargan 1985, Wong and Frank 2013). Minute pirate bugs are also more abundant where pollen is present and will migrate in the absence of pollen (Malais and Ravensburg 1992).

Habitat diversification and the presence of flowering weeds successfully increases the numbers of natural enemies and decreases the numbers of pest insects (Showler and Greenburg, 2002; Ghodani et al. 2009, Chaplin-Kramer et al. 2011, Amaral et al. 2013) while also increasing the abundance and richness of pollinators (Chaplin-Kramer et al. 2011). The suppression of these pests and the injury they cause using habitat diversification was superior to suppression using insecticides (endosulfan and monocrotophos). The diversification also led to increased yield of cotton (Ghodani et al. 2009). In a study by Lundgren et al. 2009 the addition of plants with suitable oviposition sites and refuges from natural enemies was associated with lower herbivore densities and higher predator densities on the target plant. The densities of minute pirate bugs in this study were higher on the target plants in polycultures than in monocultures. Minute pirate bug nymphs also experienced higher fitness in diverse fields (Lundgren et al. 2009). Minute pirate bugs have the ability to rapidly recolonize plots treated with insecticides (Ramachandran et al. 2001) and this ability could be enhanced with the addition of companion plantings in which the minute pirate bugs could take shelter to avoid insecticides and then later recolonize the sprayed plots.

Many plant species offer habitat for important natural enemies of thrips and other insects (Landis, Wratten and Gurr 2000). Non-crop plants have been shown to attract enough enemies to control *F. occidentalis* populations on green beans and medicinal plants (Kasina et al. 2006, Lopez and Shepard 2007). Intercrops of baby corn, Irish potato and sunflowers with French beans in Kenya reduced populations of *F. occidentalis* and increased populations of *Orius spp.* compared with a monocrop (Nyasani et al. 2012). Intercrops of dill, coriander and buckwheat decrease pest numbers, increase predation, and increase numbers of *O. insidiosus* in bell peppers (Bickerton and Hamilton 2012).

Various species of wildflowers in Florida serve as hosts for the minute pirate bug and other natural enemies. These include *Bidens alba* (L.), sunflowers, and others. Many of these plants also host populations of the native non-damaging thrips which may outcompete *F. occidentalis* (Bottenberg et al. 1999, Northfield et al. 2008, Shirk et al. 2011). Plantings of these plants near crops of fruiting vegetables increase biological control of thrips (Frantz and Mellinger 2009). Companion plantings of these species are not sources for damaging populations of *F. occidentalis* as they are outcompeted by the native thrips species and they suffer preferential predation by minute pirate bugs. Companion plants such as those mentioned may serve to increase natural predators and competitors of *F. occidentalis* and reduce populations of *F. occidentalis* in a vegetable field.

The current study seeks to develop a novel, sustainable method of thrips management by combining the above components into a push-pull method of thrips management. The push-pull method is grounded in behavioral manipulations involving a repulsive stimulus (push) to repel insects from crops and an attractive (pull) stimulus to attract the pests to an alternate source from which they can be removed or controlled (Cook et al. 2007). This method was successful in managing stemborer pests in Kenya in a maize crop system (Khan et al. 2001). Using a combination of repellant (push) and attractive (pull) weed plants, the combination developed in this system increased yield, increased parasitism of stemborers by parasitoids, and reduced damage to maize by the competitive weed Striga (Khan et al. 2001, Khan et al. 2008a).

The current study combines the technologies of ultraviolet-reflective mulch and kaolin clay to act as push stimuli on the thrips pests, and companion plants of the native plant, *B. alba*, to act as the pull stimulus for the thrips pests while also attracting and conserving the minute pirate bug. The objectives were to determine the separate and interactive effects of each component on the abundance and population dynamics of *Frankliniella* species, *O. insidiosus*, and the yield and quality of pepper.

Materials and Methods

Plot establishment and maintenance

These experiments were conducted with funding from a FDACS specialty crop block grant number 016856.

Experiments were conducted at North Florida Research and Education Center located at 155 Research Rd, Quincy, Florida 32351. Experiments were conducted in the spring of 2011 and 2012 using ‘Florida 47’ tomato (*Solanum lycopersicum*) plants and companion plants of Spanish needles (*B. alba*).

Six week old tomato and *B. alba* plants were transplanted into the field on the same day. Dead plants were replaced as needed within the next two weeks. The plants were produced on raised beds 10 cm in height and 91.4 cm in width with 1.83 m spacing between beds. Beds were treated before mulch application with Dual Magnum (Syngenta Crop Protection LLC, Greensboro, NC 27419) at 1.2 kg active ingredient per ha for weed control. A trickle-tube placed under the mulch was used to irrigate based on plant needs. Plots were fertilized with 204, 29, and 170 kg/ha of N, P, and K, respectively to maintain growth of the plants. Pesticides for pests other than thrips were applied on an as-needed basis. Weeds were pulled by hand and sprayed with Paraquat.

Six-week old tomato and *B. alba* transplants were planted in the plastic on 29 March 2011 and on March 27, 2012. Resets of *B. alba* and Tomatoes were done on April 6 and April 9 2012.A randomized complete block split split-plot design was used. Whole plot treatments consisted of ultraviolet-reflective mulch and black polyethylene mulch (Berry Plastics Corp., Evansville, IN 47706), subplot treatments consisted of Surround WP Kaolin clay (Engelhard Corp., Iselin, NF 08830) applications and a control, and sub-sub-plot treatments consisted of companion plantings of *B. alba* and a control (See Appendix). Kaolin clay was applied using a CO_2 backpack sprayer equipped with five D7 nozzles per row. The volume of water applied after being mixed with the kaolin was 48 gallons per acre at a pressure of 40 psi. Applications of kaolin were made two times per week as a spray at a rate of 5.7 kg per acre. Kaolin was applied on 22, 26, and 29 April; 3, 6, 10, 13, 17, 20, 24, 27 and 31 May; and 3 June 2011. In 2012 kaolin was applied on 30 April; 3, 7, 10, 15, 17, 21, 24, 29, 31 May; 4, 6 June.

There were three replicates in this experiment. Each sub-sub-plot consisted of four beds 9.1 m in length. Each bed consisted of one row with 45-cm spacing between plants for a total of 80 tomato plants per sub-sub-plot. Companion plants of *B. alba* were planted in one bed on each side on the outside rows of the tomato beds for two beds of *B. alba* per sub-sub plot with companion plants. The companion plants were planted using a pepper-wheel to punch holes in the plastic with a single drip tube down the center of the mulch. Two rows of *B. alba* were planted in each of the two external beds with 30 cm spacing between plants for a total of 128 *B. alba* plants in each sub-sub plot in the companion plant condition.

Insect Sampling

Two samples of ten tomato flowers were randomly collected from each sub-sub-plot on each sample date. Samples were collected twice weekly from the beginning of flowering until near the end of the production season. Two random samples of 10 *B. alba* flowers were collected on each sample date from each sub-sub-plot with companion plants. Flowers were placed immediately into vials containing 70% ethanol.

Thrips and other insects were extracted from the flowers in each sample and the insects were identified under a stereoscope with 40 X magnification. The total number of adult males and females of each species of thrips (*F. occidentalis*, *F. bispinosa*, *F. tritici*, *F. fusca*), total thrips larvae, and adult and nymphal *Orius insidiosus* were determined. There were a total of 13 sample dates in 2011 and 12 sample dates in 2012.

Yield

Ten plants from each of the center rows (total of 20 plants) in each sub-sub plot were harvested starting in mid-June in both years. Tomatoes of marketable size were counted, weighed, and graded for marketability. Tomato fruits exhibiting signs of thrips damage were culled in both years. In 2012 a large population of armyworms caused a high amount of damage to the tomatoes. Tomatoes displaying armyworm damage were not culled out in the first or third harvest, but were culled out in the second harvest. Tomato fruits were harvested on 22 and 30 June 2011 and on 19, 26 June, 12 July in 2012.

Data Analysis

Insect populations: The number of thrips larvae per adult *Frankliniella spp.* was determined on each sample date for each treatment and plant. Ratios of < 1, 1, and > 1 were considered to indicate a declining, stable, and increasing population, respectively (Northfield et al. 2008). The ratio of total thrips (adults and larvae) per *O. insidiosus* was determined for each treatment and plant on each sample date. The predator is capable of suppressing a thrips population at a ratio of 1 predator per 217 thrips (Sabelis and van Rijn 1997).

Differences between treatments in numbers of male and female *F. bispinosa*, thrips larvae, and *O. insidiosus* nymphs on tomatoes and *B. alba* separately were analyzed using analysis of variance for a randomized complete block design for a split-split-plot treatment arrangement in 2012 (PROC GLIMMIX, SAS Institute 2008).

Response variables were transformed as needed and each analysis performed using the appropriate distribution for best fit. Differences in yield between treatments were analyzed with ANOVA using the GLIMMIX procedure. The distributions for each yield variable were normal, so the analyses were conducted on the original data.

Results

The composition of thrips species in tomatoes was different in 2011 than in 2012. In 2011 *F. tritici* was the dominant species, accounting for 71% of thrips species found in tomato flowers. The second most common thrips in pepper flowers in 2011 was *F. occidentalis* (24%) with *Frankliniella bispinosa* only accounting for 5% of total thrips found. The most common thrips in 2012 was *F. bispinosa* accounting for 73% of the thrips found, with *F. tritici* found in the second highest numbers (16%) and *F. occidentalis* was the least common of these three species in 2012 (10%). Numbers of *F. fusca* were negligible in both years. The mean number (±SEM) of all adult thrips was higher in 2012 (29.5±1.2 per 10 flowers) than in 2011 (18.5±0.8 per 10 flowers). The seasonal mean (±SEM) of *F. tritici* was higher in 2011 (13.1±0.7 per 10 flowers) than in 2012 (4.8±0.2 per 10 flowers). Mean (±SEM) numbers of *F. bispinosa* were much lower in 2011 (0.9±0.1 per 10 flowers) than in 2012 (21.6±1.0 per 10 flowers). Mean (±SEM) numbers of *F. occidentalis* were similar in 2011 (4.4±0.2 per 10 flowers) and 2012

(3.0±0.1 per 10 flowers). Larvae were found in lower numbers in 2011 (4.9±0.3 per 10 flowers) than in 2012 (7.7±0.3 per 10 flowers).

The mean ratios of thrips larvae to thrips adults in tomatoes and *B. alba* in 2011 and 2012 are shown in tables 3-1 and 3-2, respectively. Populations of thrips were decreasing on tomatoes for most of the 2011 season until the final two weeks of samples, at which point the populations appeared to be increasing. A similar pattern was observed in 2012. In both years, thrips populations were never increasing or stable on *B. alba*.

Population fluctuations of adult thrips on tomatoes in plots with and without *B. alba* companion plants during 2011 and 2012 are shown in Figures 3-1 and 3-2, respectively. Populations of all species of thrips were initially low. Populations of *F. tritici* reached a peak during the third week of sampling, in mid- May. After this peak the numbers of *F. tritici* were decreasing for the remainder of the season. Populations of *F. occidentalis* and *F. bispinosa* experienced an initial peak in numbers during the second week of sampling in early May, followed by a decrease in numbers with a major peak in population occurring in late May and early June. In 2012, *F. tritici* numbers displayed a similar pattern as in 2011, with a peak occurring in mid-May. Populations of *F. occidentalis* also displayed a similar pattern in 2012 to the pattern observed in 2011. Numbers peaked in the second week of May with a later peak at the end of May and beginning of June. Contrary to the pattern observed in 2011, *F. bispinosa* reached peak numbers congruent to the peak in *F. tritici*, in the middle of May.

Seasonal trends in the abundance of thrips larvae in 2011 and 2012 are shown in Figures 3-3 and 3-4, respectively. In 2011, numbers of thrips larvae were initially low with a peak occurring on 17 May. In 2012, initial larval numbers were higher than they were in 2011. Numbers of larvae in 2012 reached an initial peak on 16 May followed by a second peak on 22 May. Peak numbers in both years were followed by a gradual decline for the remainder of the season.

Numbers of the adult and nymphs of predator *O. insidiosus* were extremely low in both 2011 (0.1±0.0 per 10 flowers) and 2012 (0.2±0.0 per 10 flowers). The mean ratios of thrips to *Orius* in tomatoes and *B. alba* in each treatment in 2011 and 2012 are shown in Tables 3-3 and 3-4, respectively. Predators were often absent in tomatoes. Where predators were present on tomatoes and *B. alba*, they were always present in ratios sufficient for suppression of thrips with the exception of one data point on *B. alba* in 2011. The numbers of predators on tomatoes were too low for further analysis.

There were eight treatments in this experiment. These were a factorial of the two mulches, companion plants/no companion plants, and kaolin/no kaolin. The results of the ANOVAs evaluating the main and interactive treatment effects of mulch, companion plants, and kaolin on numbers of adult and larval thrips of each species in tomato flowers for individual sample dates in 2011 and 2012 are shown in Tables 3-5 and 3-6, respectively. At the beginning of the season in 2011 *F. tritici* females were significantly higher in plots with companion plants than those without (Figure 3-1). Towards the end of the season, however, the presence of companion plants resulted in significantly fewer *F. tritici* males, and *F. occidentalis* females and males compared to plots without companion plants. Numbers of *F. bispinosa* females and males were also lower in plots with companion plants in 2011, though this difference was not significant. Companion plants did not have an effect on the abundance of larvae in tomato samples in 2011 (Figure 3-3).

Companion plants had a similar effect on thrips in 2012. Numbers of *F. tritici* females, and *F. bispinosa* males and females were significantly higher in plots with companion plants than in those without at the beginning of the season (Figure 3-2). The presence of companion plants resulted in significantly fewer female and male *F. tritici* and *F. bispinosa* than tomatoes alone during the middle of the season in 2012 (Figure 3-2). Companion plants also decreased the numbers of *F. occidentalis* males at the end of the season in 2012 (Figure 3-2). Companion plants did not have an effect on *F. occidentalis* females in 2012. Companion plants significantly increased the number of thrips larvae on one date at the beginning of the season in 2012 (Figure 3-4).

Kaolin reduced thrips numbers on tomatoes in 2011 and 2012. In 2011 this reduction was significant from the middle to the end of the season (Figure 3-5). This effect was significant on *F. tritici* males and females, *F. occidentalis* males and *F. bispinosa* females. Kaolin significantly decreased numbers of thrips larvae at the end of the season in 2011 (Figure 3-3). In 2012 the reduction in thrips numbers by kaolin was significant from the beginning to the middle of the season (Figure 3-6). This effect was significant for *F. tritici* and *F. bispinosa* males and females. Kaolin did not have a significant effect on *F. occidentalis* males or females in 2012. Numbers of thrips larvae were significantly lower on plants in the kaolin condition on one date early in the season in 2012 (Figure 3-4).

The use of ultraviolet-reflective mulch significantly reduced the numbers of *F. tritici* and *F. occidentalis* males and females early and mid-season in 2011 (Figure 3-7).

Mulch did not significantly affect numbers of male or female *F. bispinosa* (Figure 3-7) or thrips larvae (Figure 3-3) in 2011. The use of ultraviolet-reflective mulch reduced the numbers of thrips on tomatoes in the beginning and mid-season in 2012. However, this reduction did not reach significance with the exception of *F. bispinosa* males on 8 May (Figure 3-8). The effect of mulch on thrips larvae in 2012 also did not reach significance, and resulted instead in a non-significant increase in the number of larvae in tomato flowers (Figure 3-4).

There was a significant mulch*kaolin interaction effect on the numbers of female *F. tritici* on tomatoes on 10 May 2011. On this date the highest mean (±SEM) number of female *F. tritici* were found in the black mulch condition (30.67±3.50), followed by the ultraviolet-reflective mulch condition (17.42±2.94) with the fewest thrips found in the black mulch with kaolin (8.92±2.24) and ultraviolet-reflective mulch and kaolin (7.58±1.11) conditions. This interaction also had a significant effect on the number of male *F. tritici* found on tomato flowers on 5 and 10 May 2011. On 5 May the highest mean (±SEM) number of *F. tritici* males were found in tomato flowers in the black mulch with no kaolin condition (18.17±2.00) followed by the black mulch with kaolin condition (6.75±1.48). The lowest mean (±SEM) number of *F. tritici* males were found in the reflective mulch and kaolin (2.75±0.58) and the reflective mulch only condition (2.67±0.43). On 10 May the highest mean (±SEM) number of *F. tritici* males were found in tomato flowers in the black mulch only condition (34.83±3.68). The second highest mean (±SEM) number of *F. tritici* males were found in tomato flowers in the ultraviolet-reflective mulch only condition (12.00±1.99). The lowest numbers were found in the black mulch with kaolin (9.92±1.79) and the ultraviolet-reflective mulch with kaolin (7.42±1.76) conditions.

The mulch*kaolin interaction effect also reached significance in 2012. On 16 May kaolin reduced the number of female *F. tritici* to a greater degree on ultraviolet-reflective mulch (4.00±0.43 mean thrips in the kaolin condition, 8.42±1.20 without kaolin) than on black mulch (9.67±0.86 mean thrips in the kaolin condition, 9.75 ±1.48 without kaolin). There was also a significant interaction of mulch and kaolin on the number of female and male *F. occidentalis* found on the tomatoes in May 2012. Kaolin increased the number of male and female *F. occidentalis* found in the black mulch condition, while decreasing the number in the ultraviolet-reflective mulch condition. On 8 May the mean (±SEM) numbers of *F. occidentalis* females in each sample were as follows: 4.33±0.70 in the black mulch only condition, 6.67±0.71 in the black mulch with kaolin condition, 6.17±1.04 in the ultraviolet-reflective mulch only condition, and 3.75±0.45 in the ultraviolet-reflective mulch with kaolin condition. On 25 May the mean (±SEM) numbers of *F. occidentalis* females in each sample were as follows: 0.50±0.15 in the black mulch only condition, 2.17±0.49 in the black mulch with kaolin condition, 1.67±0.26 in the ultraviolet-reflective mulch only condition, and 1.42±0.26 in the ultraviolet-reflective mulch with kaolin condition. . On 22 May the mean (±SEM) numbers of *F. occidentalis* males in each sample were as follows: 0.67±0.22 in the black mulch only condition, 1.42±0.54 in the black mulch with kaolin condition, 1.58±0.38 in the ultraviolet-reflective mulch only condition, and 0.50±0.19 in the ultraviolet-reflective mulch with kaolin condition.

There was a significant interaction effect of mulch and companion plants on the numbers of *F. tritici* males and thrips larvae in 2011 and on the numbers on *F. bispinosa* males and thrips larvae in 2012. In each of these instances the presence of companion plants reduced thrips numbers on black mulch, but increased numbers on ultraviolet-reflective mulch. This interaction effect was significant on *F. tritici* males on 24 May 2011 resulting in the following mean number *F. tritici* males per sample: 4.92±1.25 in the black mulch only condition, 2.00±0.43 in the black mulch with companion plants condition, 1.00±0.28 in the ultraviolet-reflective mulch only condition and 1.42±0.38 in the ultraviolet-reflective mulch with companion plants condition. The interaction significantly affected numbers of thrips larvae found in tomato flowers on 26 May and 2 June 2011. On 26 May the mean (±SEM) numbers of thrips larvae per sample were as follows: 6.33±1.19 in the black mulch only condition, 4.50±0.95 in the black mulch with companion plants condition, 4.58±0.94 in the ultraviolet-reflective mulch only condition and 6.83±1.22 in the ultraviolet-reflective mulch with companion plants condition. On 2 June the mean (±SEM) numbers of thrips larvae per sample were as follows: 9.75±2.27 in the black mulch only condition, 12.58±1.52 in the black mulch with companion plants condition, 14.17±2.39 in the ultraviolet-reflective mulch only condition and 9.42±2.67 in the ultraviolet-reflective mulch with companion plants condition.

In 2012 the interaction between mulch and companion plants significantly affected numbers of *F. bispinosa* males and thrips larvae. On 8 May the mean (±SEM) numbers of *F. bispinosa* males per sample were as follows: 12.42±2.01 in the black mulch only condition, 6.83±1.26 in the black mulch with companion plants condition, 3.17±0.96 in the ultraviolet-reflective mulch only condition and 4.00±1.01 in the ultraviolet-reflective mulch with companion plants condition. On 18 May the mean (±SEM) numbers of thrips larvae per sample were as follows: 9.92±1.94 in the black mulch only condition, 8.00±1.53 in the black mulch with companion plants condition, 9.50±3.16 in the ultraviolet-reflective mulch only condition and 15.33±4.18 in the ultraviolet-reflective mulch with companion plants condition.

There was a significant interaction effect of companion plants and kaolin on *F. tritici* females on two dates and on *F. tritici* males on one date in 2011. For the females the presence of companion plants reduced numbers where no kaolin was used (16.42±2.41 with companion plants, 24.42±3.10 with no companion plants), but increased numbers of female *F. tritici* where kaolin was used (14.17±2.05 with companion plants, 11.92±1.60 with no companion plants) on 19 May. The same pattern was observed on 7 June, although to a smaller degree: 2.42±0.53 female *F. tritici* in the kaolin without companion plants condition, 2.67±0.48 in the kaolin with companion plants condition, 3.17±0.59 in the no kaolin with companion plants condition, 6.33±1.55 in the control condition.

The companion plant and kaolin interaction affected the numbers of male *F. tritici* differently than the females. The presence of companion plants reduced the number of male *F. tritici* found on tomatoes in the kaolin plots (Mean±SEM=8.33±1.97 with companion plants, 9.00±1.63 without companion plants), but increased the number found in the plots without kaolin (Mean±SEM=24.33±3.27 with companion plants, 22.50±5.51 without companion plants). This interaction had a different effect on *F. tritici* females on 16 May 2012. Kaolin decreased numbers of female *F. tritici* in plots without companion plants (Mean±SEM=7.50±1.17 with kaolin, 12.17±1.26 without kaolin), but increased numbers of female *F. tritici* in plots with companion plants (Mean±SEM= 6.17±0.97 with kaolin, 6.00±0.63 without kaolin).

The interaction of mulch, kaolin and companion plants also produced significant effects. In 2011 this interaction significantly affected *F. tritici* females on three dates. The effect revealed that the largest reduction in numbers of *F. tritici* females could be attained by using kaolin with black mulch and either kaolin or a combination of kaolin and companion plants on ultraviolet-reflective mulch. The means (±SEM) in each treatment on 10 May 2011 in decreasing order were: 41 ± 6.09 in the black mulch plots, 37.5 ± 3.94 in the black mulch/companion plants plots, 22.17 ± 3.99 in the ultraviolet-reflective mulch/companion plants plots, 17.83 ± 2.86 in the black mulch/kaolin/companion plants plots, 10.83 ± 1.64 in the ultraviolet-reflective mulch/kaolin plots, 8.33 ± 2.23 in the black mulch/kaolin plots, 8.33 ± 1.76 in the ultraviolet-reflective mulch plots, and 7.5 ± 1.28 in the ultraviolet-reflective mulch/kaolin/companion plants plots. On 12 May 2011 the means (±SEM) in decreasing order were: in the 37.5 ± 10.74 black mulch plots, 23.83 ± 3.1 in the black mulch/companion plants plots, 20.33 ± 4.37 in the ultraviolet-reflective mulch/companion plants plots, 14.5 ± 2.2 in the ultraviolet-reflective mulch plots, 11.83 ± 2.33 in the black mulch/kaolin/companion plants plots, 7.83 ± 1.74 in the ultraviolet-reflective mulch/kaolin/companion plants plots, 7.33 ± 2.22 in the ultraviolet-reflective mulch/kaolin plots, and 6 ± 1.59 in the black mulch/kaolin plots. On 17 May 2011 the means (±SEM) in decreasing order were: 39.67 ± 6.87 in the black mulch plots, 19.17 ± 3.44 in the black mulch/companion plants plots, 18 ± 4.52 in the ultraviolet-reflective mulch/companion plants plots, 17.83 ± 3.96 in the black mulch/kaolin/companion plants plots, 13.67 ± 4.94 in the black mulch/kaolin plots, 11.83 ± 0.87 in the ultraviolet-reflective mulch plots, 11.5 ± 3.05 in the ultraviolet-reflective mulch/kaolin plots, and 10.17 ± 1.78 in the ultraviolet-reflective mulch/kaolin/companion plants plots.

This interaction affected numbers of *F. tritici* males in 2011 similarly to the females. The lowest numbers of *F. tritici* males were found in plots with black mulch and kaolin or reflective mulch, kaolin, and companion plants. The mean (±SEM) numbers of *F. tritici* males in descending order on 10 May 2011 are as follows: 37.33 ± 6.65 in the black mulch plots, 32.33 ± 3.59 in the black mulch/companion plants plots, 16.33 ± 2.92 in the ultraviolet-reflective mulch/companion plants plots, 13.17 ± 2.64 in the black mulch/kaolin/companion plants plots, 11.33 ± 2.58 in the ultraviolet-reflective mulch/kaolin plots, 7.67 ± 1.2 in the ultraviolet-reflective mulch plots, 6.67 ± 1.71 in the black mulch/kaolin plots, and 3.5 ± 0.89 in the ultraviolet-reflective mulch/kaolin/companion plants plots.

The effect of this interaction on *F. tritici* males was also significant on 17 May 2011 with a similar pattern. The mean (±SEM) numbers of *F. tritici* males in tomato flowers on 17 May 2011 in descending order are as follows: 20 ± 2.97 in the black mulch plots, 11.83 ± 2.27 in the black mulch/companion plants plots, 7.33 ± 1.74 in the black mulch/kaolin/companion plants plots, 6 ± 1.03 in the ultraviolet-reflective mulch/companion plants plots, 5.83 ± 1.49 in the black mulch/kaolin plots, 4.67 ± 0.95 in the ultraviolet-reflective mulch plots, 3.5 ± 1.06 in the ultraviolet-reflective mulch/kaolin plots, and 3.17 ± 0.87 in the ultraviolet-reflective mulch/kaolin/companion plants plots.

In 2012 the effect of the mulch, kaolin, companion plant interaction was only significant on one date for one variable. The interaction significantly affected the number of thrips larvae on tomato flowers on 16 May 2012. Kaolin and companion plants increased numbers of thrips larvae on ultraviolet-reflective mulch, and decreased thrips larvae on black mulch. The mean (±SEM) numbers of thrips larvae in tomato flowers on in descending order are as follows: 25.5 ± 7.44 in the ultraviolet-reflective mulch/companion plants plots, 15.33 ± 1.45 in the black mulch plots, 11.67 ± 3.78 in the ultraviolet-reflective mulch/kaolin plots, 11.17 ± 3.08 in the black mulch/kaolin/companion plants plots, 10 ± 2.83 in the ultraviolet-reflective mulch/kaolin/companion plants plots, 9 ± 3.28 in the black mulch/kaolin plots, 8.67 ± 2.4 in the black mulch/companion plants plots, and 8 ± 2.14 in the ultraviolet-reflective mulch plots.

. The results of the ANOVAs evaluating the main and interactive treatment effects of mulch and kaolin on numbers of adult and larval thrips of each species and *Orius* adults and nymphs in *B. alba* flowers for individual sample dates in 2011 and 2012 are shown in Tables 3-7 and 3-8, respectively. There were few significant effects on insect numbers in the *B. alba* flowers. Significantly more female *F. tritici* were found on *B. alba* flowers in the ultraviolet-reflective mulch plots (Mean= 55.75±2.29) than in the black mulch plots (Mean= 38.00±1.95). There were no other significant effects of mulch.

There was a significant effect of kaolin on *O. insidiosus* on 10 May 2011. Significantly fewer *O. insidiosus* were found on *B. alba* flowers in plots with kaolin (Mean= 5.33±0.62) than in plots without kaolin (Mean= 7.08±1.22). Apart from these main effects the interaction of mulch and kaolin significantly affected *F. tritici* females and *O. insidiosus* in 2011 and *F. bispinosa* females, *F. tritici* females and thrips larvae in 2012 though only on one date for each of these. On 7 June 2011 kaolin decreased the number of female *F. tritici* found on *B. alba* flowers in the black mulch condition (Mean=30.67 ± 4.29 with kaolin, 45.33 ± 3.63 without kaolin), but increased the number in the ultraviolet-reflective mulch condition (Mean=61.33 ± 8.26 with kaolin, 50.17 ± 5.15). The same pattern was observed for *O. insidiosus* on 10 May 2011. Fewer *O. insidiosus* were found on *B. alba* flowers in the black mulch with kaolin plots (Mean=4.67 ± 0.99) than in the black mulch only plots (Mean=9.67 ± 1.45) whereas more *O. insidiosus* were found in ultraviolet-reflective mulch and kaolin plots (Mean=6 ± 0.73) than in the ultraviolet-reflective mulch only plots (Mean=4.5 ± 1.34). In 2012 the interaction affected *F. bispinosa* females similarly (Mean= 40 ± 3.48 in black mulch with kaolin plots, 58.67 ± 6.56 in the black mulch only plots, 46.33 ± 4.44 in the ultraviolet-reflective mulch with kaolin plots, 37.5 ± 1.41 in the ultraviolet-reflective mulch only plots).

The interaction of mulch and kaolin had the opposite effect on *F. tritici* females and larvae in 2012. Kaolin increased numbers of *F. tritici* on black mulch (Mean=27.67 ± 3.81 with kaolin, 20 ± 1.57 without kaolin) and decreased their numbers on ultraviolet-reflective mulch (Mean=14.33 ± 1.2 with kaolin, 18.67 ± 2.86 without kaolin). This effect was similar on thrips larvae in 2012 (Mean= 2.83 ± 0.95 in the black mulch with kaolin plots, 1.17 ± 0.48 in the black mulch without kaolin plots, 1.17 ± 0.48 on ultraviolet-reflective mulch with kaolin, 2.83 ± 0.75 on ultraviolet-reflective mulch without kaolin).

The means (±SEM) of the yield of marketable and unmarketable tomato fruits and the results of the ANOVAs evaluating main and interactive effects of mulch, kaolin, and companion plants for 2011 and 2012 are shown in tables 3-9 and 3-10, respectively. The effect of companion plants on yield was consistent between years. In 2011 and 2012 the presence of *B. alba* companion plants significantly increased yield (number and weight) of medium and large marketable tomatoes (Tables 3-9 and 3-10). Mulch significantly affected yield in 2011 only. Ultraviolet-reflective mulch increased the yield of marketable extra-large fruits on the second harvest date and the season total of large fruits (Table 3-9). In 2011 a significant effect of the kaolin and companion plant interaction led to increased yields of large fruits when both were used together, with decreased yields occurring when only kaolin was used (Table 3-9). The interaction of companion plant and mulch significantly affected the season total number of large fruits indicating a greater increase in yield with companion plants in the ultraviolet-reflective mulch plots than in the black mulch plots. There were no other significant effects in 2011.

In 2012 companion plants significantly increased the number and weight of marketable medium and large tomatoes on the first two harvests (Table 3-10). On 26 June the interaction of companion plants and mulch significantly affected the number of large tomatoes harvested (Table 3-10). Companion plants increased yield on ultraviolet-reflective mulch plots to a greater extent than in black mulch plots, where the yield was increased slightly and in one case decreased by the presence of companion plants. No other effects were significant.

Discussion

Increasing populations of thrips were not present on tomato or *B. alba* with both plants only supporting decreasing thrips populations in both years of the experiments. This confirms that neither of these plants serve as adequate reproductive hosts for the three species of *Frankliniella* thrips in the study (Baez et al. 2011, Frantz and Mellinger 2009). Populations of *F. occidentalis* reached their peak in tomatoes corresponding to those times when *F. tritici* numbers were low in 2011 and 2012. In 2012 *F. bispinosa* numbers were much higher due to an abnormally mild winter in north Florida and they were able to outcompete *F. occidentalis*. This suggests an effect of interspecies competition between the three species, with *F. tritici* outcompeting *F. occidentalis*. This confirms the findings of (Paini et al. 2008) who found that native species of thrips outcompete the invasive *F. occidentalis*.

Populations of *O. insidiosus* on tomatoes and *B. alba* in this experiment were low and sometimes absent. However, when *O. insidiosus* were present in the flowers they were present at ratios sufficient for suppression of thrips. The presence of *O. insidiosus* in these ratios in this experiment indicate the ability of *O. insidiosus* to reach levels appropriate for suppression when insecticides are not used (Funderburk et al. 2000).

While companion plants initially increased the number of thrips on tomatoes, they produce a reduction in numbers of adult thrips throughout the season for *F. tritici*, *F. occidentalis* and *F. bispinosa* (non-significant). Companion plants did not affect larvae due to the inability of larvae to choose their host plant. Larvae must live on the plant where they are oviposited. As neither of these plants are preferred hosts, oviposition behavior would not be expected to be affected.

Kaolin reduces thrips numbers from the middle to the end of the season, in agreement with previous studies (Spiers et al. 2004, Larentzaki et al. 2008). This reduction included *F. tritici, F. bispinosa,* and males of *F. occidentalis*, which differs from a previous study finding no effects on *F. occidentalis* or *F. bispinosa* (Reitz et al. 2008). The mechanism behind the reduction in thrips numbers in this study is unknown, but could be combination of reasons. As suggested in previous studies this reduction could be due to reflective properties of the clay, deterrence to oviposition and feeding by thrips, delay of larval development time and increase of mortality to thrips (Larentzaki et al. 2008, Peng et al. 2010). Although kaolin clay may reduce predator numbers, predators are able to rebound after kaolin treatments are terminated (Marko et al. 2008). *Orius* can quickly reinvade a field after pesticide applications are terminated (Ramachandran et al. 2001) and would likely also increase in number once kaolin treatments have ended and in high enough numbers to control thrips. Kaolin clay treatments at the beginning of the season can suppress thrips numbers and keep them low until *Orius* numbers are high enough in *B. alba* to control thrips in the field, at which time kaolin applications can be terminated. Additionally, previous studies indicate that later applications of kaolin clay are not more beneficial, suggest that ending applications mid-season (Spiers et al. 2004) will save resources without reducing the reduction of thrips. Kaolin is also used on plants to reduce plant stress from temperature, and late season applications are not as beneficial for decreasing plant stress (Creamer et al. 2005).

In 2012 kaolin decreased *F. tritici* females and *F. occidentalis* males and females on ultraviolet-reflective mulch while increasing their numbers on black mulch. This increase on black mulch may be due to the kaolin reducing temperatures on the plants (Cantore et al. 2009) thereby creating a more hospitable environment in terms of temperature for the thrips. However, this effect was only observed on one date and may be of no practical or repeatable importance.

Ultraviolet-reflective mulch significantly decreased thrips in 2011 but not in 2012. The reason for this inconsistency is unknown but could be due to different species composition in 2012, or different solar radiation in the two years affecting the amount of light reflected from the mulch. However, previous studies indicated consistent reductions in the numbers of adult thrips when ultraviolet-reflective mulch is used (Greenough et al. 1990, Greer and Dole 2003, Reitz et al. 2003, Riley et al. 2012) suggesting that the results in 2012 are aberrant. One study on bell peppers found that thrips were not affected by plastic mulch types (Diaz-Perez, 2010), however this study did not identify thrips to species and may have missed key species differences in response to mulch. In 2012 the key thrips species in the tomato flowers were *F. occidentalis* and *F. tritici*, in 2011 the main thrips species was *F. bispinosa*. It is possible that these species respond differently to the mulch and *F. bispinosa* may not be deterred by the ultraviolet-reflective mulch to the degree that the other two species were affected in 2011. Importantly, ultraviolet-reflective mulch only effectively reduces thrips early in the season before foliar growth and chemical residues have obscured the reflectance. After this happens other tactics are needed.

Interactions between mulch and kaolin were sparse and inconsistent. The most common interaction resulted in the fewest thrips in the plots using both ultraviolet-reflective mulch and kaolin. This indicates a potential synergistic activity between these two components.

Companion plant and mulch interactions were also inconsistent and sparse, but seem to suggest that the highest numbers of thrips (larvae) are found in plots with companion plants and reflective mulch. It is possible that companion plants acted as a pull (away from the tomatoes) in the black mulch condition but attracted insects into the plots in the ultraviolet-reflective mulch plots, helping them to overcome the reflectance. Once a thrips lands on the ultraviolet-reflective mulch the mulch is thought to have an arresting affect, preventing the thrips from leaving. Female thrips may then be more likely to oviposit onto these plants (Reitz et al. 2003).

Three way interactions indicate the best reduction in thrips numbers can be procured using black mulch with kaolin, or reflective mulch with kaolin or reflective mulch with kaolin and companion plants. The effects of these components on yield must be considered, and the economics also considered, before a grower can decide which components offer the greatest return on investment.

The use of ultraviolet-reflective mulch increased extra-large fruits in this experiment, although this effect was not consistent between years. The increase in yield in 2011 is consistent with previous studies which found increased yield when using ultraviolet-reflective mulches (Greer and Dole 2003, Reitz et al. 2003, Riley et al. 2012). The lack of increased yield in 2012 may be due to the low disease incidence. Previous studies found that yield is not affected in years of low disease incidence (Stavisky et al.

2002, Riley et al. 2012) and one study found that yield of bell peppers is not influenced by mulch type during the spring season (Diaz-Perez 2010). Both of these situations match the conditions from the 2012 experiment. Additionally, a mild 2011-2012 winter changed the species composition of thrips and other insects in the fields which also may have contributed to the lack of yield differences. It is expected in years with normal winters, during the fall season, and with high disease pressure to see a yield difference.

Companion plants increased yield of medium and large fruits consistently. Companion plants increase yield more in the ultraviolet-reflective mulch plots than in the black plots. The reason for this could be due to reduction in thrips damage by reduced thrips numbers, as the companion plants did significantly decrease thrips numbers. However, if this were true we would expect to see a difference in the unmarketable tomatoes harvested, which we did not find. Companion plants may also increase yield in both plots by attracting wild pollinators to the field (Chaplin-Kramer et al. 2011) and increasing pollination, thereby increasing fruit set. If this were the reason for increased yield, the yield of unmarketable tomatoes would be unaffected, as it was. Additionally, habitat complexity increases the richness and abundance of generalist natural enemies (Langellotto and Denno, 2004, Chaplin-Kramer et al. 2011). This increase of generalist natural enemies could increase vertical control of numerous species of pests in the same field. Reductions of other pest species and their resulting damage, which were not measured in this study, could also have contributed to the increased yield (Showler and Greenburg, 2002, Ghodani et al. 2009). Future studies should measure all pest species and damage on the crop to determine whether such reductions occur.

The larger increase in yield in ultraviolet-reflective mulch plots when using companion plants than in the black mulch plots may be due to a reduction in pollinators in ultraviolet-reflective mulch plots due to reflectance. Companion plants in these plots may help to overcome this problem, by attracting pollinators from a different angle to the field. As pollinators travel from flower to flower the reflectance would not deter them if they travel from the *B. alba* to the tomatoes in the next row. Reduction of other pests and attraction of various other beneficial organisms to the field are also possible contributions to the increased yield and have been found in previous studies (Robinson et al. 1972, Bickerton and Hamilton 2012)

The effect of kaolin on yield is unclear. Use of kaolin may increase yield when used in combination with companion plants. In previous studies kaolin clay was found to reduce total weight of harvested tomatoes (Kahn and Damicone 2008), and had no effect on yield of peanuts (Wilson et al. 2004), chile peppers (Creamer et al. 2005) or onions (Larentzaki et al. 2008). In another study, kaolin increased fruit set on blueberries, but decreased the size of the berries (Spiers et al. 2004). The current results are in agreement with those studies which did not find a difference in yield. Additionally, kaolin may not have affected yield in this experiment due to low disease incidence (Reitz et al. 2008), similar to the effect seen with ultraviolet-reflective mulches (Riley et al. 2012). Kaolin clay increases yield by reducing disease incidence rather than affecting thrips directly (Reitz et al. 2008). In years of higher disease incidence kaolin may offer protection that is economical. Kaolin clay consistently decreases thrips on tomatoes, but does not affect yield. Therefore, it is important for growers to consider the cost of the kaolin compared with the lack of increase in yield when considering whether to use this material on their fields. In areas or years of higher disease incidence it may increase yield (Creamer et al. 2005, Reitz et al. 2008, Riley et al. 2012).

The conditions producing the greatest reduction in thrips numbers likewise produced the greatest yield with the highest yields in 2011 being obtained from plots with ultraviolet-reflective mulch, kaolin, and companion plants, or black mulch with companion plants. The yield in 2012 wasn't as consistent, with highest yields obtained in the plots with ultraviolet-reflective mulch, ultraviolet-reflective mulch, kaolin, and companion plants, black mulch and companion plants, or black mulch and kaolin depending on the harvest date and tomato size.

On *B. alba* kaolin decreased the number of thrips and *O. insidiosus* in the *B. alba* flowers. The kaolin was not applied to *B. alba* plants, only the tomatoes. Therefor the reduction may be due to direct mortality of insects in those plots, reducing the number of insects also on *B. alba*. The kaolin may also disguise the host plants (Bar-Joseph and Frenkel 1983) thereby confusing insects and preventing both thrips and *Orius* from landing in those plots. This pattern is reversed in the plots with ultraviolet-reflective mulch. In these plots the numbers of insects were higher on *B. alba* when kaolin was used. In this case the kaolin may decrease the reflectivity of the mulch thereby reducing the number of insects repelled from those plots. However, these affects were intermittent in nature and the practical significance of these interactions is dubious.

The presence of *B. alba* companion plants reduced thrips and increased yield of tomatoes in this experiment. However, a few practical questions involving the implementation of this component of a pest management strategy remain to be answered. One of these questions is the scale at which this method can be increased to without losing functionality. In addition to the size of farms at which this method can function is the distance from the crop that these plants must be planted to be effective. Bickerton and Hamilton (2012) found that distance from flowers was not a significant factor for predation by *O. insidiosus* on *Ostrinia nubilalis*. If this is true it could solve another problem impeding implementation of this strategy- loss of arable land for crops to be used instead for planting companion plants. If distance is not a significant factor, *B. alba* or other plants could be planted in the roads between blocks of crops, in rows between beds, at the ends of rows, or even along the ditches in between blocks and around the farms. Many farms already have natural populations of *B. alba* growing along the ditches and other uncultivated areas (personal observation) and the growers could potentially save money on herbicides and pesticides by allowing these to remain growing rather than eliminating them with herbicides. If these plants are present before the crop is planted they may serve as a source for established beneficial insects including natural predators and pollinators.

Additionally it remains to be determined what effect, if any, these companion plantings have on pollinators, other pest species, and other natural enemy species. More pollinators and natural enemies were observed in the plots with *B. alba* on the tomatoes and *B. alba* alike; however this was only an observation and was not quantified. Future studies would be prudent to measure these parameters. It would also be very useful to ascertain the effectiveness of these companion plants in reducing pest species when compared directly to current common insecticide regimens. The pest reduction as well as return on investment should be measured in such a study to assist growers in determining which method to employ in their fields for the greatest profit. A combination of companion plants with selective insecticide applications should also be evaluated as a third possibility for use by growers.

The results of this study revealed that the three components used in this method each provide benefits and some disadvantages to growers. The most promising component for increasing yield and reducing thrips is the planting of *B. alba* in the field as companion plants. Ultraviolet-reflective mulch reduces thrips numbers early in the season and increases yield and kaolin clay reduces thrips but does not increase yield. Kaolin clay may be a useful component to reduce thrips numbers after ultraviolet-reflective mulch has lost its reflective effect and before predators are present in the field. Companion plants are effective and can be used with or without the other components. To determine which combination is the most beneficial to growers, however, certain questions remain to be answered. Future investigations should determine the economics of these different components for increasing revenue without increasing investment. Future studies should consider disease pressure, as some of these components may be more appropriate and produce larger yield increases in years with higher disease incidence. Additionally, a cost comparison with common insecticides is needed. The effect of these components on other pest species and their damage, diseases, and beneficial insects should also be evaluated to ascertain the ability of these components to be used in vertically integrated pest management programs. Lastly, this method should be evaluated at larger, commercial scale farms to determine the effect of scale on the efficacy of the components. Despite these gaps, the current research provides three effective and promising elements which can be used separately or in various combinations with each other and other pest management tactics to manage thrips and tospoviruses on tomatoes while reducing pesticides and delaying resistance development.

Table 3-1. The ratio of the total number of larval *Frankliniella* species to the total number of *Frankliniella* adults in the flowers of tomatoes planted without *Bidens alba*, tomatoes planted with *B. alba*, and *B. alba* on each sample date in the experiment conducted in 2011 in Gadsden County, Florida.

Treatment	19-April	26-April	29-April	3-May	5-May	10-May	12-May	17-May	19-May	24-May	26-May	31-May	2-June	7-June
	Tomatoes alone													
B[a]	.[b]	---[c]	0.16	0.08	0.05	0.01	0.01	0.32	0.16	0.28	0.39	0.37	1.45	1.24
B/K	.	---	0.12	0.09	0.02	0.02	0.01	0.52	0.32	0.59	0.68	0.78	0.62	1.80
R	.	---	---	0.04	0.11	0.01	0.00	0.43	0.18	0.42	0.38	0.16	1.26	2.99
R/K	.	---	---	0.33	0.09	0.02	0.00	0.39	0.26	0.83	0.45	0.25	1.40	1.61
	Tomatoes with *Bidens alba*													
B	.	---	0.43	0.09	0.05	0.00	0.00	0.30	0.28	0.45	0.39	0.72	1.86	2.59
B/K	.	---	0.12	0.07	0.06	0.00	0.00	0.53	0.27	0.79	0.55	0.51	2.00	2.28
R	.	---	---	---	0.04	0.01	0.01	0.36	0.20	0.26	0.89	0.17	1.39	2.07
R/K	.	---	---	0.17	0.03	0.01	0.02	0.43	0.31	0.82	1.06	0.60	0.92	4.08
	Bidens alba													
B	0.33	0.02	0	0	0	0	0	0.1	0	0.1	0.1	0.01	0.01	0.06
B/K	0	0.02	0	0.01	0.01	0	0	0	0	0	0.1	0.05	0.03	0.06
R	0	0.03	0	0	0	0	0	0	0	0	0	0.01	0.03	0.02
R/K	0	0	0.01	0	0	0	0	0	0	0	0	0.02	0.02	0.02

[a] B indicates plants planted on black mulch, K indicates kaolin clay and R indicates pepper plants planted on reflective mulch

[b] . indicates no samples collected on that date.

[c] --- indicates no adults present in the collections on that date.

Table 3-2. The ratio of the total number of larval *Frankliniella* species to the total number of *Frankliniella* adults in the flowers of tomatoes planted without *Bidens alba*, tomatoes planted with *B. alba*, and *B. alba* on each sample date in the experiment conducted in 2012 in Gadsden County, Florida.

Treatment	1-May	4-May	8-May	11-May	16-May	18-May	22-May	25-May	30-May	1-June	5-June	7-June
	Tomatoes alone											
B[a]	0.12	0.35	0.01	0.03	0.13	0.21	0.33	0.33	0.56	0.59	1.14	1.26
B/K	0.58	0.44	0.08	0.03	0.09	0.16	0.65	0.86	0.58	0.60	0.75	0.63
R	0.32	0.07	0.02	0.03	0.07	0.24	0.70	0.64	0.61	0.43	0.84	0.70
R/K	0.85	0.25	0.08	0.05	0.15	0.18	0.41	0.70	0.66	0.25	1.69	1.13
	Tomatoes with *Bidens alba*											
B	0.11	0.13	0.11	0.04	0.12	0.17	0.39	0.29	0.35	0.32	0.89	1.36
B/K	0.44	0.28	0.05	0.08	0.18	0.20	0.68	2.49	0.34	0.67	1.32	1.55
R	0.12	0.26	0.04	0.13	0.36	0.51	0.50	0.56	0.62	0.42	1.94	1.17
R/K	0.10	0.28	0.10	0.09	0.19	0.25	0.85	1.49	1.00	0.99	1.55	1.52
	Bidens alba											
B	0.01	0.01	0.01	0.00	0.01	0.02	0.02	0.02	0.02	0.04	0.03	0.04
B/K	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.04	0.05	0.04	0.02
R	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.01	0.05	0.04	0.05	0.04
R/K	0.01	0.01	0.00	0.00	0.01	0.02	0.02	0.01	0.02	0.03	0.03	0.02

[a] B indicates plants planted on black mulch, K indicates kaolin clay and R indicates pepper plants planted on reflective mulch

Table 3-3. The ratio of the total number of thrips adults and nymphs to the total number of *Orius insidiosus* adults and nymphs in the flowers of tomatoes planted without *Bidens alba*, tomatoes planted with *B. alba*, and flowers of *B. alba* on each sample date in the experiment conducted in 2011 in Gadsden County, Florida.

Treatment	19-April	26-April	29-April	3-May	5-May	10-May	12-May	17-May	19-May	24-May	26-May	31-May	2-June	7-June
	Tomatoes alone													
B[a]	.[b]	---[c]	---	---	---	59.75	16.5	47.5	70	---	---	---	---	---
B/K	.	---	---	22	---	---	33	---	50	---	---	23	9	---
R	.	---	---	---	---	16	40.5	18	45	---	20	---	30.5	43
R/K	.	---	---	---	---	---	36	---	19.25	18.25	---	26	24.5	---
	Tomatoes with *Bidens alba*													
B	.	---	---	10	---	60	59.56	.	64.67	---	---	19	30	12
B/K	.	---	---	---	---	23	12	22.75	14.5	---	---	---	12.5	---
R	.	---	---	---	6	27.83	48	63	34.33	23	6.5	28	22	---
R/K	.	---	---	---	---	---	19.67	---	21	---	---	---	---	16.33
	Bidens alba													
B	---	---	95	140.17	91.8	43.61	36.61	8.96	15.46	29.63	21.86	20.65	31.25	64.5
B/K	---	3	---	99.25	68.7	98.89	63.65	11.8	12.57	25.58	15.92	18.25	28.25	21
R	0	---	103.5	226.25	74.1	85.68	43.39	13.64	20.36	17.9	16.71	22.4	40.28	49.6
R/K	---	8	94	192	60.7	56.57	34.6	9.76	32.41	41.75	13.37	14.46	29.96	51.42

[a] B indicates plants planted on black mulch, K indicates kaolin clay and R indicates pepper plants planted on reflective mulch

[b] . indicates

[c] --- indicates no *Orius* were present in the samples on the respective date

Table 3-4. The ratio of the total number of thrips adults and nymphs to the total number of *Orius insidiosus* adults and nymphs in the flowers of tomatoes planted without *Bidens alba*, tomatoes planted with *B. alba*, and flowers of *B. alba* on each sample date in the experiment conducted in 2012 in Gadsden County, Florida.

Treatment	1-May	4-May	8-May	11-May	16-May	18-May	22-May	25-May	30-May	1-June	5-June	7-June
	Tomatoes alone											
B[a]	---[b]	---	56.00	159.00	121.17	111.00	---	37.00	37.00	---	---	---
B/K	---	---	---	35.75	132.00	---	40.00	---	17.00	---	15.00	16.00
R	---	---	25.00	73.33	97.75	68.00	27.00	---	13.50	---	---	12.00
R/K	---	---	---	23.00	72.50	25.00	54.00	---	---	---	---	29.00
	Tomatoes with *Bidens alba*											
B	60.00	28.50	61.00	65.00	77.25	50.00	41.00	---	---	14.00	---	41.00
B/K	---	28.00	33.50	---	83.00	47.00	---	---	11.00	---	11.00	17.00
R	---	---	20.50	48.25	88.17	60.00	---	---	30.00	---	---	33.00
R/K	---	---	---	39.00	24.67	46.00	33.00	38.00	---	39.00	7.00	---
	Bidens alba											
B	119.74	62.85	20.23	16.20	23.71	15.87	19.53	25.19	47.78	25.27	43.19	47.88
B/K	84.02	60.28	17.91	15.63	15.75	14.42	13.80	24.68	20.25	38.64	52.00	36.04
R	63.09	87.09	29.21	22.31	20.88	19.05	19.76	17.36	27.74	42.70	55.69	23.43
R/K	124.50	32.82	20.80	19.72	12.07	10.65	19.42	28.87	29.79	29.84	60.19	28.96

[a] B indicates plants planted on black mulch, K indicates kaolin clay and R indicates pepper plants planted on reflective mulch

[b] --- indicates no *Orius* were present in the samples on the respective date

Table 3-5. *F*-values for treatment effects in the ANOVAs conducted for individual 2011 sample dates to determine the effects of mulch, companion plants, and kaolin clay on the numbers of adults and larvae of *F. bispinosa*, *F. tritici*, and *F. occidentalis* species found in tomato flower in the experiment conducted in Gadsden County, Florida.

ANOVA treatment effect	d.f.	*F*-value												
		26-Apr	29-Apr	3-May	5-May	10-May	12-May	17-May	19-May	24-May	26-May	31-May	2-Jun	7-Jun
F. bispinosa adult females														
C	1, 8	n/a	n/a	n/a	n/a	n/a	n/a	0.3	0.1	4	n/a	0.3	0.9	0.2
M	1, 2	n/a	n/a	n/a	n/a	n/a	n/a	1.7	2.8	0	n/a	6	1.9	0.8
C x M	1, 8	n/a	n/a	n/a	n/a	n/a	n/a	1.2	0.1	0.1	n/a	0.3	3.2	0.2
K	1, 4	n/a	n/a	n/a	n/a	n/a	n/a	0	0.1	6.4	n/a	12.2*	14.7*	1.4
C x K	1, 8	n/a	n/a	n/a	n/a	n/a	n/a	1.2	0.7	0.2	n/a	3	0	0.8
M x K	1, 4	n/a	n/a	n/a	n/a	n/a	n/a	0.1	3.6	2.2	n/a	3.8	0.1	0.2
C x M x K	1, 8	n/a	n/a	n/a	n/a	n/a	n/a	2.9	1.8	0	n/a	2.1	0.1	0
F. bispinosa adult males														
C	1, 8	n/a	n/a	n/a	n/a	n/a	n/a	2.3	0.1	0.5	n/a	n/a	n/a	n/a
M	1, 2	n/a	n/a	n/a	n/a	n/a	n/a	0.1	2	7.9	n/a	n/a	n/a	n/a
C x M	1, 8	n/a	n/a	n/a	n/a	n/a	n/a	0	2.1	0	n/a	n/a	n/a	n/a
K	1, 4	n/a	n/a	n/a	n/a	n/a	n/a	0.2	0.8	0.4	n/a	n/a	n/a	n/a
C x K	1, 8	n/a	n/a	n/a	n/a	n/a	n/a	0	1	0.8	n/a	n/a	n/a	n/a
M x K	1, 4	n/a	n/a	n/a	n/a	n/a	n/a	2.8	0.8	0	n/a	n/a	n/a	n/a
C x M x K	1, 8	n/a	n/a	n/a	n/a	n/a	n/a	2.5	0	0.1	n/a	n/a	n/a	n/a
F. tritici adult females														
C	1, 8	n/a	0.3	0	n/a	16.0**	1.5	0	1.6	0.2	0.1	0.1	1.9	2.8
M	1, 2	n/a	0.8	24.7*	n/a	69.4**	4.2	4.2	23.1*	7.6	0.3	0	1.1	1
C x M	1, 8	n/a	0.2	0	n/a	0	0.1	0.7	0.1	1.8	0	0.4	0	2.8
K	1, 4	n/a	0	3.3	n/a	93.2***	50.8**	7.9*	22.1**	32.1**	7.4*	53.3**	27.7**	12.0*
C x K	1, 8	n/a	0.2	0.5	n/a	2.4	2.9	0.6	9.9**	1.9	0	1.6	0	6.1*
M x K	1, 4	n/a	2.4	0.2	n/a	21.5**	2.1	1	0.3	3.5	0.9	0.1	1	2.3
C x M x K	1, 8	n/a	1.4	0.5	n/a	46.8***	5.9*	5.7*	0	0.2	0.6	0.5	0.1	0.8

Table 3-5. Continued.

ANOVA treatment effect	d.f.	*F*-value												
		26-Apr	29-Apr	3-May	5-May	10-May	12-May	17-May	19-May	24-May	26-May	31-May	2-Jun	7-Jun
F. tritici adult males														
C	1, 8	n/a	2.4	2.9	0.2	0.1	0.5	0.1	6.7*	0.2	0.2	n/a	0	n/a
M	1, 2	n/a	1.9	27.2*	61.8*	42.9*	13.2	14.3	21.9*	6.6	0.9	n/a	0	n/a
C x M	1, 8	n/a	0.3	0.8	0.1	4.1	1.1	0.8	3.8	5.9*	0.9	n/a	0.3	n/a
K	1, 4	n/a	0.1	1.7	6.9	66.4**	34.0**	29.3**	25.1**	11.7*	21.9**	n/a	10.3*	n/a
C x K	1, 8	n/a	0	0.2	0.4	5.5*	0	0.7	0	3.2	3.3	n/a	0.1	n/a
M x K	1, 4	n/a	5.5	1.7	8.0*	9.9*	2.6	2.6	0	0.9	0.3	n/a	0.5	n/a
C x M x K	1, 8	n/a	0.3	0.2	0	34.1***	0	5.1*	1.2	0	0.3	n/a	0	n/a
F. occidentalis adult females														
C	1, 8	n/a	1.93	n/a	0.98	0	1.36	0	0.28	1.15	0.69	4.64	14.4**	2.3
M	1, 2	n/a	32.0*	n/a	9.05	0.79	0.04	1.08	0.06	0.5	0	0.94	5.19	3.26
C x M	1, 8	n/a	1.7	n/a	1.42	1.16	4.07	0.03	0.76	0.23	3.09	0.13	0.17	0
K	1, 4	n/a	0.37	n/a	1.16	0.3	0.23	2.28	0.71	0.5	1.46	0.1	5.61	3.1
C x K	1, 8	n/a	0	n/a	0.04	0.28	0.21	0.23	4.45	0.86	0.53	3.14	0.83	0.71
M x K	1, 4	n/a	0.37	n/a	0.27	2.35	2.92	0.2	2.26	2.91	5.15	3.41	4.87	0.3
C x M x K	1, 8	n/a	0	n/a	0.07	0.02	0.81	0.01	0.97	1.15	0.19	0.95	2.1	1.54
F. occidentalis adult males														
C	1, 8	n/a	n/a	0.1	0.9	0	n/a	1.5	0.1	5.6*	5.3*	13.0**	7.8*	11.3**
M	1, 2	n/a	n/a	21.7*	5.2	0.2	n/a	1.5	2.9	1	0.3	0.4	2.1	1.1
C x M	1, 8	n/a	n/a	0	0.1	0	n/a	0.8	0.1	1	0.1	0.1	0.8	1.6
K	1, 4	n/a	n/a	0.4	0	0.2	n/a	7.9*	2.7	3.9	3.2	6.3	2.5	7.4*
C x K	1, 8	n/a	n/a	1.5	0.5	0.2	n/a	0.8	0.6	0.4	0	3	1	0.3
M x K	1, 4	n/a	n/a	0.6	0.4	0.2	n/a	0	1.6	2.1	0	0	0.2	0.5
C x M x K	1, 8	n/a	n/a	3.2	0.3	0.2	n/a	0.2	0	1.1	0	0.1	0.1	3.4

Table 3-5. Continued.

ANOVA treatment effect	d.f.	F-value												
		26-Apr	29-Apr	3-May	5-May	10-May	12-May	17-May	19-May	24-May	26-May	31-May	2-Jun	7-Jun
		Thrips larvae												
C	1, 8	n/a	0	n/a	0.1	n/a	n/a	0.4	0.1	0.1	0.1	0.4	0.7	0.1
M	1, 2	n/a	3.1	n/a	3.4	n/a	n/a	7.7	7.6	3.5	0	2.2	0	6.1
C x M	1, 8	n/a	0	n/a	0.6	n/a	n/a	0.8	0.5	0.1	5.2*	1.2	9.5*	0.1
K	1, 4	n/a	0	n/a	1.1	n/a	n/a	3.3	0.6	0.1	6.5	1.8	21.3**	7.3*
C x K	1, 8	n/a	0	n/a	0.3	n/a	n/a	2.8	0	1	0.6	0	0.2	0
M x K	1, 4	n/a	3.8	n/a	2.3	n/a	n/a	0	0	0.3	1.9	2.3	0.3	0.1
C x M x K	1, 8	n/a	0	n/a	1.1	n/a	n/a	2.3	0.3	0.2	0	0.4	4.4	0.4

[a]C indicates effect of companion plants, M indicates mulch effects, K indicates kaolin clay effects.

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

Table 3-6. *F*-values for treatment effects in the ANOVAs conducted for individual 2011 sample dates to determine the effects of mulch, companion plants, and kaolin clay on the numbers of adults and larvae of *F. bispinosa*, *F. tritici*, and *F. occidentalis* species found in tomato flowers in the experiment conducted in Gadsden County, Florida.

ANOVA treatment effect	d.f.	*F*-value											
		1-May	4-May	8-May	11-May	16-May	18-May	22-May	25-May	30-May	1-Jun	5-Jun	7-Jun
F. bispinosa adult females													
C[a]	1, 8	6.1*	16.1**	1.1	n/a	n/a	2.9	1.9	9.3*	2.6	0.5	1.5	1.2
M	1, 2	23.2*	7.9	4.8	n/a	n/a	0	0.3	4.3	3.5	0.1	0	0
C x M	1, 8	0.7	1.3	4.9	n/a	n/a	0	1	0	0.3	0.7	1.9	0.6
K	1, 4	15.2*	7.3*	42.4**	n/a	n/a	18.1*	5.7	11.9*	4.2	1.1	1.1	2.7
C x K	1, 8	0.4	0.1	1.6	n/a	n/a	0.5	0.7	0.9	1.1	2.3	0.1	1.3
M x K	1, 4	1.5	0.6	0.6	n/a	n/a	0	0.7	3.7	0	0.1	0.3	0.7
C x M x K	1, 8	0.5	1.7	0.4	n/a	n/a	1.2	0.1	1.4	0.4	1	0.8	0
F. bispinosa adult males													
C	1, 8	n/a	5.5*	0.4	4.9	46.3***	21.5**	8.8*	8.1*	0.1	0.3	n/a	0.3
M	1, 2	n/a	11.6	28.9*	6.9	0.3	3.9	0.9	0.3	0	0.3	n/a	0.1
C x M	1, 8	n/a	0	5.6*	0.8	0.7	0.8	0.8	0	2.8	0.1	n/a	1.5
K	1, 4	n/a	5.1	23.0**	41.8**	21.5**	20.1**	0.8	4.9	4.8	2.1	n/a	6.3
C x K	1, 8	n/a	0.1	0.8	1.7	1.6	1.6	1.1	4.2	0.5	1.5	n/a	1.1
M x K	1, 4	n/a	0	0.1	0.5	0.2	0.2	2.5	0.1	0.1	1.5	n/a	0.1
C x M x K	1, 8	n/a	2.5	0	0.2	0.7	0.2	0.4	0.1	0.3	0.1	n/a	0.2
F. tritici adult females													
C	1, 8	10.8**	5.3*	0.2	0.9	12.2**	0.6	7.1*	5	0.7	3.7	0	2.4
M	1, 2	13.2	4.2	2.8	7.8	15.5	1.1	0.5	1.9	3.8	0.3	2.3	0
C x M	1, 8	0	0.5	3.9	0.3	2.5	0.1	0.1	4.3	0.5	0.1	0.2	0.2
K	1, 4	6	6.2	17.4**	32.1**	6.9	2.7	0.6	6.9	5	8.2*	0.4	0
C x K	1, 8	1.4	4.9	1	0.3	5.5*	0.5	0	0	1.5	2.4	1.7	3.5
M x K	1, 4	1.8	0	2.5	0.5	11.3*	0.5	0.8	1.6	0.8	1	0.4	1
C x M x K	1, 8	1	0.7	0.2	0.8	0.2	0	0.8	0	1.2	2.3	2.6	0.1

Table 3-6. Continued.

ANOVA treatment effect	d.f.	*F*-value											
		1-May	4-May	8-May	11-May	16-May	18-May	22-May	25-May	30-May	1-Jun	5-Jun	7-Jun
		F. tritici adult males											
C	1, 8	n/a	0.2	0	1.6	3.5	9.2*	n/a	n/a	n/a	n/a	n/a	n/a
M	1, 2	n/a	3	2.7	1.1	11.9	1.2	n/a	n/a	n/a	n/a	n/a	n/a
C x M	1, 8	n/a	0	2.6	2.4	0	0.3	n/a	n/a	n/a	n/a	n/a	n/a
K	1, 4	n/a	1.3	12.4*	5.7	15.2*	4.6	n/a	n/a	n/a	n/a	n/a	n/a
C x K	1, 8	n/a	0.6	0.1	0.6	2.5	2.7	n/a	n/a	n/a	n/a	n/a	n/a
M x K	1, 4	n/a	3	0	7	0.3	1.1	n/a	n/a	n/a	n/a	n/a	n/a
C x M x K	1, 8	n/a	0	0.1	1.2	0.1	0.7	n/a	n/a	n/a	n/a	n/a	n/a
		F. occidentalis adult females											
C	1, 8	0.4	2	0.2	0.9	1	1	2.4	2.8	1.3	2.8	1.7	3.8
M	1, 2	3.7	3.1	0.5	3	1.9	1.5	0.1	1.9	2.3	1.8	0.1	0.5
C x M	1, 8	0.5	0.5	0.5	0.2	2.4	4.9	2.3	0.1	0.5	0.1	1.2	0
K	1, 4	0	4.7	0	0.4	5	5.1	4.9	4.9	0	0.3	1.4	1.2
C x K	1, 8	0.5	1.9	1.3	0.1	0.3	0	1.1	0	0.7	1.1	0.3	1.2
M x K	1, 4	0.3	0	9.6*	2.8	0	1.2	0	8.4*	3.2	0.1	0.1	0.6
C x M x K	1, 8	0	0.8	0.1	1.1	0.5	0.3	2.9	0.3	0.1	0.9	0.1	0.6
		F. occidentalis adult males											
C	1, 8	n/a	0.8	1.5	n/a	0.1	0.3	1.2	3.1	1.2	8.9*	n/a	2
M	1, 2	n/a	0.8	0.8	n/a	0.1	0.6	0	1	8.2	0.5	n/a	0
C x M	1, 8	n/a	0	0	n/a	0.4	0.3	0	0.2	1.2	0	n/a	3.5
K	1, 4	n/a	1.8	0.2	n/a	0.1	0.1	0.8	2.8	0	0.1	n/a	0.1
C x K	1, 8	n/a	0	0.2	n/a	0.6	0.9	2.9	1.2	2.7	1.4	n/a	0.2
M x K	1, 4	n/a	0	0.1	n/a	0	1.6	7.4*	0.1	0	0.1	n/a	0
C x M x K	1, 8	n/a	0.3	1.9	n/a	0.1	2.2	0.7	0.1	0.9	0.5	n/a	0.7

Table 3-6. Continued.

ANOVA treatment effect	d.f.	F-value											
		1-May	4-May	8-May	11-May	16-May	18-May	22-May	25-May	30-May	1-Jun	5-Jun	7-Jun
		Thrips larvae											
C	1, 8	0.4	1	n/a	7.1*	0.5	0.6	1.2	0.2	4.2	0.7	0.9	4.7
M	1, 2	0.6	2.6	n/a	0	0.2	0.3	0.4	4	0.7	0.1	2.8	0.1
C x M	1, 8	0.9	2.6	n/a	3.7	2.4	5.7*	0.7	1	2.4	3.4	1.3	0
K	1, 4	0.8	1.7	n/a	7.7*	0.9	5.2	0.4	2.9	1.3	0.4	0.1	0.6
C x K	1, 8	0.7	0.4	n/a	0.1	0.1	0	1	1.3	0.1	3.6	1.1	0.2
M x K	1, 4	1.1	0.1	n/a	0.1	0.1	0.4	0.4	0.9	0.3	0.1	0	0.1
C x M x K	1, 8	0.7	3.5	n/a	1	5.6*	0.6	0.1	0.1	0.6	0	1.7	0.6

[a]C indicates effect of companion plants, M indicates mulch effects, K indicates kaolin clay effects.

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

Table 3-7. ANOVA values for the effects of mulch, kaolin, and the interaction of mulch and kaolin on thrips and *O. insidiosus* on *B. alba* in the experiment conducted in Gadsden county, Florida in 2011.

ANOVA Treatment effect	d.f.	*F*-value 19-April	26-April	29-April	3-May	5-May	10-May	12-May	17-May	19-May	24-May	26-May	31-May	2-June	7-June
		F. bispinosa adult females													
M[a]	1,2	.[b]	.	.	0.4	0.8	1.4	.	0.4	0.1	0.0	6.0	1.1	1.5	2.5
K	1,4	.	.	.	0.0	0.0	0.1	.	3.5	0.1	0.8	2.7	1.1	0.4	0.9
M*K	1,4	.	.	.	0.1	0.8	0.7	.	0.4	2.5	0.0	2.7	0.0	0.4	4.8
		F. bispinosa adult males													
M	1,2	.	.	0.3	1.0	1	.	.	.	.	.	.	.	.	.
K	1,4	.	.	3.4	4.0	1	.	.	.	.	.	.	.	.	.
M*K	1,4	.	.	0.6	1.0	1	.	.	.	.	.	.	.	.	.
		F. tritici adult females													
M	1,2	.	0.9	0.0	0.3	.	2.2	0.5	0.0	1.1	0.3	0.0	0.0	2.4	16.9*
K	1,4	.	0.8	0.0	0.6	.	0.3	0.0	1.0	0.4	0.1	0.2	1.5	0.3	1.0
M*K	1,4	.	0.8	0.1	0.9	.	1.6	4.0	0.0	4.4	5.2	0.0	1.9	0.0	9.5*
		F. tritici adult males													
M	1,2	0.4	0.2	0.5	0.8	1.1	0.6	0.2	0.4	0.5	0.2	0.0	0.2	3.4	4.4
K	1,4	0.1	0.0	1.2	4.4	1.5	4.9	1.1	2.2	0.8	0.6	0.7	5.4	1.2	3.4
M*K	1,4	0.0	0.3	0.0	0.0	0.4	0.0	1.2	2.6	0.9	0.9	1.0	1.3	1.3	2.9
		F. occidentalis adult females													
M	1,2	2.1	1.6	0.6	0.1	2.7	0.1	0.1	1.5	0.6	0.2	0.2	1.0	0.5	0.5
K	1,4	1.7	3.0	1.3	0.3	2.4	1.5	0.0	0.7	1.3	0.2	0.5	0.3	0.1	0.2
M*K	1,4	2.1	0.0	1.7	0.0	0.0	0.1	3.2	1.5	0.3	0.0	0.1	0.3	1.4	0.0

Table 3-7. Continued.

ANOVA Treatment effect	d.f.	*F*-value													
		19-April	26-April	29-April	3-May	5-May	10-May	12-May	17-May	19-May	24-May	26-May	31-May	2-June	7-June
		F. occidentalis adult males													
M	1,2	1.2	0.4	1.1	0.8	1.4	0.1	0.1	0.2	0.2	1.6	0.5	0.3	0.0	0.0
K	1,4	1.2	0.0	0.4	0.0	0.4	0.1	0.1	1.8	2.0	0.8	0.5	0.0	0.0	0.0
M*K	1,4	1.2	6.8	0.0	0.0	0.4	0.1	7.1	0.2	0.2	0.8	0.5	0.0	2.0	0.3
		O. insidiosus adults and nymphs													
M	1,2	0.8	0.0	0.1	1.3	0.2	0.4	0.1	2.4	4.8	0.4	0.5	0.0	0.1	3.0
K	1,4	0.8	2.8	2.3	0.3	0.5	7.7*	1.3	0.2	0.8	2.3	0.7	1.1	0.1	0.3
M*K	1,4	0.8	0.0	0.1	0.3	0.0	8.8*	1.7	0.2	0.1	0.5	0.0	1.8	0.6	0.3
		Thrips larvae													
M	1,2	1.7	0.5	0.0	0.5	1.0	0.0	1.1	2.5	.	0.8	5.0	0.7	0.1	5.5
K	1,4	1.7	0.0	0.0	1.3	1.0	1.3	3.3	2.5	.	0.0	0.0	0.0	0.1	1.5
M*K	1,4	1.7	0.3	1.2	0.5	1.0	0.8	0.4	2.5	.	0.8	0.0	0.2	0.4	0.4

[a] M indicates the effect of the mulch treatments, K is the effect of kaolin treatments and M*K indicates the interaction effect.

[b] . indicates numbers were not sufficient for analysis.

Table 3-8. ANOVA values for the effects of mulch, kaolin, and the interaction of mulch and kaolin on thrips adults and larvae and *O. insidiosus* adults and nymphs on *B. alba* in the experiment conducted in 2012.

ANOVA Treatment effect	d.f.	*F*-value											
		1-May	4-May	8-May	11-May	16-May	18-May	22-May	25-May	30-May	1-June	5-June	7-June
		F. bispinosa adult females											
M[a]	1,2	1.1	14.0	1.9	0.8	2.1	0.1	2.7	0.0	1.6	0.0	0.1	0.0
K	1,4	1.0	0.5	0.1	0.3	0.6	0.2	0.9	0.0	1.3	0.3	1.5	0.7
M*K	1,4	1.7	6.5	1.0	4.8	1.0	0.3	10.6*	0.0	1.0	0.2	0.1	0.0
		F. bispinosa adult males											
M	1,2	6.0	10.6	0.2	1.9	1.6	0.2	0.0	0.0	1.0	3.5	3.1	3.1
K	1,4	1.5	1.1	0.4	0.5	1.0	0.1	0.1	0.1	1.3	0.0	2.4	0.3
M*K	1,4	0.2	1.8	0.0	1.2	5.7	0.0	0.4	3.0	0.6	1.3	0.3	3.1
		F. tritici adult females											
M	1,2	0.0	11.8	3.3	0.4	0.1	0.2	0.2	0.1	0.1	0.8	0.1	.[b]
K	1,4	0.1	0.1	1.1	1.4	0.5	0.6	0.5	0.0	0.8	0.0	0.6	.
M*K	1,4	2.2	7.6*	0.3	0.2	0.3	0.1	2.5	0.0	0.1	0.2	2.1	.
		F. tritici adult males											
M	1,2	13.6	0.3	1.8	1.9	0.2	0.1	0.0	0.8	0.9	0.1	1.5	0.2
K	1,4	0.0	1.4	1.4	4.9	0.2	0.7	0.5	0.8	0.0	0.2	1.2	2.0
M*K	1,4	6.2	6.7	0.3	3.0	1.1	0.2	0.8	0.4	1.8	0.2	0.3	1.1
		F. occidentalis adult females											
M	1,2	0.2	0.0	0.1	1.3	1.8	.	.	.	.	.	.	.
K	1,4	0.0	0.1	0.1	1.3	0.0	.	.	.	.	.	.	.
M*K	1,4	1.2	0.0	1.1	2.1	0.0	.	.	.	.	.	.	.

Table 3-8. Continued.

ANOVA Treatment effect	d.f.	*F*-value											
		1-May	4-May	8-May	11-May	16-May	18-May	22-May	25-May	30-May	1-June	5-June	7-June
		F. occidentalis adult males											
M	1,2	0.9	1.2	0.4	0.1	.	0.2	0.2	0.7	0.0	2.3	0.0	.
K	1,4	1.9	3.0	0.4	0.1	.	0.2	0.5	0.1	0.9	1.3	0.2	.
M*K	1,4	0.3	0.1	0.4	4.1	.	1.6	0.0	0.1	0.9	0.1	0.9	.
		O. insidiosus adults and nymphs											
M	1,2	0.0	0.1	0.5	0.3	0.1	0.2	2.1	1.9	1.2	0.0	0.5	1.4
K	1,4	0.1	0.4	1.2	0.9	1.4	0.1	0.9	0.3	0.2	1.0	2.1	1.8
M*K	1,4	1.6	0.6	0.0	0.2	0.5	1.3	0.1	0.0	0.8	0.0	2.1	3.0
		Thrips larvae											
M	1,2	0.7	0.7	1.4	0.3	0.0	0.2	0.4	.	0.0	1.1	0.0	0.4
K	1,4	0.2	0.0	0.1	0.3	0.4	0.2	0.2	.	0.0	0.1	0.0	4.0
M*K	1,4	0.2	0.1	0.7	0.3	0.4	0.2	0.1	.	7.8*	0.2	0.3	0.4

[a] M indicates the effect of the mulch treatments, K is the effect of kaolin treatments and M*K indicates the interaction effect.
[b] . indicates numbers were not sufficient for analysis.

Table 3-9. Mean (± SEM) number and weight per plot of medium, large, and extra-large tomato fruits harvested on 22 and 30 June 2011 and the ANOVA effects for those variables in the push-pull experiment conducted in Gadsden County, Florida.

Treatment	Mean number (no.) and weight (kgs) per 20 tomato plants (SEM)						
	Unmarketable	Medium fruits		Large fruits		Extra-Large	
	kgs	No	kgs	no	kgs	no	kgs
	22-Jun-2011						
B[a]	7 ± 0	10 ± 2	1 ± 0	11 ± 1	2 ± 0	29 ± 5	6 ± 1
B/C	4 ± 1	8 ± 2	1 ± 0	12 ± 3	2 ± 1	32 ± 8	8 ± 2
B/K	6 ± 1	11 ± 1	1 ± 0	16 ± 1	3 ± 0	48 ± 6	11 ± 1
B/C/K	5 ± 1	15 ± 2	2 ± 0	22± 3	3 ± 0	48 ± 10	11 ± 3
R	6 ± 2	12 ± 2	1 ± 0	15 ± 2	2 ± 0	45 ± 7	11 ± 2
R/C	8 ± 1	15 ± 0	2 ± 0	22 ± 5	3 ± 1	70 ± 5	16 ± 2
R/K	7 ± 0	10 ± 1	1± 0	18 ± 5	3 ± 1	47 ± 22	10 ± 5
R/C/K	7± 2	16 ± 2	2 ± 0	25 ± 2	4 ± 0	54 ± 8	12 ± 2
ANOVA F-value							
C (1, 8 d.f.)[b]	0.2	6.6*	7.3*	6.2*	3.9	4.6	4.2
M (1, 2 d.f.)	2.3	3.4	4.1	2.4	2.8	3.5	3.6
C x M (1, 8 d.f.)	2.4	2.8	2.4	1.0	0.7	3.2	2.4
K (1, 4 d.f.)	0.1	2.0	2.0	7.1	6.1	0.4	0.2
C x K (1, 8 d.f.)	0.1	3.3	1.8	0.3	0.2	1.5	1.5
M x K (1, 4 d.f.)	0.0	5.1	5.6	1.4	1.3	2.8	3.6
M x C x K (1, 8 d.f.)	0.4	0.4	0.5	0.3	0.1	0.7	0.4

Table 3-9 Continued

Treatment	Mean number (no.) and weight (kgs) per 20 tomato plants (SEM)						
	Unmarketable	Medium fruits		Large fruits		Extra-Large fruits	
	kgs	No	kgs	no	kgs	no	kgs
	30-Jun-2011						
B	4 ± 1	27 ± 3	3 ± 0	14 ± 3	2 ± 0	4 ± 1	1 ± 0
B/C	4 ± 1	28 ± 7	3 ± 1	9 ± 2	1± 0	2 ± 1	0 ± 0
B/K	4 ± 0	22 ± 7	2 ± 1	9 ±4	1 ± 1	4 ± 1	1 ± 0
B/C/K	5 ± 1	33 ± 3	4 ± 0	15± 3	2 ± 0	4 ± 2	1 ± 0
R	5 ± 0	24± 6	3 ± 1	20 ± 4	3 ± 1	10 ± 3	2 ± 1
R/C	4 ± 0	27 ± 3	3 ± 0	24 ± 1	4 ± 0	14 ± 2	3 ± 0
R/K	5± 1	29 ± 2	4 ± 1	15 ± 2	2 ± 0	14 ± 6	3 ± 1
R/C/K	4 ± 0	30 ± 8	3± 1	27 ± 6	4 ± 1	11 ± 2	2 ± 0
ANOVA F-value							
C (1, 8 d.f.)	1.2	1.2	0.2	5.9*	5.2*	0.1	0.0
M (1, 2 d.f.)	0.0	0.0	0.2	10.9	13.7	24.0*	25.6*
C x M (1, 8 d.f.)	0.9	0.3	1.0	4.6	3.2	0.0	0.0
K (1, 4 d.f.)	0.1	0.4	0.9	0.0	0.1	0.3	0.1
C x K (1, 8 d.f.)	0.0	0.4	0.0	7.3*	5.3*	0.7	0.7
M x K (1, 4 d.f.)	0.1	0.3	0.6	0.3	0.6	0.1	0.4
M x C x K (1, 8 d.f.)	0.2	0.6	1.4	0.4	0.5	1.0	1.2

Table 3-9 Continued

Treatment	Mean number (no.) and weight (kgs) per 20 tomato plants (SEM)						
	Unmarketable	Medium fruits		Large fruits		Extra-Large fruits	
	kgs	No	kgs	no	kgs	no	kgs
	Season Total 22-June-2011 and 30-June-2011						
B	11 ± 1	36 ± 3	4 ± 1	25 ± 3	4 ± 0	31 ± 6	7 ± 1
B/C	9 ± 2	36 ± 7	4 ± 1	20 ± 5	3 ± 1	34 ± 9	8 ± 2
B/K	11 ± 1	34 ± 7	4 ± 1	25 ± 3	4 ± 1	52 ± 6	12 ± 1
B/C/K	10 ± 1	48 ± 4	5 ± 1	37 ± 5	5 ± 1	53 ± 12	12 ± 3
R	11 ± 2	36 ± 5	4 ± 1	35 ± 4	5 ± 1	55 ± 9	13 ± 2
R/C	12 ± 1	42 ± 4	5 ± 1	46 ± 5	7 ± 1	84 ± 7	19 ± 2
R/K	11 ± 1	39 ± 0	5 ± 1	33 ± 5	5 ± 1	59 ± 28	13 ± 6
R/C/K	11 ± 2	46 ± 6	5 ± 1	52 ± 5	7 ± 1	65 ± 6	14 ± 1
	ANOVA F-value						
C (1, 8 d.f.)	0.5	4.8	2.1	13.6**	9.6*	2.7	2.4
M (1, 2 d.f.)	1.5	0.3	1.5	33.1*	29.1*	8.5	8.4
C x M (1, 8 d.f.)	1.2	0.0	0.3	5.3*	3.3	1.8	1.4
K (1, 4 d.f.)	0.1	1.7	2.3	4.4	3.6	0.6	0.3
C x K (1, 8 d.f.)	0.1	1.9	0.4	5.6*	3.5	1.3	1.3
M x K (1, 4 d.f.)	0.1	0.1	0.0	1.7	2.1	2.9	3.8
M x C x K (1, 8 d.f.)	0.4	1.2	2.3	0.8	0.6	0.9	0.6

[a]B indicates black mulch, K indicates kaolin, R indicates reflective mulch, C indicates companion plants.
[b]C indicates effect of companion plants, M indicates mulch effects, K indicates kaolin clay effects.
*, *P* < 0.05; **, *P* < 0.01; ***, *P* < 0.001

Table 3-10. Mean (± SEM) number and weight per 0.007-ha plot of medium, large, and extra-large tomato fruits harvested on 19, 26 June, and 12 July 2012and the respective ANOVA effects in the push-pull experiment conducted in Gadsden County, Florida.

Treatment	Mean number (no.) and weight (kgs) per 20 tomato plants (SEM)						
	Unmarketable	Medium fruits		Large fruits		Extra-Large fruits	
	kgs	no	kgs	no	kgs	no	kgs
	19-Jun-2012						
B[a]	2 ± 1	3 ± 1	0 ± 0	8 ± 4	1 ± 1	61 ± 11	14 ± 3
B/C	3 ± 1	4 ± 2	0 ± 0	12 ± 4	2 ± 1	62 ± 10	14 ± 2
B/K	3 ± 0	3 ± 2	0 ± 0	11 ± 1	2 ± 0	82 ± 15	19 ± 4
B/C/K	3 ± 0	8 ± 2	1 ± 0	16 ± 4	2 ± 1	83 ± 21	18 ± 5
R	4 ± 2	1 ± 1	0 ± 0	3 ± 1	0 ± 0	49 ± 20	12 ± 5
R/C	2 ± 0	5 ± 1	1 ± 0	9 ± 3	1 ± 0	66 ± 15	15 ± 4
R/K	3 ± 1	3 ± 2	0 ± 0	8 ± 2	1 ± 0	70 ± 22	17 ± 6
R/C/K	3 ± 1	4 ± 3	1 ± 0	13 ± 4	2 ± 1	63 ± 14	15 ± 4
ANOVA F-value							
C (1, 8 d.f.)[b]	0.4	6.7*	6.5*	6.0*	5.0*	0.1	0.0
M (1, 2 d.f.)	0.2	0.7	0.6	2.1	1.5	0.9	0.2
C x M (1, 8 d.f.)	0.1	0.1	0.1	0.1	0.3	0.1	0.0
K (1, 4 d.f.)	0.2	1.2	1.1	3.4	3.6	3.4	3.0
C x K (1, 8 d.f.)	0.3	0.2	0.1	0.0	0.0	0.5	0.7
M x K (1, 4 d.f.)	0.8	0.3	0.3	0.0	0.1	0.6	0.2
M x C x K (1, 8 d.f.)	1.6	2.3	2.5	0.1	0.0	0.6	0.5

Table 3-10. Continued.

Treatment	Mean number (no.) and weight (kgs) per 20 tomato plants (SEM)						
	Unmarketable	Medium fruits		Large fruits		Extra-Large fruits	
	kgs	no	kgs	no	kgs	no	kgs
	26-Jun-2012						
B	10 ± 2	16 ± 4	2 ± 0	52 ± 9	8 ± 1	112 ± 8	23 ± 2
B/C	8 ± 1	38 ± 13	4 ± 2	55 ± 7	9 ± 1	149 ± 12	30 ± 3
B/K	5 ± 0	17 ± 5	2 ± 1	51 ± 8	8 ± 1	155 ± 23	33 ± 6
B/C/K	8 ± 1	28 ± 7	3 ± 1	48 ± 9	9 ± 1	140 ± 14	28 ± 3
R	13 ± 4	19 ± 7	2 ± 1	32 ± 6	5 ± 1	128 ± 12	27 ± 3
R/C	10 ± 1	29 ± 8	3 ± 1	49 ± 9	8 ± 1	129 ± 25	28 ± 6
R/K	9 ± 1	20 ± 9	2 ± 1	36 ± 3	6 ± 0	151 ± 11	32 ± 3
R/C/K	10 ± 1	25 ± 7	3 ± 1	55 ± 5	8 ± 0	145 ± 27	30 ± 6
ANOVA F-value							
C (1, 8 d.f.)	0.1	10.5**	9.3*	7.1*	13.4**	0.1	0.0
M (1, 2 d.f.)	5.5	0.0	0.0	1.3	1.8	0.0	0.0
C x M (1, 8 d.f.)	0.2	1.5	1.3	7.0*	3.8	0.3	0.1
K (1, 4 d.f.)	4.2	0.3	0.3	0.0	0.2	2.1	1.6
C x K (1, 8 d.f.)	2.9	1.0	0.9	0.1	1.5	1.4	1.5
M x K (1, 4 d.f.)	0.1	0.1	0.1	0.8	0.1	0.0	0.0
M x C x K (1, 8 d.f.)	0.0	0.1	0.1	0.3	0.9	0.8	0.6

Table 3-10. Continued.

Treatment	Mean number (no.) and weight (kgs) per 20 tomato plants (SEM)						
	Unmarketable	Medium fruits		Large fruits		Extra-Large fruits	
	kgs	no	kgs	no	kgs	no	kgs
	12-Jul-12						
B	7 ± 2	31 ± 4	3 ± 1	26 ± 10	4 ± 2	30 ± 14	6 ± 3
B/C	7 ± 1	33 ± 8	4 ± 1	26 ± 7	4 ± 1	28 ± 12	6 ± 2
B/K	7 ± 1	37 ± 10	4 ± 1	46 ± 9	7 ± 1	44 ± 6	9 ± 1
B/C/K	8 ± 1	28 ± 7	3 ± 1	33 ± 13	5 ± 2	38 ± 24	8 ± 5
R	12 ± 2	53 ± 23	6 ± 3	50 ± 20	7 ± 2	52 ± 23	11 ± 5
R/C	10 ± 2	35 ± 12	4 ± 1	32 ± 4	6 ± 1	37 ± 16	8 ± 3
R/K	9 ± 1	29 ± 4	3 ± 1	33 ± 5	5 ± 1	49 ± 14	10 ± 3
R/C/K	9 ± 2	29 ± 11	3 ± 1	32 ± 16	5 ± 2	36 ± 23	7 ± 4
ANOVA F-value							
C (1, 8 d.f.)	0.6	0.9	0.8	1.9	1.5	1.7	2.0
M (1, 2 d.f.)	9.0	0.4	0.4	0.3	0.2	0.2	0.2
C x M (1, 8 d.f.)	0.4	0.2	0.3	0.1	0.1	0.5	0.7
K (1, 4 d.f.)	0.9	1.2	1.0	0.1	0.1	0.6	0.4
C x K (1, 8 d.f.)	0.5	0.0	0.1	0.0	0.0	0.0	0.0
M x K (1, 4 d.f.)	2.6	1.3	1.2	2.0	2.8	1.0	1.2
M x C x K (1, 8 d.f.)	0.2	1.2	1.2	1.7	0.7	0.1	0.0

Table 3-10. Continued.

Treatment	Mean number (no.) and weight (kgs) per 20 tomato plants (SEM)						
	Unmarketable	Medium fruits		Large fruits		Extra-Large fruits	
	kgs	no	kgs	no	kgs	no	kgs
	Season total June 19, 26, and July 12 2012						
B	19 ± 2	50 ± 1	5 ± 0	86 ± 4	13 ± 0	203 ± 5	44 ± 2
B/C	17 ± 1	75 ± 8	8 ± 1	93 ± 6	14 ± 1	239 ± 10	50 ± 2
B/K	16 ± 1	57 ± 9	6 ± 1	108 ± 5	17 ± 1	281 ± 31	61 ± 8
B/C/K	18 ± 2	64 ± 10	7 ± 1	97 ± 13	16 ± 2	261 ± 31	55 ± 7
R	29 ± 4	73 ± 23	8 ± 3	85 ± 24	12 ± 3	229 ± 13	50 ± 4
R/C	23 ± 2	69 ± 3	8 ± 0	89 ± 9	15 ± 1	231 ± 24	51 ± 6
R/K	20 ± 2	52 ± 8	6 ± 1	77 ± 1	13 ± 0	270 ± 28	60 ± 8
R/C/K	21 ± 2	58 ± 6	7 ± 1	99 ± 17	15 ± 2	244 ± 24	51 ± 4
ANOVA F-value							
C (1, 8 d.f.)	1.0	1.3	1.4	0.8	2.2	0.0	0.2
M (1, 2 d.f.)	15.4	0.1	0.1	0.6	1.1	0.0	0.0
C x M (1, 8 d.f.)	0.8	1.0	1.2	1.3	2.1	0.4	0.2
K (1, 4 d.f.)	4.4	1.4	1.2	0.4	0.8	5.9	4.2
C x K (1, 8 d.f.)	4.1	0.1	0.0	0.0	0.8	1.7	1.9
M x K (1, 4 d.f.)	2.2	0.8	0.8	0.3	1.1	0.5	0.5
M x C x K (1, 8 d.f.)	0.5	0.9	0.7	1.9	0.1	0.2	0.1

[a] B indicates plants planted on black mulch, C indicates companion plants, K indicates kaolin clay and R indicates plants planted on reflective mulch.
[b]C indicates effect of companion plants, M indicates mulch effects, K indicates kaolin clay effects.
*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$;

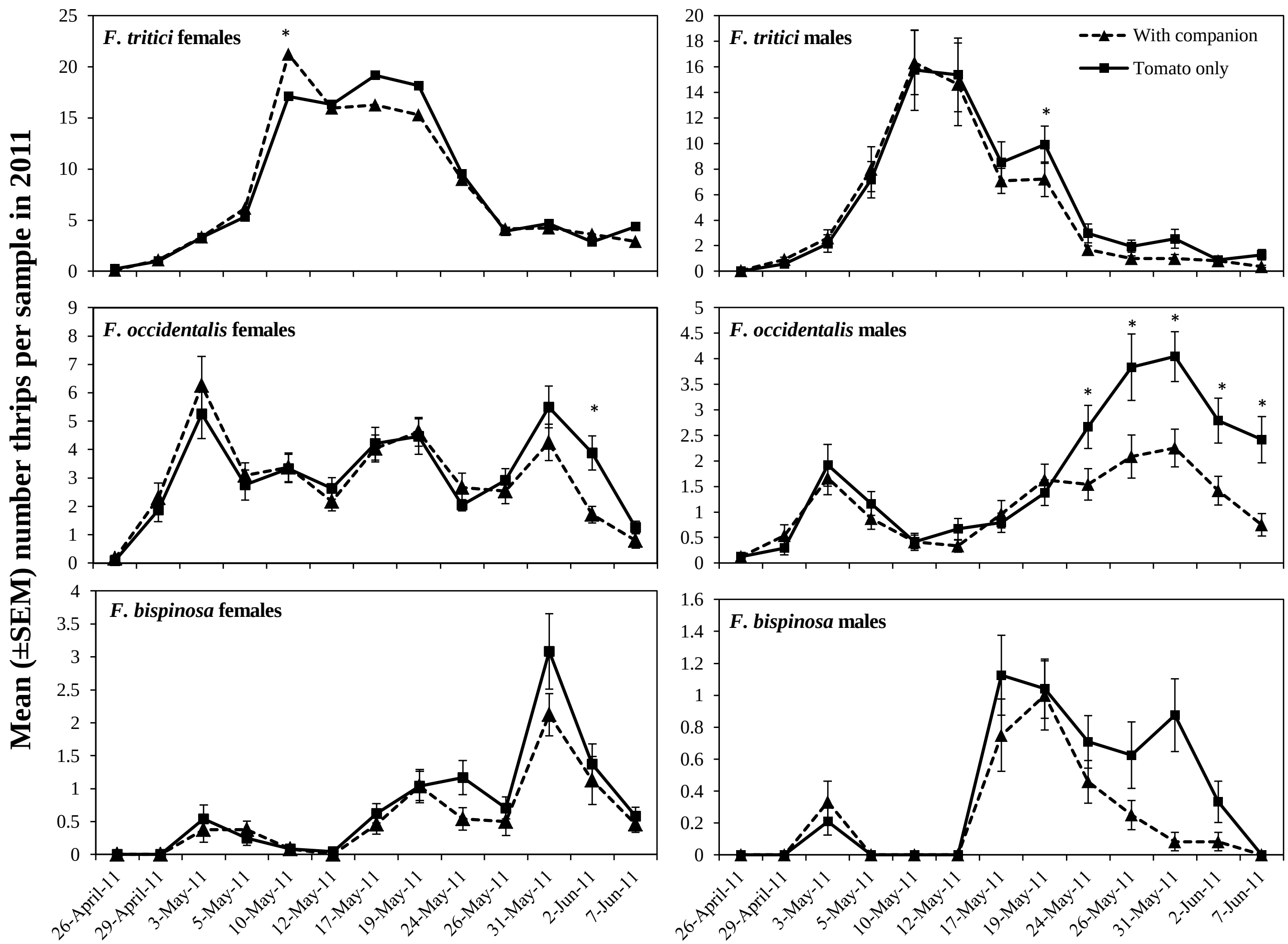


Figure 3-1. Seasonal variations in the mean (±SEM) number of adult thrips found in tomato flowers in plots with and without companion plantings of *B. alba* in the experiment conducted in Gadsden county, Florida in 2011.

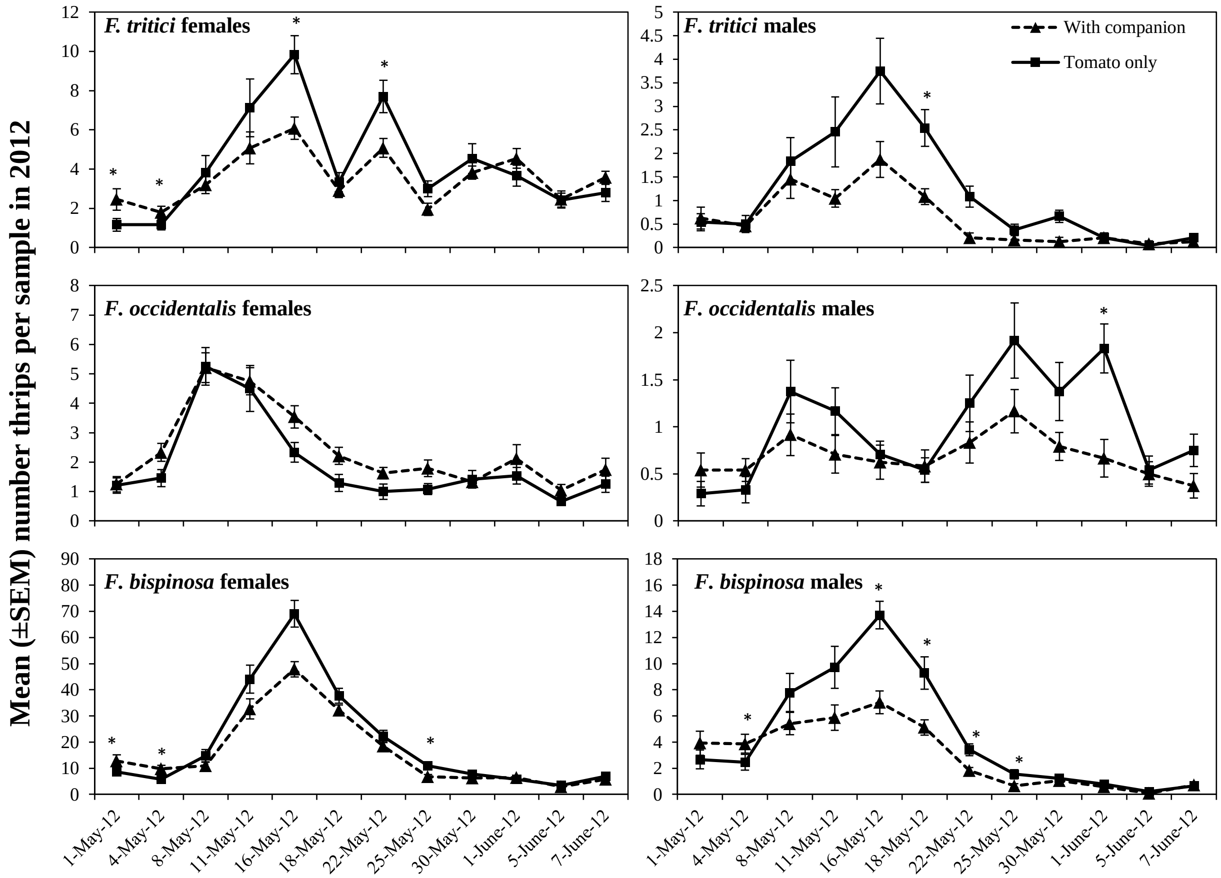


Figure 3-2. Seasonal variations in the mean (±SEM) number of adult thrips found in tomato flowers in plots with and without companion plantings of *B. alba* in the experiment conducted in Gadsden county, Florida in 2012.

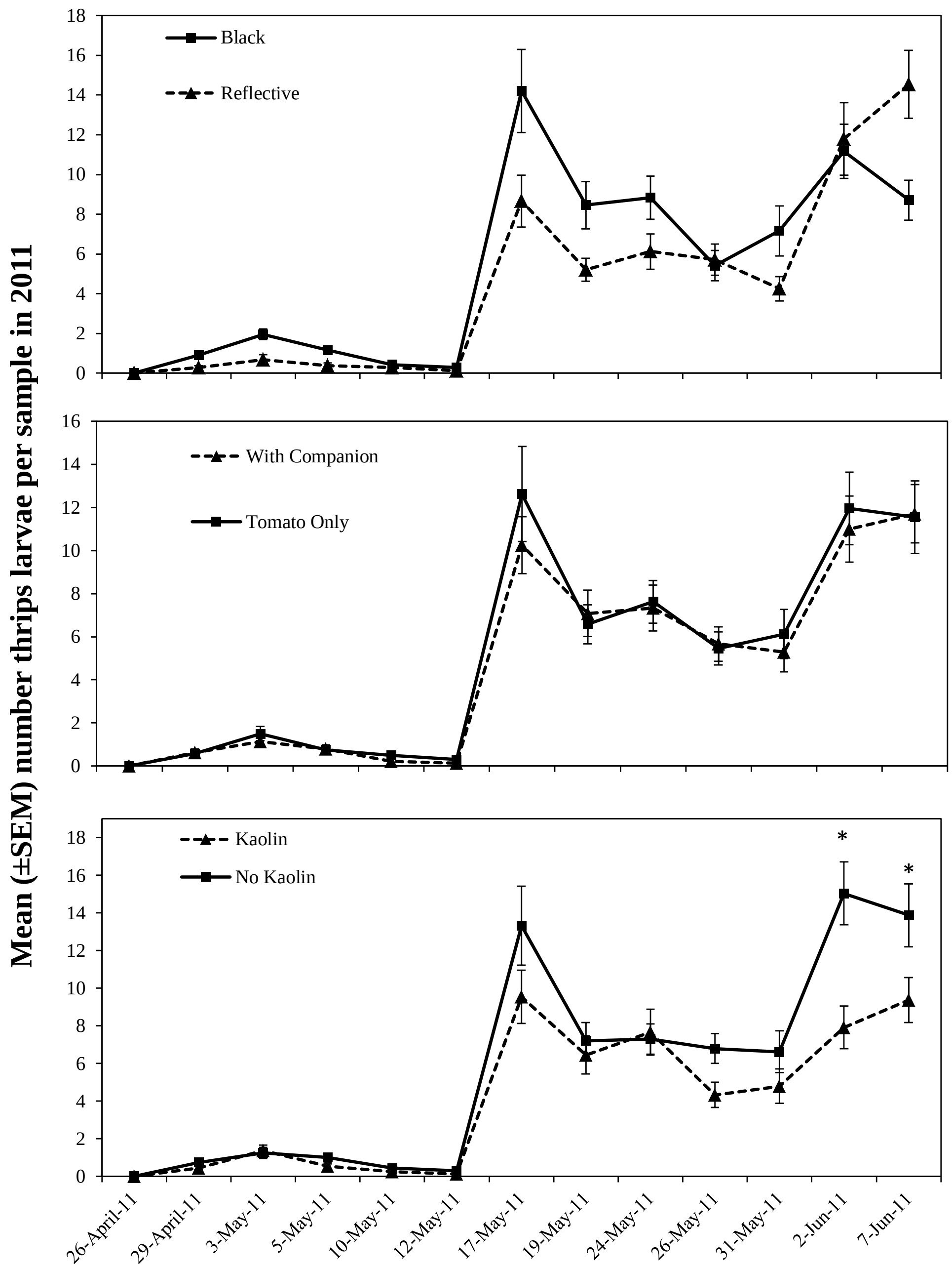


Figure 3-3**.** Seasonal variations in the mean (±SEM) number of larval thrips found in tomato flowers in plots with black or reflective mulch, with and without companion plantings of *B. alba*, and with or without kaolin clay in the experiment conducted in Gadsden county, Florida in 2011.

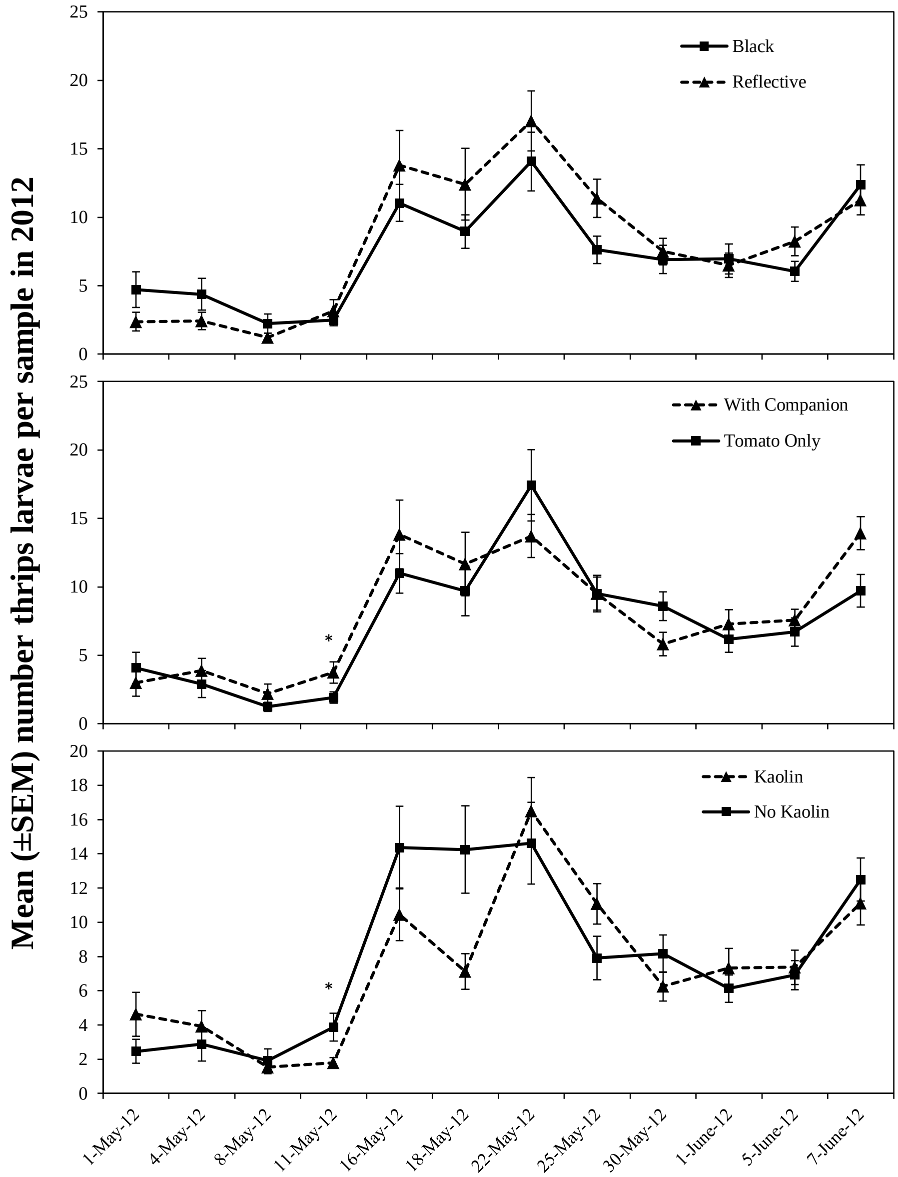


Figure 3-4**.** Seasonal variations in the mean (±SEM) number of larval thrips found in tomato flowers in plots with black or reflective mulch, with and without companion plantings of *B. alba*, and with or without kaolin clay in the experiment conducted in Gadsden county, Florida in 2012.

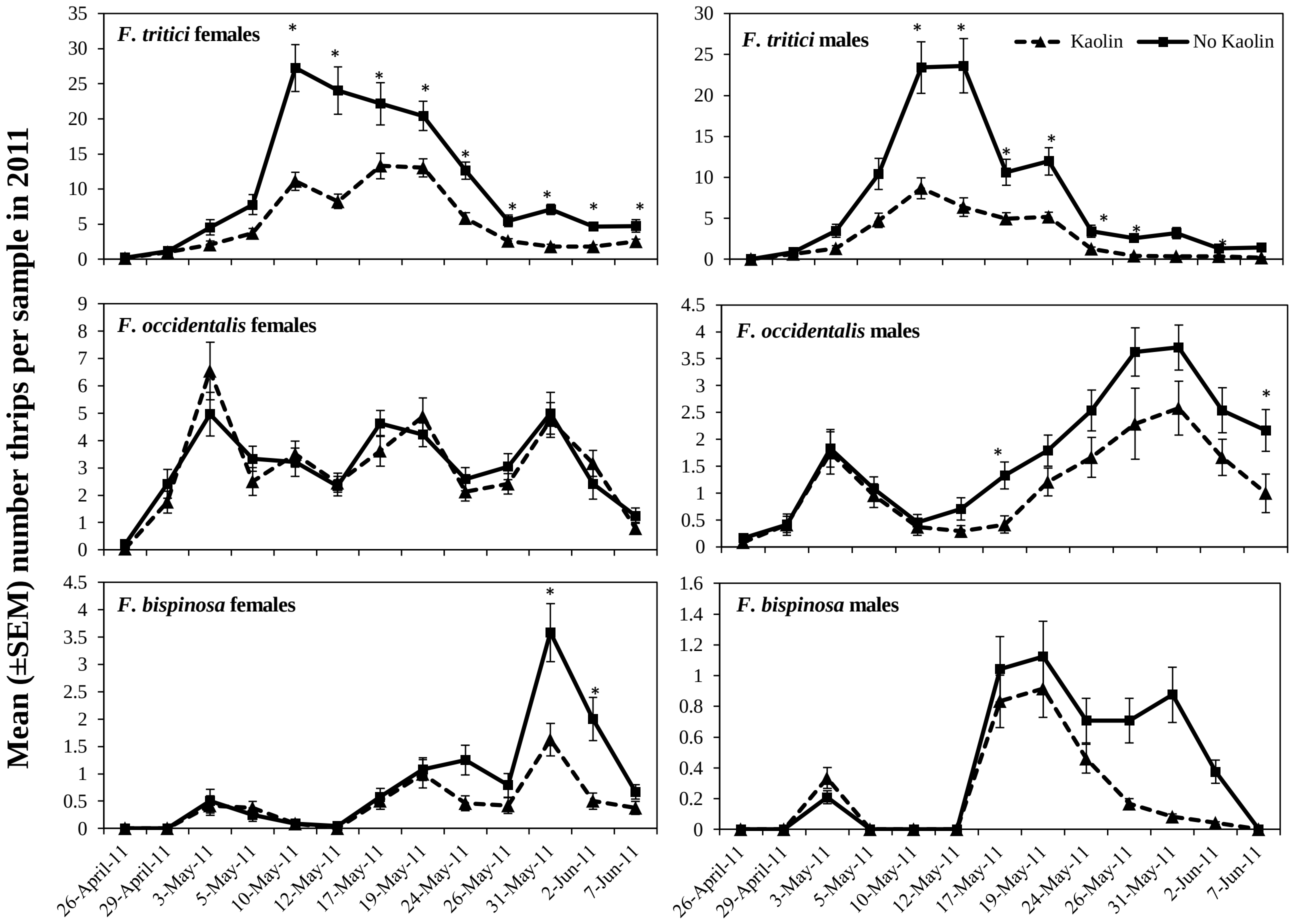


Figure 3-5. Seasonal variations in the mean (±SEM) number of adult thrips found in tomato flowers in plots with and without applications of kaolin clay in the experiment conducted in Gadsden county, Florida in 2011.

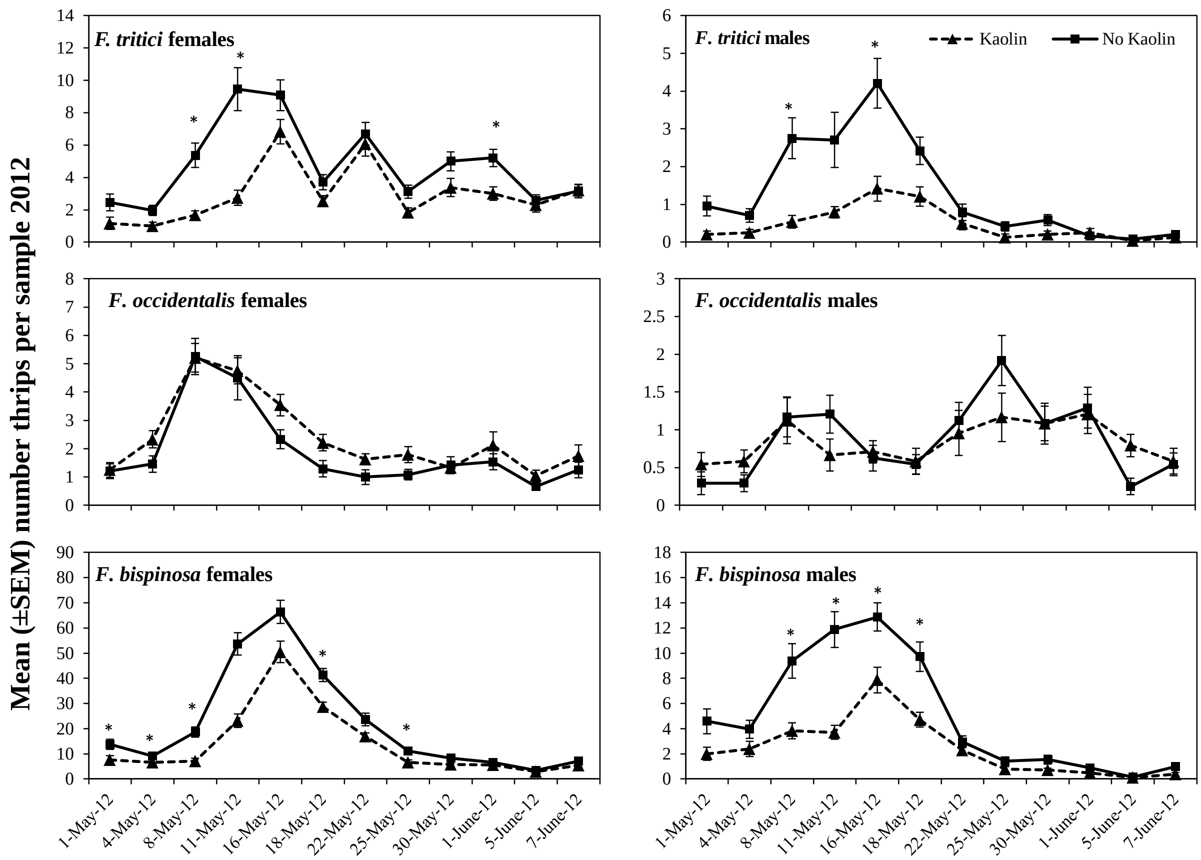


Figure 3-6. Seasonal variations in the mean (±SEM) number of adult thrips found in tomato flowers in plots with and without applications of kaolin clay in the experiment conducted in Gadsden county, Florida in 2012.

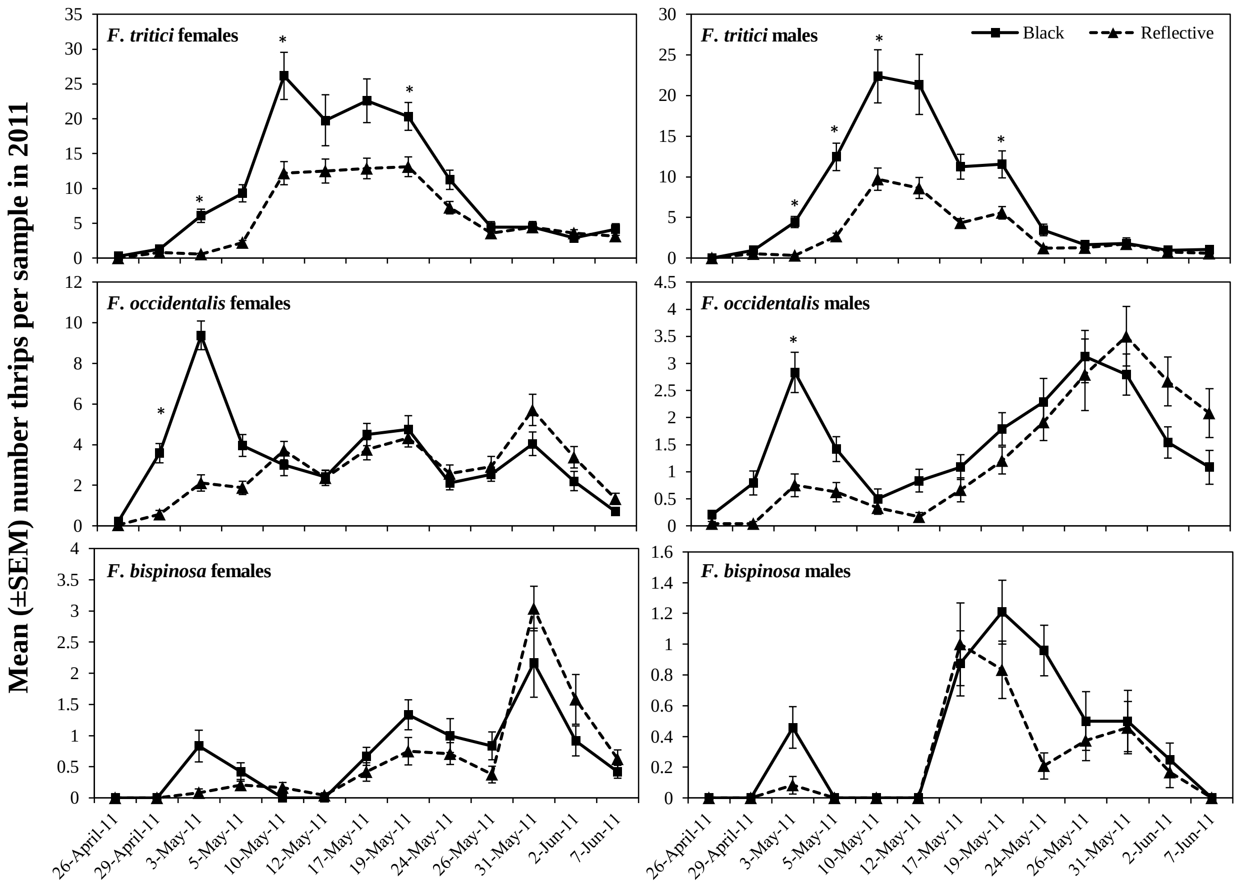


Figure 3-7. Seasonal variations in the mean (±SEM) number of adult thrips found in tomato flowers in plots with ultraviolet-reflective or black mulch in the experiment conducted in Gadsden county, Florida in 2011.

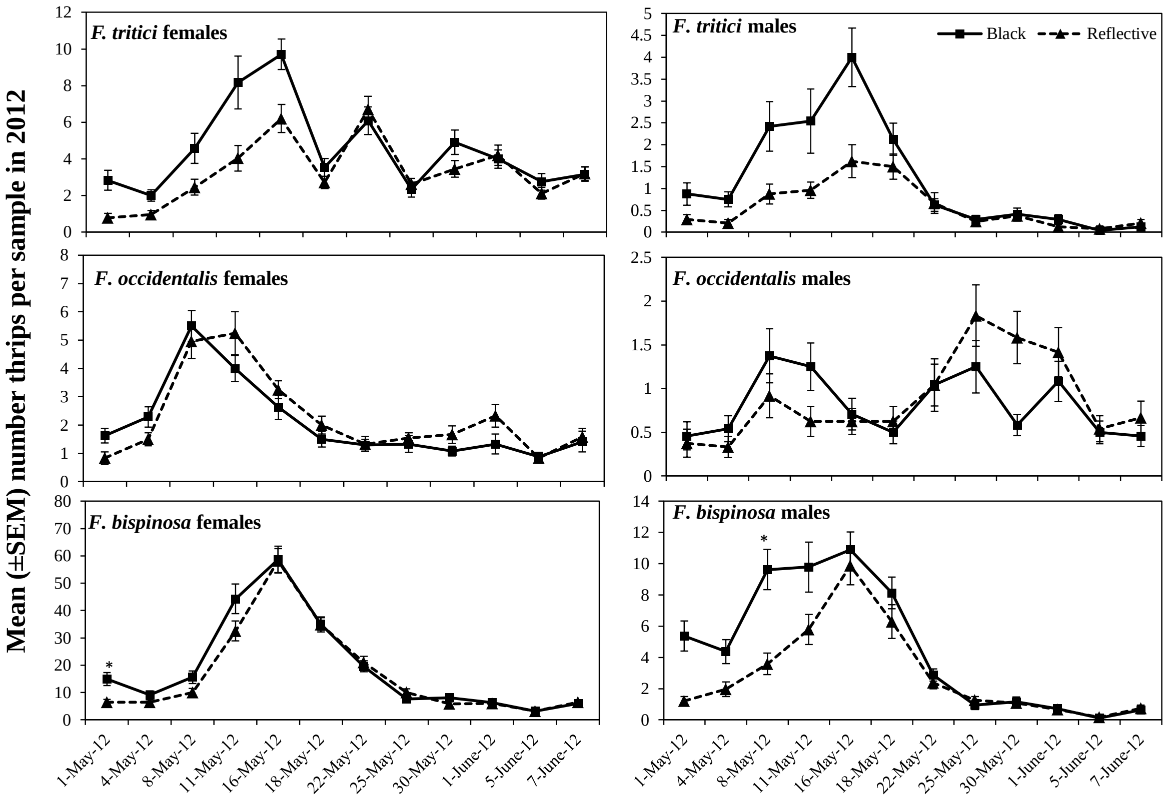


Figure 3-8. Seasonal variations in the mean (±SEM) number of adult thrips found in tomato flowers in plots with ultraviolet-reflective or black mulch in the experiment conducted in Gadsden county, Florida in 2012

CHAPTER 4
AN EVALUATION OF A PUSH-PULL METHOD TO MANAGE *TOMATO SPOTTED WILT VIRUS* ON TOMATOES IN NORTH FLORIDA.

Introduction

In Florida, the western flower thrips (*Frankliniella occidentalis* Pergande) is an invasive species of thrips which injures leaves, fruits and flowers of multiple vegetable crops (Childers 1997) and vectors *Tomato spotted wilt virus* (OEPP/EPPO 2004). The loss to farmers from Tomato spotted wilt is estimated at $1 billion annually (Goldbach and Peters 1994). In the past and present, farmers have dealt with thrips and other pests using multiple applications of broad-spectrum pesticides. The use of broad-spectrum insecticides does not always alleviate the problem and instead interferes with the natural control of thrips by the minute pirate bug (*Orius insidiosus*) causing an increase in the numbers of *F. occidentalis* (Funderburk et al. 2000). Additionally, *F. occidentalis* has the propensity to quickly develop resistance to many classes of pesticides (Gao et al. 2012). Several technologies have been developed which circumvent the issues associated with pesticide use while still decreasing pest populations, reducing disease incidence, and increasing yield. These technologies include, but are not limited to: spinosads and other new insecticides (Funderburk 2009); ultraviolet-reflective mulch technologies (Stavisky et al. 2002, Reitz et al. 2003); the use of companion plants (Kasina et al. 2006, Lopez and Shepard 2007); particle films such as kaolin clay (Glenn et al. 1999, Spiers et al. 2004); and biocontrol using natural enemies, such as *O. insidiosus* (Funderburk et al. 2000).

A recently developed technology, called the push-pull or stimulo-deterrent method, combines both repellant plants and attractive plants in a field to repel pest insects from the crop and attract them to a non-crop plant on which they are controlled (Khan et al. 2001). This method was effective in reducing damage to maize plants from stemborers in Kenya and may be promising for use with other crops and pests. The current study evaluates a new push-pull methodology to reduce thrips numbers and the incidence of Tomato spotted wilt on tomatoes. This method combines ultraviolet-reflective mulch (push), kaolin clay sprays (push) and companion plants (pull) to deter thrips and attract natural predators.

Materials and Methods

Experiments were conducted in North Florida in the spring of 2011 and 2012 using ‘Florida 47’ tomato (*Solanum lycopersicum*) and companion plants of Spanish needles (*Bidens alba*).

Six-week-old tomato plants and Spanish needle plants were transplanted in late March each year. The plants were produced on raised beds 10 cm in height and 91.4 cm in width with beds spaced 1.83 m and treated before mulch application with Dual Magnum® (Syngenta Crop Protection LLC, Greensboro, NC 27419) at 1.2 kg active ingredient per ha for weed control. A trickle-tube placed 15 cm off center under the mulch was used to irrigate based on plant needs. Plots were fertilized with 204, 29, and 170 kg/ha of N, P, and K, respectively. Pesticides to control other pests such as armyworms were applied on an as-needed basis.

A randomized complete block split-split-plot design was used. Whole-plot treatments consisted of ultraviolet-reflective mulch and black polyethylene mulch (Berry Plastics Corp., Evansville, IN), subplot treatments consisted of Surround WP® Kaolin clay (Engelhard Corp., Iselin, NJ) applications and a control, and sub-sub-plot treatments consisted of companion plantings of Spanish needles and a control. Kaolin clay was applied two times per week as a spray at a rate of 14 kg per ha. There were three replicates in this experiment with a total of 80 tomato plants per sub-sub-plot.

Each plant in each plot was examined weekly for visual symptoms of Tospovirus infection. Leaf samples were taken from any plant displaying visual symptoms. Infection was verified by testing leaf samples with ImmunoStrips® (Agdia, Elkhart, IN). Plants showing no visual symptoms were tested as negative controls. Proportions of Tomato spotted wilt were transformed with arcsine square-root transformations to improve homogeneity of variance before analyses were conducted. Differences in the cumulative incidence of Tomato spotted wilt between treatments were analyzed over date with ANOVA using the GLIMMIX procedure (SAS Institute 2008).

Results and Discussion

In 2011, the mean seasonal incidence ($\pm$SEM) of Tomato spotted wilt per plot was 5.2±1.0%. In the 2011 season the most common thrips found on the tomato plants was *F. tritici*, with *F. occidentalis* being the second most numerous thrips and *F. bispinosa* occurring rarely.

In 2012, by contrast, the mean seasonal incidence ($\pm$SEM) of Tomato spotted wilt per plot was much lower, at 1.1±0.3%. During 2012 the most common thrips species found was *F. bispinosa*, followed by *F. tritici,* with *F. occidentalis* occurring very rarely. The 2012 season followed a very mild and warm winter which may have allowed *F. bispinosa* to survive and out-compete *F.*

occidentalis which resulted in lower incidence of Tomato spotted wilt in our experimental plots.

The results of the ANOVAs for the 2011 and 2012 experiments are shown in Tables 4-1 and 4-2, respectively. Companion plants had a significant effect on the cumulative incidence of Tomato spotted wilt on the final two dates. The presence of companion plantings significantly reduced the seasonal incidence of Tomato spotted wilt in 2011, and while not significant, such plantings also reduced Tomato spotted wilt incidence in 2012 (Fig. 4-1). The lack of significance in 2012 was likely due to the low disease pressure during that season. Overall, these results have practical significance to growers wishing to reduce incidence of disease in their fields. The reasons for this reduction may be twofold: the first is that thrips were attracted to the companion plant reducing the numbers of thrips feeding and ovipositing on the tomatoes. The second possible explanation is that the companion plant attracted natural predators of thrips to the field, thereby increasing predation and decreasing the number of thrips. Previous studies have found support for the second explanation with the use of intercrops to attract predators of thrips (Kasina et al. 2006, Lopez and Shepard 2007, Frantz and Mellinger 2009, Nyasani et al. 2012).

The use of ultraviolet-reflective mulch reduced incidence of Tomato spotted wilt in the fields in both seasons, with significant reductions occurring on the fourth and fifth dates in 2011 (Fig 4-2.). Ultraviolet-reflective mulch disrupts the ability of thrips to find their hosts resulting in a reduction of thrips alighting on the plants, and a reduction in the spread of disease to these plants. Our results are in agreement with previous studies, which found significant reductions in the incidence of Tomato spotted wilt on ultraviolet-reflective mulch compared to black mulch (Greenough et al. 1990, Reitz et al. 2003).

Applications of the kaolin clay particle film also resulted in lower incidence of Tomato spotted wilt in the tomatoes. This effect, while not statistically significant, was observed in both years of the experiment (Fig. 4-3). Kaolin clay forms a protective barrier on the plant which reduces heat stress and is deterrent to thrips and other insects. Kaolin clay also deters thrips from onions (Larentzaki et al. 2008) and blueberries (Spiers et al. 2004) and significantly decreased incidence of disease in another study (Reitz et al. 2008). It may be that the thrips cannot grip plants through the clay, are deterred from feeding by the texture of the clay, or may be visually deterred from the plants by increased ultraviolet-reflection resulting from the white layer of film.

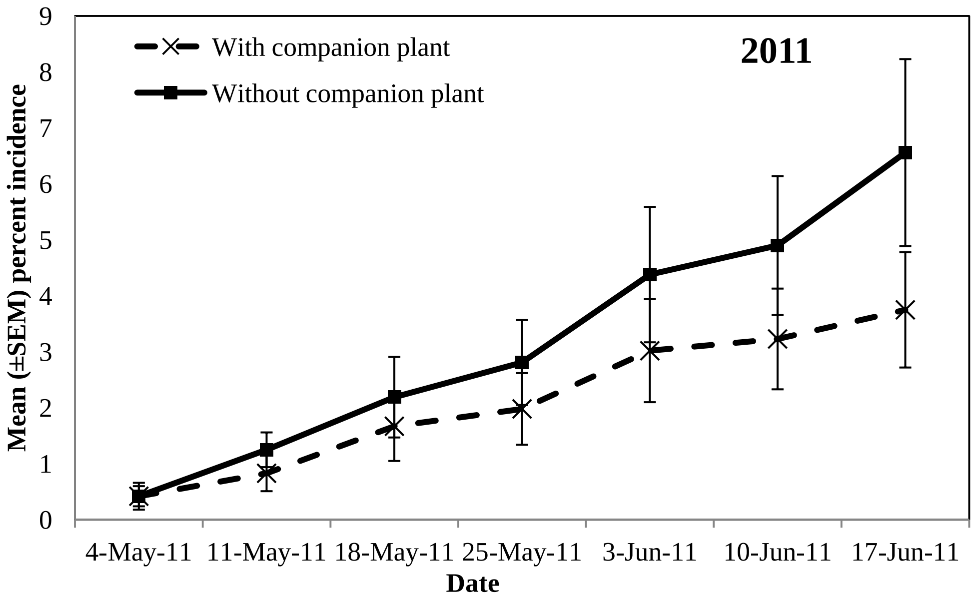
The results of our study provide evidence to support the use of ultraviolet-reflective mulch, kaolin clay, and Spanish needle companion plants either alone or in various combinations to reduce the numbers of thrips and the incidence of Tomato spotted wilt on tomatoes. Additionally, these methods can be combined with pesticides and other cultural control methods to increase the efficacy of an integrated pest management program.

Table 4-1. ANOVA values for the effects of companion plants, kaolin clay, mulch types, and their interactions on the incidence of Tomato spotted wilt in tomatoes in the experiment conducted in Gadsden County, Florida in 2011.

ANOVA treatment effect		*F*-value, *p*-value						
	d.f.	4-May-11	11-May-11	18-May-11	25-May-11	3-Jun-11	10-Jun-11	17-Jun-11
Companion plant	1, 8	0.05, 0.83	1.84, 0.21	0.79, 0.41	1.13, 0.32	3.46, 0.10	5.96, 0.04	6.83, 0.03
Mulch	1, 2	1.67, 0.33	12.25, 0.07	16, 0.06	32.38, 0.03	16.89, 0.05	13.32, 0.07	6.44, 0.13
Companion plant*Mulch	1, 8	0.05, 0.83	0.32, 0.59	0, 0.99	0.13, 0.73	0.13, 0.73	0.15, 0.71	0.01, 0.91
Kaolin	1, 4	0.95, 0.38	0.8, 0.42	0.74, 0.44	0.57, 0.49	0.62, 0.47	0.69, 0.45	0.35, 0.58
Companion plant*Kaolin	1, 8	0.29, 0.61	0.05, 0.82	0.28, 0.61	0.2, 0.67	0.29, 0.61	0.19, 0.67	1.15, 0.32
Mulch*Kaolin	1, 4	0.29, 0.62	0.01, 0.93	0.24, 0.65	0.1, 0.77	2, 0.23	1.67, 0.27	1, 0.37
Companion plant*Mulch*Kaolin	1, 8	0.29, 0.61	0.32, 0.59	0.14, 0.72	0.18, 0.68	0.17, 0.69	1, 0.35	1.07, 0.33

Table 4-2. ANOVA values for the effects of companion plants, kaolin clay, mulch types, and their interactions on the incidence of Tomato spotted wilt in tomatoes in the experiment conducted in Gadsden County, Florida in 2012.

ANOVA treatment effect	d.f.	*F*-value, *p*-value				
		11-May-12	18-May-12	25-May-12	28-May-12	8-Jun-12
Companion plant	1, 8	1, 0.35	0.07, 0.80	0.17, 0.69	0.89, 0.38	2.39, 0.16
Mulch	1, 2	1, 0.43	1.08, 0.41	0.75, 0.48	1.04, 0.41	0.53, 0.54
Companion plant*Mulch	1, 8	1, 0.35	0.97, 0.35	4.12, 0.08	2.93, 0.13	2.61, 0.15
Kaolin	1, 4	1, 0.37	3.6, 0.13	1.13, 0.35	0.49, 0.53	2.21, 0.21
Companion plant*Kaolin	1, 8	1, 0.35	0.07, 0.80	1.5, 0.26	0.89, 0.37	1.11, 0.32
Mulch*Kaolin	1, 4	1, 0.37	1.08, 0.36	0.13, 0.74	0.01, 0.91	0.11, 0.75
Companion plant*Mulch*Kaolin	1, 8	1, 0.35	0.97, 0.35	0.17, 0.69	0.02, 0.88	1.63, 0.24



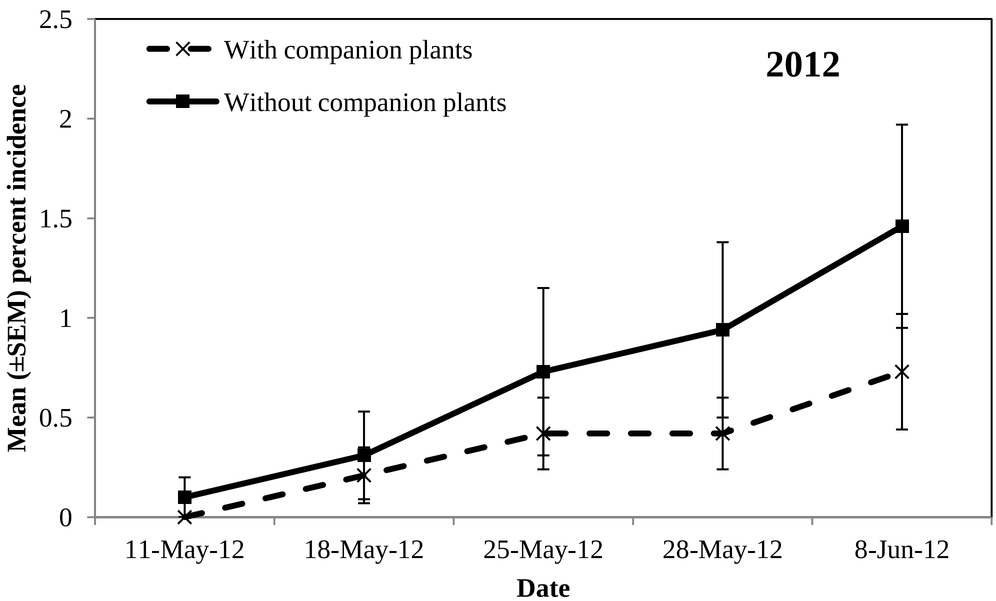


Figure 4-1. Mean percent incidence of Tomato spotted wilt in tomato plots in 2011 and 2012 in plots with and without companion plants in the experiment conducted in Gadsden county, Florida.

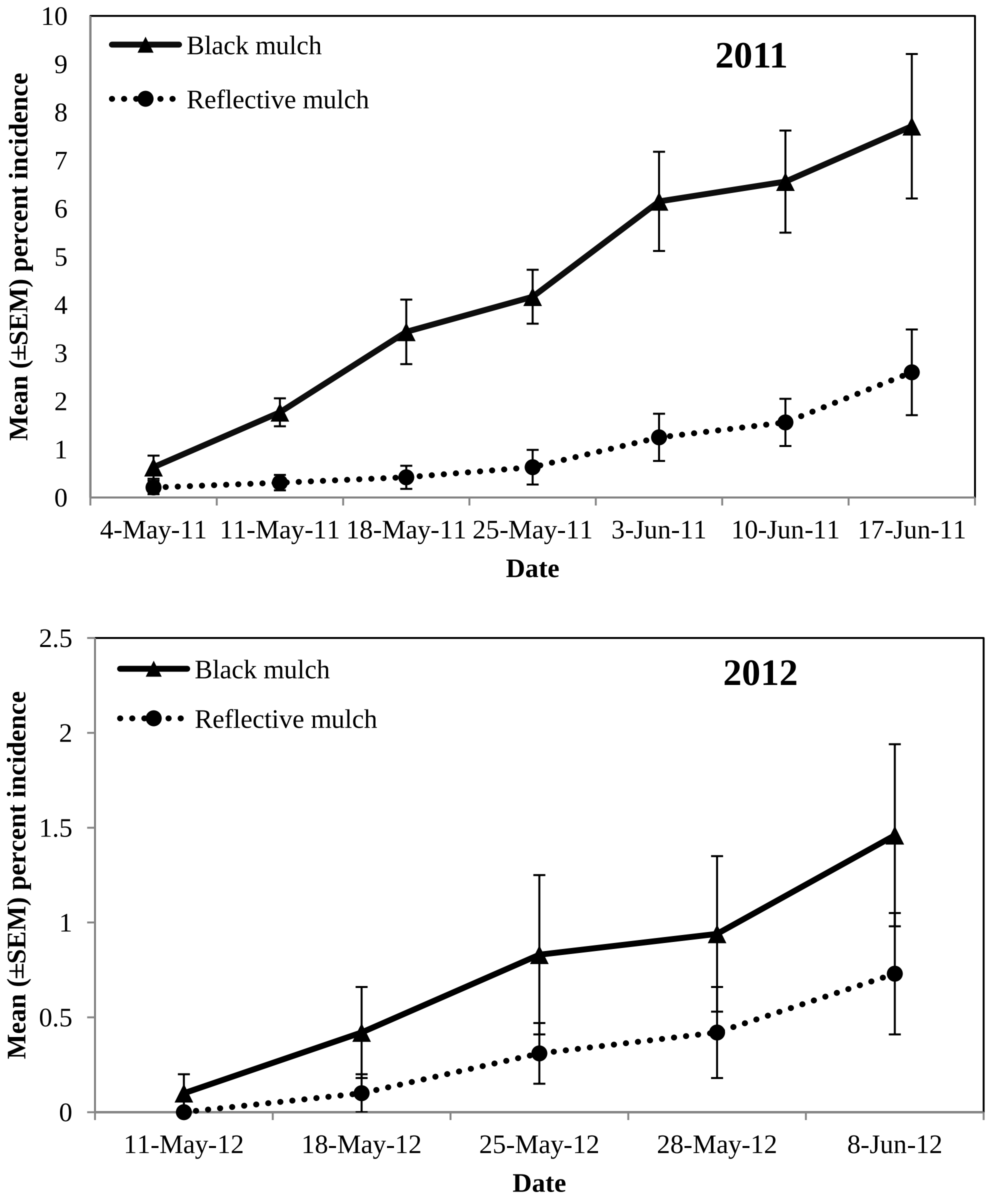


Figure 4-2. Mean percent incidence of Tomato spotted wilt in tomato plots in 2011 and 2012 for each mulch type.

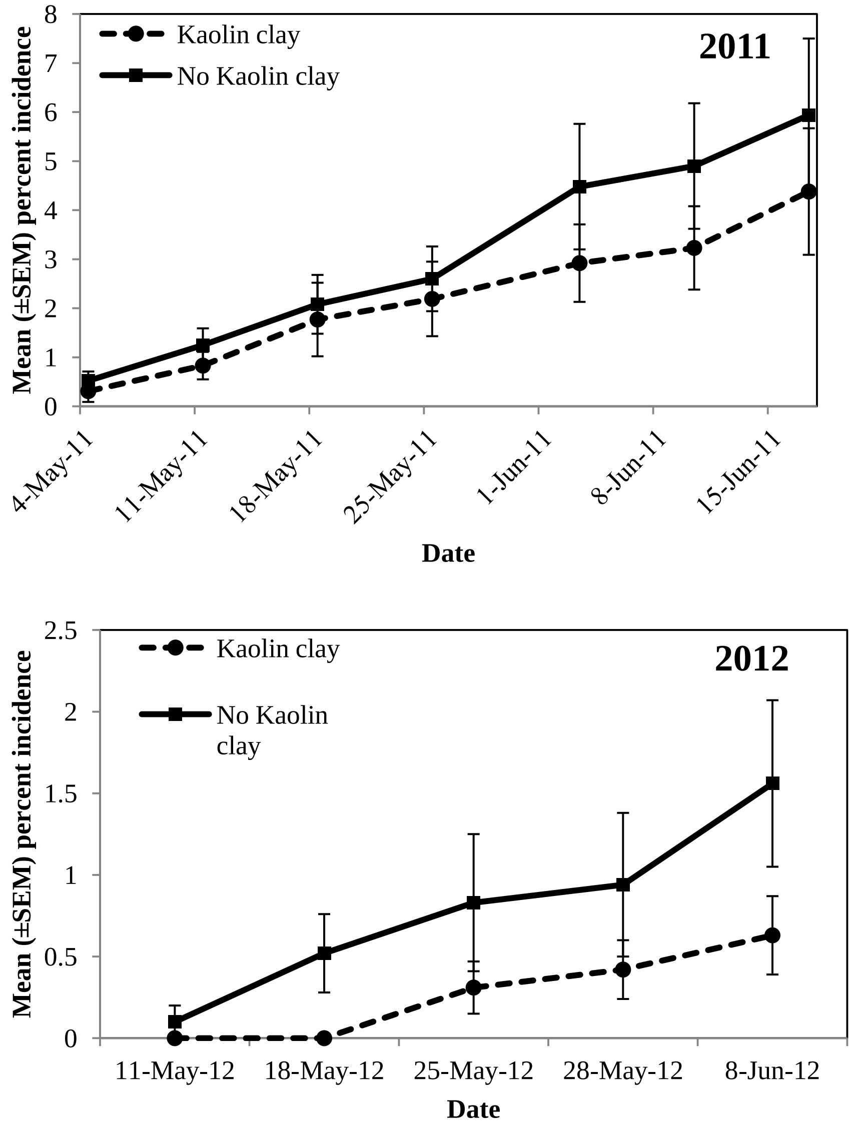


Figure 4-3. Mean percent incidence of Tomato spotted wilt in tomato plots in 2011 and 2012 in plots that did or did not receive applications of kaolin clay.

CHAPTER 5
CONCLUSIONS AND FUTURE DIRECTIONS

Recent outbreaks of *F. occidentalis* which are resistant to numerous classes of insecticides have led to outbreaks or Tomato spotted wilt and other Tospoviruses in Florida. In response to this crisis, and in response to a changing consumer climate with higher demands of organic produce and sustainability, a novel push pull method of thrips and Tospovirus management was evaluated. This method was tested on tomatoes and peppers using two different companion plants.

The three components involved in this method displayed separate and interactive effects on thrips populations, disease, and yield. Kaolin provides the greatest level of thrips control in peppers, and ultraviolet-reflective mulch also reduced thrips numbers in peppers. However, both of these components may interfere with natural predation and kaolin should be stopped mid-season to allow predators to return to fields to suppress thrips naturally. Both of these components lead to increased yield. Sunflower and *B. alba* companion plants increased thrips numbers early in the season with reductions occurring later. Unfortunately sunflowers did not increase yield whereas *B. alba* did increase yield of tomatoes. Ultraviolet-reflective mulch also increased yield of tomatoes while the effects of kaolin on tomato yield were inconsistent. Ultraviolet-reflective mulch and *B. alba* companion plants both significantly reduce Tomato spotted wilt incidence in tomatoes. Kaolin also decreases this incidence, though not significantly.

Consistent effects suggest the ultraviolet-reflective mulch and *B. alba* companion plants reduce thrips numbers, increase yield and reduce disease incidence significantly. Kaolin reduces thrips consistently but does not have consistent or predictable effects on disease or yield. While thrips and disease reduction are desirable, future investigations into this method need to determine the economics of the various combinations of this system. Ideally these economic analyses would evaluate the costs of these components compared with the cost of buying and using pesticides and the resulting revenue from yield from each of those alternatives. Growers would greatly benefit from this information and would be better able to make a beneficial choice.

Future studies should also test other species of companion plants as possibilities for the two crops. In addition to other species of companion plants, different landscape designs need to be evaluated to determine the appropriation of land needed for these plants to be effective. Whether the plants would be more effective in between rows, along roads and ditches or directly in between plants is useful information that is lacking. The effects on these companion plants on other pest species, natural enemies and pollinators should also be researched to determine its compatibility with other ecosystem services and vertically integrated pest management systems.

Additionally, evaluating these components side by side with traditional pest management strategies in years and areas with different disease pressure would be highly informative. This method needs also to be evaluated while operating at larger scales such as on larger commercial farms. Results from investigations such as these could provide valuable information to be presented to extension agents and directly to growers. Information alone is helpful, however, an even more crucial component is education and extension. Persuading growers to change their own pest management programs to such a new method will be difficult, to say the least. Partnerships with extension agents, influential growers and crop consultants will be key to pushing the implementation of this new method on Florida farms. Although it may be difficult, this method is flexible to many crop, pest, and climate situations in addition to being organic and sustainable. Growers can experiment with these components on their own farms and apply pesticides when needed, if the method does not appear to be effective for their situation.

Although there are still facets of this method to be investigated, and although the implementation of this method on commercial farms will be difficult, it will be worth it. The reduction in chemicals entering our food system and waterways, the reduction in pesticide-resistance, and the reduction in environmental degradation make the challenge well worth it. I hope the results of this thesis will encourage growers to try these methods on their farms and will encourage more research into alternatives to pesticides for controlling insect pests in agricultural systems in Florida.

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BIOGRAPHICAL SKETCH

Kara Tyler-Julian was born in Exeter, New Hampshire. She was raised in Land O' Lakes, Florida. She obtained her Bachelor of the Arts from New College of Florida in 2009 where she studied behavior of the Florida Manatee. She married her husband, Paul Julian II, an environmental scientist in 2009. In graduate school she studied Integrated Pest Management and all aspects of Thysanoptera. She will obtain her Master of Science in 2013.