DEVELOPING IPM STRATEGIES FOR CONTROL OF TWOSPOTTED SPIDER MITES IN STRAWBERRIES IN NORTH-CENTRAL FLORIDA

By

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The effects of soil moisture and temperature on the reproduction of twospotted spider mite (TSSM), *Tetranychus urticae* Koch (Acari: Tetranychidae), were examined in laboratory and field studies in strawberries, *Fragaria x ananassa* Duchesne, in Florida. Low, moderate and high soil moisture levels were compared to determine how soil moisture affects the reproductive rates of TSSM. Similar studies were conducted to determine how various temperatures (18, 27 and 35°C) affect the reproductive rates of TSSM. In the laboratory, low soil moisture as well as temperatures above 27°C promotes TSSM development. In addition to soil moisture levels, two irrigation techniques (drip versus drip and overhead) were studied to determine their effects on TSSM populations as well as plant response. Irrespective of moisture levels, significantly more TSSMs as well as diseases were recorded in treatments that had a combination of drip and overhead irrigation.

The direct and residual effects of several miticides were examined in laboratory studies against *Neoseiulus californicus* McGregor, *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) and TSSMs. Five treatments that included fenbutatin-oxide (Vendex®), binfenazate (Acramite 50WP®), Repel®, an organic oil (Wipeout®) and a water-treated control were tested on TSSM on strawberry leaf discs while the residual effects of Vendex® and Acramite® were evaluated against predatory mites on whole strawberry plants. Acramite® was the most effective miticide against TSSM resulting in an 85% decrease in motile population with no egg production after one week. Vendex® and Wipeout® achieved a 70% decrease in motile population with limited egg production. Repel® showed a 50% decrease in motile population but egg production increased. *Neoseiulus californicus* was more susceptible to Vendex® and Acramite® when compared with *P. persimilis*.

Two strawberry growers in Alachua county with different production practices were studied to monitor abundance and distribution of TSSM on their farms. Farm A applied pesticides and water "as-needed" while farm B had a set spray schedule and watered plants daily regardless of rain. Twospotted spider mite populations were monitored weekly and comparisons of the mite pressure were made. Farm A had a high population of TSSM by mid-February and control measures were necessary. Farm B did not experience high populations of TSSM until late April, just prior to the end of the season. Therefore, instead of applying control measures the field was plowed. Recommendations to strawberry growers in north-central Florida would be to establish a spray schedule for TSSM based on monitoring data. Also, the plants should be watered daily using drip irrigation.

CHAPTER 1
INTRODUCTION

In Florida, strawberries, *Fragaria x ananassa* Duchesne, are produced on approximately 7,000 acres with a farm gate value estimated at $170 million annually (Chip Hinton, personal communication). This value makes strawberries the most profitable small fruit crop to produce in Florida. Strawberries are attacked by several insect and mite pests in the greenhouse, but only two are recognized as major problems in the field in Florida. One group of these pests is strawberry sap beetles. Several species within this group affect strawberries including *Lobiopa insularis* (Castelnau), and *Carpophilus* spp. (Coleoptera: Nitidulidae). Sap beetles can be problematic in fields with ripe fruit exposed to heavy rains or a delayed harvest. However, acceptable control of sap beetles can be achieved culturally by simply picking the fruit before it over-ripens.

The twospotted spider mite (TSSM) *Tetranychus urticae* Koch (Acari: Tetranychidae), has been recognized as the most important arthropod pest in strawberries in Florida (Decou 1994). *Tetranychus urticae* feeds on strawberry leaves and alters their anatomical structure drastically (Kielkiewicz 1985). Feeding results in chlorosis, which leads to a decrease in photosynthetic activity and a subsequent reduction in yield (Sances et al. 1982). In the past, TSSM has been controlled with several applications of acaricides. However, due to the high fecundity and problems associated with resistance to acaricides, the management of TSSM has become a major problem for growers (Trumble and Morse 1993). As an alternative to chemical control, researchers have focused on inoculative releases of many species of predatory mites.

Phytoseiulus persimilis Athias-Henriot (Acari: Phytoseiidae) has been the main predatory mite released in Florida but its establishment in suppressing populations of TSSM has only been successful in southern areas of the state. *Neoseiulus californicus* McGregor (Acari: Phytoseiidae) is another predatory mite that has been released sporadically throughout Florida but information regarding its potential to control TSSM, especially in northern Florida, is unavailable. *Neoseiulus californicus* has been shown to be more adapted to adverse environmental conditions. Subsequently, *N. californicus* may function well under northern Florida conditions where low temperatures often kill predatory mites. If strawberry growers in northern Florida have access to an effective predatory mite, this will substantially reduce their reliance on acaricides, ultimately reducing selection pressure (for resistance to TSSM) against new miticides.

In Florida, field releases have been the standard method used for dispersing predatory mites in strawberry fields. Recently, a new strategy is being attempted called "predator-in-first" where transplants are being inoculated with the predator before they are shipped and planted in the fields. By having the predators in the field from the beginning of the strawberry production season, it is hypothesized that better control of TSSM will be achieved throughout the field season.

Strawberries are produced in many regions of the world, with production practices differing in each climatic region. Depending on the region where strawberries are grown, they are planted at different times of the year due to their need for cooler temperatures. Strawberries are watered using various techniques, drip or overhead, depending on the amount of rainfall a region receives as well as the manner in which they are planted (Hancock 1999).

In north-central Florida, strawberries are planted in mid-October on raised plastic beds with drip irrigation being the primary method for watering. Overhead irrigation is recommended during the first two weeks until plants develop a adequate root system. Overhead sprinklers are also used for frost and freeze protection when overnight temperatures fall below $0^{o}C$ (Legard et al. 2002). Some growers use bed covers for frost protection but these are often expensive and require several workers to cover the entire field.

Two types of transplants are used to start the field, bare-root green-top plants and containerized plants. Bare-root transplants are available commercially from several companies and are often more affordable compared to containerized plants. The advantage of transplanting containerized plants is that they tend to establish better than bare-root transplants (Legard et al. 2002). Furthermore, they reach maturity at an earlier date.

Several varieties of strawberries are grown. Popular varieties grown in Florida are Camarosa, Festival and Sweet Charlie. Each variety has advantages and disadvantages and the grower should be aware of these so that he can make the proper choice. For instance, Sweet Charlie has been reported to be more susceptible to TSSM development but the fruit this variety produces tends to be sweeter and more desirable to consumers (Marjorie Hoy, personal communication).

Plant pollination is another important factor to consider when establishing a strawberry field. Many insects pollinate strawberry plants. It is generally recommended to have a honeybee hive near the strawberry field because they are the primary and most efficient way to pollinate the plants (Hancock 1999).

Insect, weed and disease management should follow the protocol for the region where the strawberries are being grown. Insect management can be complex due to the presence of honeybees in the field, so professional advice is recommended. Various weeds and diseases occur in each region and certain pesticides can help in protecting plants from these problems (Legard et al. 2002).

The first harvest is usually in December and then harvest continues until early May when the plants are usually plowed under. The amount and quality of each harvest is usually dependant on many different factors that include temperature and rainfall (Hancock 1999). Low temperatures usually slow plant growth and if the temperature is low enough to create frost or freeze conditions, the plants can be killed. High amounts of water can change the flavor of the berry itself, which often lowers the price to consumers.

CHAPTER 2
LITERATURE REVIEW

Twospotted Spider Mite

TSSM is a cosmopolitan pest belonging to the family Tetranychidae (Hinomoto et al. 2001). It attacks several crops and greenhouse plants year round. TSSM has a life cycle that goes through five phases: egg, larvae, protonymph, deutonymph and adult (Krantz 1978). The eggs are usually round with a clear to light brown color and are laid on the leaf surface in clusters near the egg-laying female (Margolies et al. 1997). Strawberry leaves have trichomes present on the leaf surface, which protects TSSM (eggs and motiles) from predators (Roda et al. 2000). The larva can be distinguished from the other life stages because it has six legs and is the same size as the egg (about 0.1 mm). The protonymph and deutonymph resemble the adult with size being the only useful differentiating character. The protonymph, deutonymph and adult usually has two spots on the abdomen while the body can range from light green to dark red.

The life cycle from egg to adult can take anywhere from 5 days to 1 month depending on environmental conditions. Optimal conditions for development are high temperatures (up to 38^{o}C) and low humidity (Ho and Lo 1979). TSSM adults also deposit fine webbing on the leaves to maintain beneficial environmental conditions (such as a high temperature and humidity) on the leaf surface as well as for protection against predators (Krantz 1978). Other factors that can influence TSSM reproduction are the presence of nutrients and minerals, such as nitrogen (Wermelinger et al. 1985), variation in soil moisturs and host plant variety.

Dispersal of TSSM can take place by either ambulatory or aerial means. Almost all substantial dispersal takes place aerially due to the small size of the mites and the amount of time it would take for a spider mite to travel from one plant to another. Winds as low as 8 km/h have been shown to disperse mites throughout an agricultural field (Boykin and Campbell 1984). The method of dispersal involves aggregating on the leaf edges and using their webbing during strong winds to balloon themselves to another area of the field.

TSSMs also have an arrhenotokous genetic system that makes them ideal for developing resistances to pesticides. Mated females can produce either haploid males or diploid females. When these haploid male alleles are exposed to new mutations they are immediately susceptible to selection pressures (Houck 1994). This mode of reproduction, combined with high reproductive rates, allows beneficial mutations to evolve rapidly through several generations.

Monitoring

TSSM is usually monitored by taking a known number of leaf samples and counting the number of mites on the leaves. The average number of mites or eggs per leaf is then calculated. In southern Florida, when 5% of the leaf sample is infested, *P. persimilis* or chemical control is applied to the field. In north-central Florida, a threshold for releasing predatory mites against TSSM has not been established.

Chemical Control

Many miticides are approved for use in strawberries for control of TSSM. One compound that is reduced-risk and has shown promise is bifenazate (Acramite 50WP®). This compound is relatively new and has recently been approved for use in strawberries. Bifenazate also is reported to be selective to maintaining predatory mite populations in the field (Liburd et al. 2003b). Other registered miticides frequently used by growers in strawberries include fenbutatin-oxide (Vendex®) and propargite (Omite®) (Wise et al. 1999). Vendex® is a broad-spectrum miticide that is destructive to other beneficial mites.

Predatory Mites: Phytoseiidae

Phytoseiulus persimilis and *N. californicus* belong to the family of predatory mites Phytoseiidae. Phytoseiids are commonly used in biological control programs against TSSM. They also are used world-wide in IPM programs and include ecologically diverse species that range from specialist predators to broadly phytophagous generalist feeders (Schausberger and Walzer 2001, Blackwood et al. 2001). The life cycle of most phytoseiid mites is similar to that of the TSSM. There are five phases: egg, larva, protonymph, deutonymph and adult (Krantz 1978). The egg is clear, ovoid and at least twice the size of a TSSM egg (0.1 mm). Most phytoseiids are ovoid and often crawl around the leaf surface much faster than TSSM. Phytoseiid mites use kairomones from host plants to locate their prey (Dicke and Sabelis 1988). They locate TSSM in a patch by the leaf webbing released by TSSM and chemoreceptors located on their bodies (Dicke et al. 1998 and Helle and Sabelis 1985). *Phytoseiulus persimilis* have been shown to spend more time on leaves that have TSSM webbing as opposed to leaves without webbing (Schmidt 1976).

Predator mites often overexploit TSSM patches and are therefore forced to move to a new patch or die of starvation (Jung and Croft 2001). Movement of phytoseiid mites from one food source to another is accomplished in a manner similar to that described for TSSM. Generally, phytoseiid mites will use their own webbing to catch wind currents for dispersal from one plant to another. Once these predators find a substantial spider mite patch, they can reproduce at a very fast rate. For *P. persimilis*, as much as 70% of its food intake can go into egg production (Houck 1994). Eggs are oviposited near or in the TSSM patches to allow the larvae to have access to food.

Phytoseiulus persimilis

Phytoseiulus persimilis is a specialist Type I predator (Jung and Croft 2001). This means that the mite is a strict predator of tetranychid mites and most of its prey is TSSM. Type I specialist predatory mites such as *P. persimilis* often distribute themselves in patches, and may overexploit their prey before emigrating to a new area or dying of starvation. Due to this habit, these predators often go through a "boom-bust" cycle where the population will get very high when abundant food resources are available, and when the food source is exhausted the predator will often disappear (Jung and Croft 2001). This type of population growth exhibited by P. persimilis may make it necessary to release this predator more than once to give quick control when populations of TSSM exceed the economic threshold.

Neoseiulus californicus

Neoseiulus californicus has been shown to be a generalist Type IV predator. This predator feeds on mites, thrips, and pollen as well as other sources of food. Generalist Type IV predators such as *N. californicus* tend to have a lower rate of dispersal when compared with *P. persimilis* but can have a high ambulatory rate between local mite patches (Jung and Croft 2001). Generalist predators often can persist in fields with a lower population of TSSMs and therefore may be better for season-long control. Subsequently, *N. californicus* could be released at a lower density of TSSM in comparison with *P. persimilis*.

Justification

In northern Florida, mid-season strawberry production occurs in late January and early February when overnight temperatures average between 3-10^{o}C. In southern Florida overnight temperatures average 7-15^{o}C during January and February. This variation in environmental conditions between southern and northern Florida may be a principal reason why *P. persimilis* does not function well in strawberry systems under northern Florida conditions. The adoption of another predator mite species, such as *N. californicus* or other generalist predators that feed on TSSM, may alleviate some of the problems encountered with *P. persimilis* in northern Florida strawberry fields.

Over the last two decades, *P. persimilis* has been the principal mite species released in Florida for biological control of TSSM. *Phytoseiulus persimilis* performs well under southwestern Florida conditions, where more than 70% of the strawberries are grown. Unfortunately, attempts to deliver similar programs with *P. persimilis* for growers in north-central Florida have failed. The specific reason for these failures is unknown. However, many growers and extension specialists have speculated that environmental conditions in north-central Florida are not conducive for the survival of *P. persimilis*. This failure to use *P. persimilis* in biological control programs against TSSM has negatively affected strawberry production in northern Florida, resulting in growers who wish to grow pesticide-free strawberries abandoning their farms or moving further south.

Another factor affecting strawberry production systems is soil moisture and watering regimes. Preliminary laboratory data have indicated that TSSM reproduction is strongly influenced by soil moisture and the physiological status of the plant (unpublished data).

Our primary goals were to investigate environmental conditions, including soil moisture and temperature, to determine their effect on the reproduction of TSSM and its associated predatory mites. In an attempt to address soil moisture problems, we wanted to investigate different types of irrigation systems and different watering regimes in the field to determine their impact on TSSM reproduction. Finally, we wanted to explore alternative ways of controlling TSSM, which included the use of reduced-risk miticides on TSSM and its predators.

CHAPTER 3
EFFECTS OF SOIL MOISTURE AND TEMPERATURE ON THE REPRODUCTIVE RATES OF TWOSPOTTED SPIDER MITE, *Tetranychus urticae* Koch (ACARI: TETRANYCHIDAE)

Strawberries are an important crop in Florida with a farm gate value estimated at $170 million annually. Current production is threatened due to high populations of twospotted spider mite (TSSM), *Tetranychus urticae* Koch, the key arthropod pest during strawberry production season in Florida (Jepson et al. 1975, Hochmuth 1988). In the past, TSSM has been controlled with several applications of acaricides. However, due to high fecundity and problems associated with resistance to acaricides (Trumble and Morse 1993), the management of TSSM has become a major problem for strawberry growers in the US.

Predatory mite releases, including *Phytoseiulus persimilis* Athias-Henriot, have had moderate success, especially in southern and central Florida (Decou 1994). However, growers in northern Florida as well as other strawberry-producing areas in the Southeast have not had much success with augmentative releases of *P. persimilis*. One hypothesis is that *P. persimilis* cannot survive the cooler temperatures in the winter months typical in the southeastern US. A better understanding of *P. persimilis* and other predatory mites' response to prey under varying environmental conditions may help to alleviate problems that strawberry growers in northern Florida and other areas of the southeast experience.

Low temperatures have been shown to affect TSSM populations in several types of beans, *Phaseolus* spp. and *Glycine max* (L.) Merr., by slowing their reproductive rates (Everson 1980, Ho and Lo 1979). Earlier, Ferro and Chapman (1979) recorded a higher percentage of TSSM egg hatch at 35°C compared with a temperature of 25°C. In another study, Hoy (1985) found that insufficient irrigation accentuated TSSM feeding damage in almonds. Field and laboratory studies to determine how soil moisture regulates populations of TSSM in strawberries have not been conducted.

Our research goals were to study environmental conditions, specifically temperature and soil moisture, and to determine how they would affect the reproductive rates of predatory mites and twospotted spider mite. Soil moisture and temperature were first examined in the laboratory in a controlled environment and then in the field. Irrigation systems were studied in the field to determine how watering devices (drip versus overhead irrigation) affected growth and reproduction of TSSM.

Methods

Laboratory experiments were conducted at the University of Florida, Fruit and Vegetable Laboratory in Gainesville, FL. Field experiments were conducted at the University of Florida, Plant Science Research Unit, Citra, Florida.

Laboratory

Soil moisture

Fifteen potted strawberry plants cv. "Sweet Charlie" were randomly selected from our greenhouse strawberry nursery stock. The potted plants were pruned to six leaf-trifoliates and placed inside 20 cm pot saucers and then examined using a 2x circular illuminated magnifier (Cole-Parmer, Vernon Hills, IL) to ensure that they were free from mites. The soil containing potted plants was then allowed to air-dry to conform to the required soil moisture levels according to each experimental treatment.

The soil moisture levels were tested using a Soil Moisture Meter (Lincoln Irrigation Company, Lincoln, NE). The soil moisture meter (tensiometer) measures moisture levels and translates the results to a scale of 0 to 10 (zero being completely dry soil and ten being entirely saturated). Three treatments were evaluated including: 1) a low soil moisture (representing 1-3 on the soil moisture meter), 2) a moderate soil moisture ([Control] 4-6 on the soil moisture meter) and 3) a high soil moisture (7-9 on the soil moisture meter). Experimental design was a completely randomized block with four replicates per treatment.

Ten TSSM (adults) were placed onto each plant. Plants were subjected to the various treatments (low, moderate and high moisture levels). Every third day all of the mites on the plant were counted using a 40x adjustable stereo-microscope. The duration of the experiment was 2 weeks.

Temperature

Using a similar protocol described for the soil moisture experiment, fifteen plants were selected at random from the greenhouse and screened to ensure that plants were mite-free. Three environmental rearing chambers (Percival Environmental Chambers, Boone, IA) were used for this experiment that can control temperature and photoperiod. Each chamber was set for a 16-hour light period and 8-hour dark period. Each plant was pruned to six leaf-trifoliates.

Experimental design was completely randomized block with four replicates. Three treatments were evaluated including: 1) a low temperature set at 18^{o}C, 2) a moderate temperature set at 27^{o}C (Control) and 3) a high temperature set at 35^{o}C. During the 8-hour dark period the temperature was set at 15^{o}C in all rearing chambers. Ten TSSM were placed on the plants and all of the motile TSSM and eggs were counted on every third day using the equipment and methods used for counting mites in the soil moisture experiment. As in the soil moisture experiment, the experiment ran for two weeks.

Statistical analysis

Data from the soil moisture and temperature experiments were analyzed using repeated measures analysis of variance with mean separation using least significant differences (LSD) to show treatment differences (PROC MIXED in SAS V.9.0, SAS 2002). Data were considered significant when *P* values were ≤ 0.05.

Field Trials

The field experiment was located at the University of Florida, Plant Science Research Unit, in Citra, FL. Strawberries, cv. "Sweet Charlie", were planted into twenty-four plots. Plot size was 7.3 x 6 m with a 10 m buffer between each plot. Rows were 1.2 m wide and plants were spaced about 30 cm apart. Overhead sprinklers were installed on all plots for frost protection (when needed).

Experimental design was a completely randomized block with four replicates. Six treatments were evaluated. The watering program for each treatment was split into two 15-minute watering cycles during the specific day when watering was administered. Treatments included: 1) watering every day using drip irrigation (high moisture level), 2) watering every day using drip and overhead irrigation (high moisture level), 3) watering every other day using drip irrigation (Control), 4) watering every other day using drip and overhead irrigation (Control), 5) watering every third day using drip irrigation (low moisture level) and 6) watering every third day using drip and overhead irrigation (low moisture level). Strawberry transplants were inoculated with laboratory-reared two-spotted spider mites when needed.

Sampling

Twenty leaves were collected each week from every plot (80 leaves/treatment). Leaves were examined under a 40x stereo-microscope for TSSM and predatory mites.

The numbers of motiles and eggs were counted and recorded. If the TSSM were mature enough they were seperated by sex (male and female). Plants in each plot also were examined visually for disease symptoms. The duration of this experiment was from October 2002 to April 2003.

Statistical analysis

Data for this experiment were separated by time according to production season (early, mid and late season) then subjected to Poisson Regression with PROC GENMOD in SAS V.9.0 (SAS 2002) to estimate parameters. Means were separated using least significant differences (LSD). Data were considered significant when the *P* values were ≤ 0.05.

Results

Laboratory

Soil moisture

There were significantly higher populations of TSSM eggs in the low soil moisture when compared with the high soil moisture after 3, 6 and 9 days (Table 3-1). Overall, the low soil moisture averaged 2.3, 5.2 and 3.6 times as many eggs compared with high soil moisture for 3, 6 and 9 days, respectively. Similarly, there also were significantly higher populations of TSSM motiles in the low soil moisture compared with the high soil moisture after 6 days and 9 days (Table 3-1). Treatments were significant over time for both the eggs ($F = 10.2$; df = 6,18; $P < 0.01$) and motiles ($F = 5.1$; df = 6,18; $P < 0.01$) indicating that higher numbers of eggs and motiles were recorded irrespective of time (3, 6 and 9 days) when plants were sampled.

Temperature

There were significantly higher populations of TSSM eggs in the high temperature (35^{o}C) when compared with the low temperature (18^{o}C) after 3 and 6 days (Table 3-2). After 9 days, TSSM egg numbers at all three temperatures (low, moderate and high) were significantly different. Similarly, significantly higher populations of TSSM motiles were recorded at the high temperature when compared with the low temperature after 6 days and 9 days respectively (Table 3-2). Again, all three temperatures had significantly different numbers of TSSM motiles after 6 and 9 days. Similarly to our moisture experiments, treatments were significant over time for both the eggs ($F = 16.7$; df = 6,18; $P < 0.01$) and motiles ($F = 2.8$; df = 6,18; $P = 0.04$) irrespective of days when sampling was conducted.

Field trials

Comparison of different moisture levels under drip irrigation during the early strawberry season (11 Nov. – 8 Dec.) revealed that there were significantly higher populations of TSSM at the low soil moisture when compared with the high soil moisture. Low soil moisture had more than twice the number of TSSM motiles compared with the high (Table 3-3). Egg production showed no significant differences among the soil moisture levels.

Comparison of drip irrigation versus drip/overhead irrigation indicated that there was a significantly higher population of TSSM motiles under drip/overhead irrigation when compared with drip irrigation during the early and late season (18 Mar. – 15 Apr.) as well as over the course of the entire season (Table 3-4). Overall, the drip and overhead irrigation averaged 5.1, 6.2 and 5.5 times as many motile TSSM compared with drip irrigation in the early, late and over the course of the entire season respectively.

Discussion

Our results showed that low soil moisture and high temperature promote TSSM reproduction in strawberries. The effects of soil moisture became clear when nearly three times as many eggs and motiles were recorded in the laboratory and field trials on plants exposed to low soil moisture compared with high soil moisture. Similar observations were recorded for temperature in that potted plants exposed to high temperatures of 35^{o}C were four times more likely to have TSSM than plants exposed to lower temperatures of 18^{o}C. Previous work has shown that when bean plants are deprived of water, the sugars inside the leaves becomes more concentrated, thus making the plant more nutritious (White 1984) and consequently increasing feeding by TSSM and promoting outbreaks (English-Loeb 1989). This situation may account for the increase in numbers of TSSM in our low soil moisture studies. Another theory is that TSSM has problems with water excretion (Boudreaux 1958). When drought stresses the plants, the amount of water retained in the leaves is decreased, as is the humidity around the leaves. This limits the amount of water that TSSM to excretes, allowing the mite to spend more energy on reproduction.

During the early strawberry season it was observed that low soil moisture under drip irrigation promotes TSSM reproduction. The field conditions during this time averaged 27^{o}C with low levels of rainfall. These conditions were similar to those created in the laboratory and thus the early results of the field experiment were similar to those recorded in the laboratory. After 8 Dec., temperatures in north-central Florida drop below 18^{o}C and rainfall became more persistent. We noted that a temperature of 18^{o}C or below elicited either a diapausal or quiescent state in TSSM in the laboratory. Consequently, the period between 8 Dec. and 15 Feb. had insignificant numbers of TSSM in the field. After 15 Feb. the temperature rebounded above 18^{o}C, thus promoting the reproduction of TSSM populations. During the same period Alachua county had unseasonably high levels of precipitation and this interfered with the moisture treatments until the end of the season. I suspected this accounted for the insignificant differences observed among the treatments for the balance of the season.

At the beginning and the end of the season, there were significantly higher populations of TSSM in the drip/overhead irrigation when compared with drip. I believe that the reason why these differences were not recorded in the mid season is because of the excessive amount of rain that fell during the mid season, which did not allow me to maintain the soil moisture treatments. Low overnight winter temperatures caused the overhead irrigation system in each plot to run from December through March to protect plants from frost injury. Thus, strawberry plants were exposed to excessive amounts of water and angular leaf spot, *Xanthomonas fragaria* Kennedy and King, was a problem during the winter months. This disease was seen more in the overhead irrigation systems probably due to excessive foliar moisture. It is possible that this disease may have made the plants more susceptible to TSSM.

These experiments demonstrate that low soil moisture as well as high temperatures (over 27^{o}C) promote TSSM reproduction. Overhead irrigation appears to increase disease symptoms and promote TSSM production. Recommendations to growers in Florida will be to plant strawberries in the early fall (1st week of October) to take advantage of cooler temperatures. We also recommend the use of drip irrigation (which has become the standard in Florida) to irrigate the crop. Once drip irrigation is installed, water should be applied for short periods several times a day to keep the strawberries well watered and lush. Drought stressing the crop not only promotes TSSM development but also creates dust, which has been documented to promote the development of TSSM. The amount of water a strawberry crop should receive depends on the grower's locality, soil type, crop stage of development as well as environmental conditions. Data from this experiment will be used to help researchers and strawberry growers better understand the TSSM's biology so that cultural practices can be used to suppress their populations. Lastly, a TSSM monitoring program should be established to detect early populations so that the appropriate management strategies can be implemented.

Table 3-1. Effect of soil moisture on twospotted spider mite (TSSM) development in the laboratory (2002)

Soil Moisture Level	Days after initial TSM transfer					
	3 days		6 days		9 days	
	Eggs [a]	Motiles [b]	Eggs [c]	Motiles [d]	Eggs [e]	Motiles [f]
Low soil moisture	451.5 ± 69.2a	27.3 ± 5.7ab	454.0 ± 138.2a	375.8 ± 100.8a	953.0 ± 287.5a	487.5 ± 99.0a
Moderate soil moisture	490.3 ± 67.4a	37.3 ± 3.3a	215.8 ± 56.6ab	202.5 ± 66.4ab	863.0 ± 136.9a	524.8 ± 112.6a
High soil moisture	195.5 ± 12.8b	16.8 ± 1.3b	87.0 ± 23.3b	89.5 ± 48.4b	260.0 ± 63.4b	147.3 ± 15.4b

Initially 10 TSSM adults transferred to plants

Total mean # of TSM eggs/motiles (±SEM)

Means followed by the same letter are not significantly different ($P = 0.05$, LSD Test)

[a] $F = 17.8$, df = 2,6, $P = <0.01$ (3 days eggs)

[b] $F = 5.3$, df = 2,6, $P = 0.05$ (3 days motiles)

[c] $F = 6.2$, df = 2,6, $P = 0.04$ (6 days eggs)

[d] $F = 4.4$, df = 2,6, $P = 0.07$ (6 days motiles)

[e] $F = 6.0$, df = 2,6, $P = 0.04$ (9 days eggs)

[f] $F = 12.8$, df = 2,6, $P = <0.01$ (9 days motiles)

Table 3-2. Effect of temperature on twospotted spider mite (TSSM) development in the laboratory (2002)

Temperature	Days after initial transfer					
	3 days		6 days		9 days	
	Eggs [a]	Motile [b]	Eggs [c]	Motiles [d]	Eggs [e]	Motiles [f]
Low temperature (18°C)	25.5 ± 8.3b	6.3 ± 1.7a	41.0 ± 5.3b	6.8 ± 2.5c	43.0 ± 10.1c	4.8 ± 1.8c
Moderate temperature (27°C)	70.3 ± 13.6a	10.5 ± 1.9a	152.8 ± 34.4a	40.8 ± 14.4b	99.0 ± 12.2b	91.3 ± 16.4b
High temperature (35°C)	115.0 ± 12.4a	8.5 ± 0.9a	149.3 ± 29.0a	137.5 ± 22.2a	203.0 ± 32.3a	204.3 ± 36.2a

Initially 10 TSSM adults transferred to plants

Total mean # of TSSM eggs/motiles (±SEM)

Means followed by the same letter are not significantly different ($P = 0.05$, LSD Test)

[a] $F = 10.9$, df = 2,6, $P = 0.01$ (3 days eggs)

[b] $F = 1.9$, df = 2,6, $P = 0.24$ (3 days motiles)

[c] $F = 8.6$, df = 2,6, $P = 0.02$ (6 days eggs)

[d] $F = 31.9$, df = 2,6, $P = <0.01$ (6 days motiles)

[e] $F = 17.4$, df = 2,6, $P = <0.01$ (9 days eggs)

[f] $F = 68.4$, df = 2,6, $P = <0.01$ (9 days motiles)

Table 3-3. Early season (11 Nov. - 8 Dec.) comparisons of twospotted spider mite (TSSM) reproduction with different moisture levels under drip irrigation (motiles)

Treatment	Avg. TSSM populations per rep ± SEM
Low	3.63 ± 1.95a
Moderate	0.44 ± 0.26b
High	1.38 ± 0.81b

Statistical analysis used Poisson regression in SAS V.9.0 with PROC GENMOD to estimate parameters (SAS 2002)
Comparison of low and high soil moistures were significantly different (Chi-Square Value = 4.84; df = 1,18; $P = 0.03$)

Table 3-4. Comparison of the reproductive rates of twospotted spider mites (TSSM) with drip irrigation versus drip/overhead within the moderate soil moisture treatments (motiles)

	Treatment			
Season	Drip	Drip/ Overhead	Chi-Square Value	*P* Value ($P = 0.05$)
Early	0.44 ± 0.26	2.25 ± 1.74	8.63	0.0033
Mid	4.69 ± 2.08	13.63 ± 7.86	0.70	0.4032
Late	17.81 ± 6.99	110.06 ± 41.75	7.74	0.0054
Entire	7.65 ± 2.61	41.98 ± 15.56	5.64	0.0175

Statistical analysis used Poisson regression in SAS v.9.0 with proc GENMOD to estimate parameters (SAS 2002)
Total mean # of TSSM motiles per rep (±SEM)

CHAPTER 4
COMPARISON OF MANAGEMENT PROGRAMS ON STRAWBERRY FARMS AND ITS EFFECTS ON TWOSPOTTED SPIDER MITES.

Across the US, agricultural practices for raising strawberries differ from region to region. Strawberries are an important small fruit crop in Florida. In north-central Florida, strawberries are planted in mid-October on raised plastic beds with drip irrigation, the primary method for watering the plants. Overhead irrigation may also be used for irrigating strawberries but there could be serious limitations with this strategy (Handley 2001). There are two types of transplants used in north-central Florida; 1) bare-root green-tops, 2) containerized plants. Bare-root green-top transplants are easily found and are much cheaper compared with containerized plants, but containerized plants tend to establish better (Legard et al. 2002). A strict pesticide application schedule, consisting of fungicides, acaricides and insecticides, is recommended for the control of diseases and arthropods but some growers apply pesticides as they are needed. The first harvest for strawberries is often in December. Harvesting may continue until the plants are plowed under around 1 May.

The most important arthropod pest in strawberries in north-central Florida is the twospotted spider mite (TSSM), *Tetranychus urticae* Koch (Decou 1994). TSSMs feed on the leaves of the plant resulting in chlorosis, which leads to a decrease in photosynthetic activity and a subsequent reduction in yield (Trumble and Morse 1993). Current control methods include the use of miticides, cultural practices and biological control with predatory mites. In many instances, effective control of TSSM has not been achieved. Some of the factors that have contributed to these failures include resistance to key acaricides including Vendex® (fenbutatin-oxide) and the inability of predatory mites to survive adverse climatic conditions.

In the Southeast, the primary predatory mite used for the control of TSSM is *Phytoseiulus persimilis* Athias-Henriot. This mite is a specialist predator that feeds exclusively on tetranychid mites (Schausberger and Croft 1999). The establishment of this mite has only been successful in southern Florida, which could be due to environmental conditions or its feeding habits. When TSSM is not present in the field, *P. persimilis* may leave the field to find other tetranychid mites. One alternative predatory mite is *Neoseiululs californicus* McGregor. This is a generalist predatory mite that feeds on mites, thrips and pollen (Croft et al. 1998). It is hypothesized that this mite may persist in the field longer in the absence of TSSM and thus may make for a more efficient predatory mite. My goal was to identify two strawberry farms with different production systems and compare TSSM pressure within these farms and make assumptions as to reasons why there are differences in mite pest pressures.

Methods

Two strawberry growers were selected in Alachua county and we asked for permission to use their fields to do on-farm studies involving TSSM abundance and dynamics. Survey data on irrigation techniques and watering regimes were collected for comparisons with other experiments being conducted. Both farms used drip irrigation as their irrigation technique with overhead sprinklers installed for frost protection. Farm A did not have a weekly pesticide spray schedule and sprayed and watered the plants as the grower saw fit. Fenbutatin-oxide [(Vendex®) (conventional)] was applied at labeled rates on 20 Feb., 2002, followed by the application of *P. persimilis* at a rate of one predator to ten TSSM to suppress populations of TSSM. Farm B sprayed pesticides on a strict weekly schedule and watered the plants daily regardless of rain. Each week fifty strawberry leaves were collected from each farm and studied under a microscope for TSSM presence. Twospotted spider mite motile and egg populations were recorded for each farm. Data collected during the 2001 and 2002 field season was analyzed using Excel Statistical Software (Microsoft Corporation 2000) and presented graphically showing weekly means.

Results and Discussion

On farm A, which sprayed pesticides and watered the plants as needed, populations of TSSM were higher than farm B for the majority of the season (1 Dec. - 20 Mar.) (Fig. 4-1). Results showed that the application of fenbutatin-oxide and a release of *P. persimilis* one week after spray provided excellent control of TSSM. By releasing *P. persimilis* one week after the application of miticide, the residual effect of the miticide on *P. persimilis* is diminished. This allows the predator to remain in the field longer and to have a greater capability to reproduce effectively.

On farm A, TSSM eggs were recorded from December 2001 until April 2002. TSSM eggs remained low until 9 Jan. when densities increased to 7.1 ± 4.4 per leaf. Populations then gradually declined until 6 Feb. when there was a rapid increase in egg numbers averaging 65.8 ± 50.5 per leaf (Fig. 4-1). The application of Vendex® during the first week of February resulted in a rapid decline in egg numbers averaging 24.8 ± 7.4 per leaf by mid-February. *Phytoseiulus persimilis* was applied on 25 Feb. and this apparently facilitated the downward trend in egg numbers until 20 Mar.. Thereafter, egg numbers continued to remain very low until the end of the season (Fig. 4-1).

Twospotted spider mite motile populations remained low throughout the sampling period except on the 6 Feb. when there was a gradual increase in populations averaging 8.8 ± 4.2 per leaf. Populations then declined rapidly, probably due to the Vendex® application and remained low thereafter (Fig. 4-1).

On farm B, TSSM eggs were recorded from January 2002 to May 2002. Egg numbers remained low until they began to gradually increase on 20 Mar. averaging 6.1 ± 2.6 eggs per leaf (Fig. 4-2). This gradual increase continued until 17 Apr. when the egg numbers began to drastically increase averaging 23.3 ± 7.0 per leaf. The egg population increased again and remained high until the end of the season on 1 May when it averaged 52.2 ± 8.7 per leaf (Fig. 4-2).

The TSSM motile population followed the same trend reported for eggs. Populations of motiles gradually increased until 20 Mar. averaging 1.5 ± 0.6 mites per leaf. After that time, there was a rapid increase in motile population on 17 Apr. averaging 20.9 ± 5.6 mites per leaf and again on 1 May to 43.5 ± 4.3 per leaf (Fig. 4-2).

One factor that may be influencing TSSM populations on both farms is average monthly temperatures. On farm A, the TSSM populations exploded in February, which may be in part due to increasing average high temperatures. The average daily high in February 2002 in Alachua county was 21^{o}C compared with January which was 19^{o}C. Temperature has been shown in numerous reports (Ho and Lo 1979, Brandenburg and Kennedy 1987) to be an important factor affecting TSSM reproduction. Farm B did not record the rapid increase as on farm A because mite and consequently egg populations were regulated with frequent applications of pesticide. Farm B's population exploded in

March, when the average daytime high was 24^{o}C. These temperatures are favorable for the development of TSSM populations making control tactics with pesticides difficult.

We assumed that the difference in mite pressure between farms was due to differing cultural practices instead of environmental conditions. Farm A had no set schedule for pesticide application or watering, thus the plants were exposed to higher densities of insects, mites and pathogens, as well as periodic droughts throughout the season. These conditions apparently made strawberry plants more susceptible or made conditions more favorable for mite development and allowed for high densities for eggs and motiles during mid-season (February). Farm B had a weekly calendar for pesticide sprays therefore the mites were exposed to many fungicides and herbicides. It is possible that these pesticides could have a negative effect on TSSM, consequently reducing their populations during the mid-season.

Our recommendation to strawberry growers in north-central Florida would be to establish a spray schedule for TSSM based on monitoring data. Also, to water plants at least once a day using drip irrigation. Current laboratory and field experiments indicate that water stressed strawberry plants promote TSSM reproduction. There should be a weekly mite monitoring program in the field to determine the average number of TSSM per leaf. Once populations reach 10 TSSM motiles per leaf a predator mite can be released. *Phytoseiulus persimilis* is currently recommended for immediate control. In the future *N. californicus* may be considered as a viable predatory mite for suppressing TSSM activity.

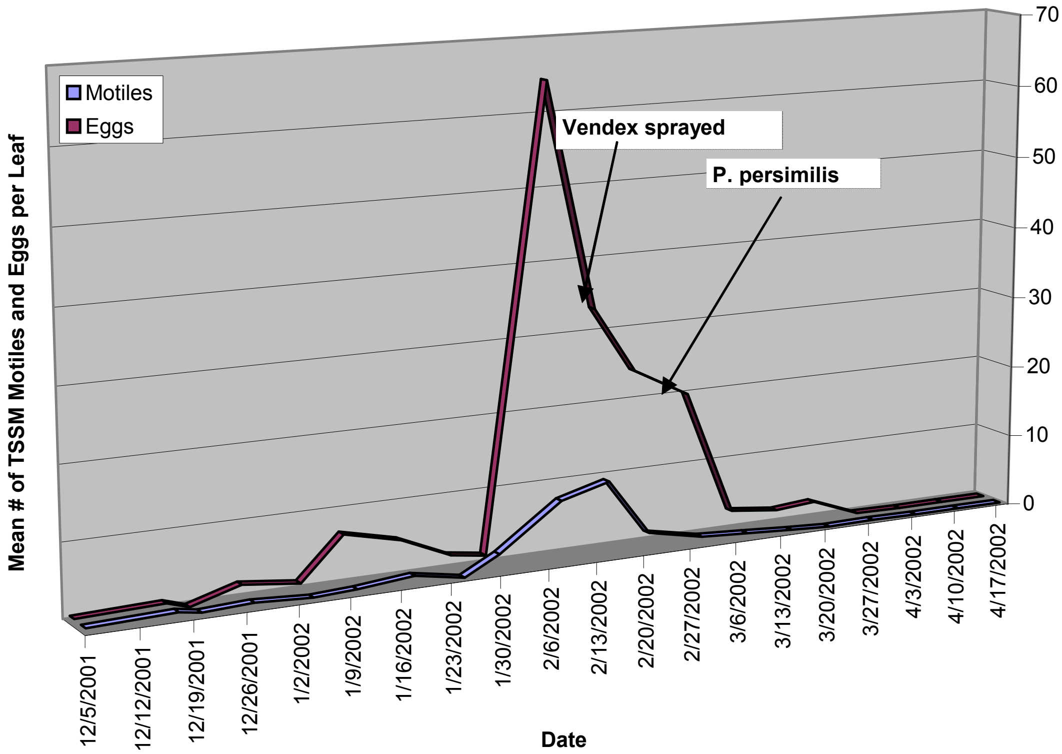

Figure 4-1. Populations of twospotted spider mite on Farm A

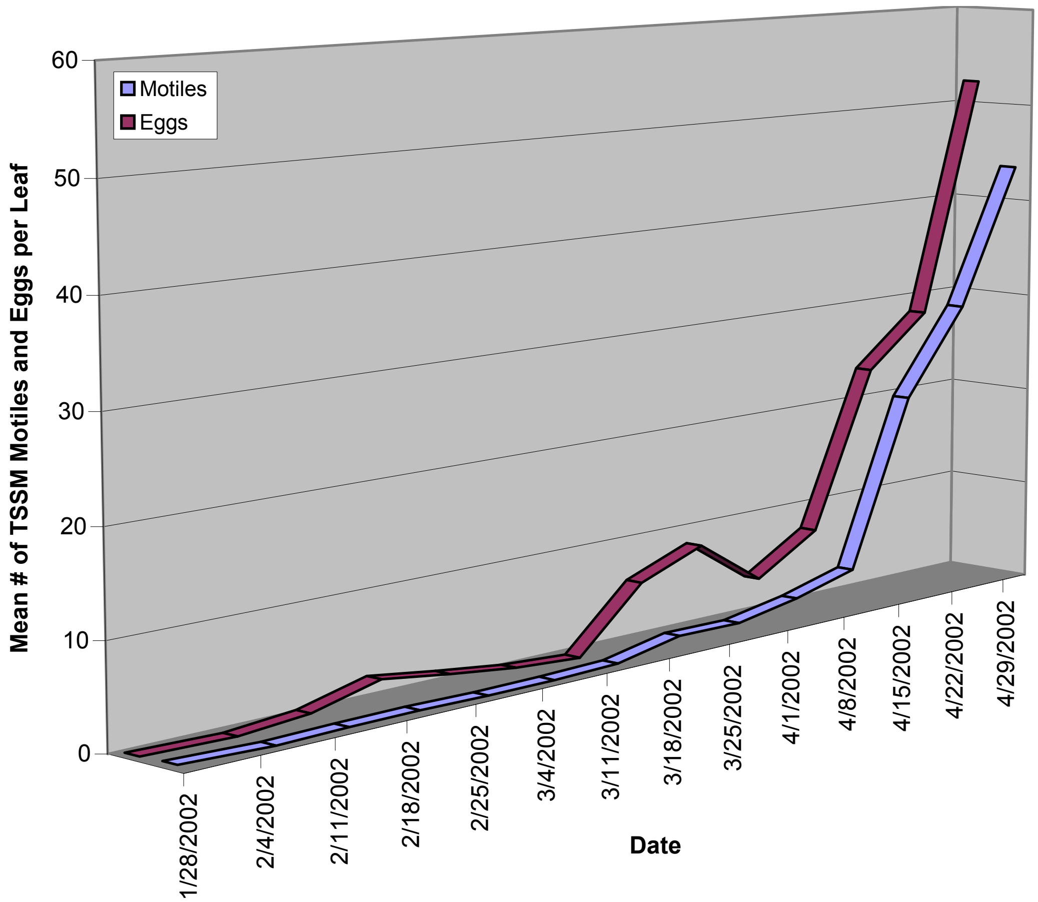

Figure 4-2. Populations of twospotted spider mite on Farm B

CHAPTER 5
THE RESIDUAL AND DIRECT EFFECT OF SEVERAL MITICIDES ON TWO PREDATORY MITES (ACARI: PHYTOSEIIDAE) AND THE TWOSPOTTED SPIDER MITE, *Tetranychus urticae* Koch (ACARI: TETRANYCHIDAE).

Pesticidal applications are the most popular method for controlling arthropod populations in most agroecosystems (Brandenburg and Kennedy 1987). If used properly, they can assist in controlling populations of the twospotted spider mite (TSSM), *Tetranychus urticae* Koch. Unfortunately due to improper usage, TSSM have developed resistance to key acaricides (Dittrich 1975, Edge and James 1986). TSSM populations have been documented to be resistant to several classes of pesticides including chlorinated hydrocarbons, organophosphates and carbamates (Wolfenberger 1968, Carbonaro et al. 1986, Flexner et al. 1988). Mineral oils have no documented resistances but insufficient coverage by these chemicals can lead to insufficient control (Amer et al. 2001). Resistance to pesticides has caused scientists to examine other methods of controlling TSSM, which include the use of predatory mites and cultural practices.

Predatory mites have been used in controlling TSSM for decades. One of the most common predatory mite is *Phytoseiulus persimilis* Athias-Henriot. This mite was imported from Chile and Italy and released in the US (McMurtry et al. 1978). It is a specialist predator that feeds exclusively on tetranychid mites (Schausberger and Croft 1999). Releases of *P. persimilis* have had moderate success and led to the release of many other predatory mites (Trumble and Morse 1993). One advantage of releasing *P. persimilis* is that it disperses quickly in the field. However, the absence of tetranychid mites could cause this predatory mite to leave the field or die (Jung and Croft 2001). This may result in additional releases if the population of TSSM persists.

Another mite that has been released is *Neoseiulus californicus* McGregor. This is a generalist predator that feeds on mites, thrips and other insects that are the same size or smaller (Croft et al. 1998). *Neoseiulus californicus* persists in agricultural fields even if mites are not present because it is capable of surviving on alternative food sources.

Effective control of TSSM may not be achieved by using a single control tactic (Kim and Seo 2001). Combining different tactics involving reduced-risk pesticides and selective releases of predatory mites can yield the most acceptable control of TSSM while maintaining predatory mite populations in the field (Hoy and Cave 1985, Hoy and Ouyang 1986, Spollen and Isman 1996). Our goal was to determine the direct and residual effects of several miticides on two predatory mites species and the twospotted spider mite.

Methods

Twospotted Spider Mite

Strawberry plants, c.v. Sweet Charlie, were grown in the fruit and vegetable IPM greenhouse. Plants were approximately 25 cm in height when leaves were detached. All leaves used were screened for twospotted spider mite and other insects prior to use. Leaf squares 2.5 x 2.5 cm were cut from the center of each strawberry leaf. Each leaf square was placed inside a petri dish on moist cotton. The cotton serves to keep leaves turgid for up to one week. Water was sprayed onto the cotton with a hand-atomizer to prevent the cotton from drying out. Five treatments including four miticides and a control were evaluated. Treatments included fenbutatin-oxide [(Vendex®) (conventional)] (Griffin L.L.C., Valdosta, GA), binfenazate [(Acramite 50WP®) (reduced-risk)] (Crompton

Manufacturing Company Inc., Bethany, CT), Repel® (UAS of America Inc., Hudson, FL), an organic oil (Wipeout®) (UAS of America Inc., Hudson, FL) and a water-treated control. There were twelve replicates per treatment.

Ten TSSM (adults) from a laboratory colony were placed upon each leaf square. Miticides were applied according to labeled rates by proportionate scaling of large quantity recipes (Liburd et al. 2003a). Leaf squares were monitored 6, 12, 24, 48 and 72 hours as well as one week after application of the miticides. The number of living and dead motile mites, eggs and larvae was recorded.

Statistical Analysis. Data were analyzed using an analysis of variance with mean separation by least significant differences (LSD). Data were considered significant when the P value ≤ 0.05.

Predator Mites

In order to determine how conventional and reduced-risk miticides affect predatory mites, two miticides, fenbutatin-oxide [(Vendex®) (conventional)] and bifenazate [(Acramite 50WP®) (reduced-risk)] were evaluated against *P. persimilis* and *N. californicus*.

Twelve strawberry plants were selected from the greenhouse and trimmed down to six leaf-trifoliates per plant. Plants were separated into two treatments with each treatment representing six plants. Two days before the experiment started, one of the treatments (six plants) was inoculated with ten adult TSSM. These six inoculated plants were designated as the cue treatment while the other treatment (six plants) was referred to as non-cue. Inoculated plants are termed “cue” because these plants received TSSM four days before the predators were released. Subsequently, these plants were more likely to have spider mite webbing and may have released kairomones to attract and maintain a predator colony. The other six plants that did not receive these TSSM in advance theoretically did not have TSSM residues on the leaves and were referred to as "non-cue".

At the start of the experiment, time zero, one of the plants from each of the treatments was sprayed with water and these plants were designated as controls 1 and 2, respectively. One-hundred TSSM and ten predatory mites were released on the control cue plants and 50 TSSM and five predatory mites were released on the control non-cue plants. The remaining plants from the cue and non-cue were labeled 6, 12, 24, 48 and 72 hours after miticide application. All of the plants were sprayed with one of the designated miticide treatments except for the controls, which were sprayed with water. A standard hand-atomizer was used to apply all of the miticide treatments. Six hours after miticide application, the 6-hour plants received the same number of mites as the control plants; that is, for the cue treatment 100 TSSM and 10 predatory mites and for non-cue 50 TSSM and 5 predatory mites. These six-hour plants were monitored for predatory mite motiles and eggs every 24 hours for a total of 72 hours after the mites were applied. The 12-hour plants received the same number of mites the 6-hour plants received 12 hours after miticide application. These plants were sampled every 24 hours up to 72 hours. Each plant followed the same protocol until the 72-hour plants were completed. These methods were repeated for both predators using both miticides.

Statistical Analysis

Data for this experiment were analyzed using an analysis of variance (ANOVA) with mean separation by least significant differences. Data were considered significant when the P value ≤ 0.05.

Results

Twospotted Spider Mite

Six hours after application of treatments Wipeout® and Acramite®, the leaf discs had significantly fewer TSSM motiles compared with the control (Table 5-1). Vendex® significantly reduced TSSM populations after 24 hours while it took Repel® 72 hours to significantly reduce TSSM populations below the control. After 72 hours, the control had more than four times the amount of TSSM motiles compared with Acramite® and twice as many TSSM motiles compared with Wipeout® and Vendex®. Repel® had 30% fewer TSSM motiles compared with the control after 72 hours.

After 1 week, there were no eggs present on the Acramite® treated leaves compared with an average of more than 17 eggs in the control (Table 5-2). Vendex® and Wipeout® were not significantly different from the control. Repel® was totally ineffective in reducing egg production.

Predator Mites

There were significant differences for *P. persimilis* with respect to Vendex® treatments for 6 and 72, 24 and 48 and 6 and 24 hours for the 1st, 2nd and 3rd sampling intervals respectively. Alternatively, Vendex® did not appear to have any significant residual effects on *N. californicus* for the first 12 hours (1st sampling interval) (Table 5-3). After 12 hours there was a significant decline in predatory mite populations at 24 hours and then again at 48 hours. During the 2nd sampling interval there was a significant decline between 12 and 24 hours. In the 3rd sampling interval *N. californicus* populations recovered so that there were no significant differences among treatments.

Twelve hours after Acramite® application (1st sampling interval), *P. persimilis* had three times less of a population when compared with the control (Table 5-4). This population then increased and recovered during the 24-hour treatment but then declined again at the 48-hour treatment. During the 2nd sampling interval *P. persimilis* populations declined significantly in the 6-hour treatment but recovered quickly at 12 hours. Finally, the population declined at the 72-hour treatment. There were no significant differences in the 3rd sampling interval. When subjected to Acramite®, *Neoseiulus californicus* demonstrated a three-fold decrease in population (1st sampling interval) in the 6-hour treatment and did not recover throughout the 1st sampling interval. There were no significant differences during the 2nd sampling interval but *N. californicus* populations were higher when compared to the 1st sampling interval. During the 3rd sampling interval there was a significant decline between the control and the 72-hour treatment but this may be due to the lack of food for the predatory mites.

Discussion

Results showed that treatments of Acramite® had a higher rate of TSSM mortality when compared with the conventional miticide Vendex®. Plants treated with Acramite® had half as many live TSSM motiles after 72 hours and had no egg production. This shows that Acramite® has more residual activity on TSSM compared with Vendex® which appears to have less activity on motile TSSM, allowing them to reproduce. Wipeout® produced similar mortality results when compared with Vendex®. Wipeout® is a fine organic horticultural oil, which can be used in mite IPM programs as a tool for resistance management. Until recently, Vendex® has been the key conventional miticide used in the field to control TSSM. This miticide has a broad spectrum and often eliminates beneficial mite species from fields thus making strawberries susceptible to TSSM outbreaks. Acramite® and Wipeout® should be considered as alternatives to

Vendex® because they are more compatible with beneficial mites and can be used in a resistance management program.

Overall, *N. californicus* demonstrated a higher level of susceptibility to both Acramite® and Vendex® when compared with *P. persimilis*. For the first 24 hours (1st sampling interval), Vendex® had no significant effect on *N. californicus* populations. But at 24 hours there was a 55% decrease in the *N. californicus* mite population and continued to decline another 44% after 48 hours. The populations started to recover at the 72-hour mark with a 58% increase compared with the 48-hour population. *Phytoseiulus persimilis* demonstrated significant differences when subjected to Vendex® but these differences did not produce any type of trend. *Phytoseiulus persimilis* has been the primary predator mite used for TSSM control over the past few decades and may have developed resistances to this compound. *Neoseiulus californicus* is a less commonly used predator mite and probably has not been subjected to high selective pressures to build up a resistance to Vendex®.

When subjected to Acramite®, *N. californicus* demonstrated a three-fold decrease in population size from the control (six-hours post-application) and did not recover during the 1st sampling interval. However, the populations of *N. californicus* recovered during the 2nd and 3rd sampling intervals. Data contrasted with those for *P. persimilis* in that *P. persimilis* recovered by the 24-hour treatment during the 1st sampling interval and by the 12-hour treatment during the 2nd sampling interval. Although there was a higher level of susceptibility to Acramite® by *N. californicus* compared with *P. persimilis*, the difference in susceptibility was not as drastic as that observed for Vendex®. The exact reason for the susceptibility is unknown but more research needs to be conducted on why *N. californicus* is more susceptible to Acramite® than is *P. persimilis*.

The predator experiment attempted to use a non-traditional technique by using whole plants as opposed to leaf discs in order to simulate field conditions. When using leaf discs, 100% coverage of the miticide is always acquired. In the field this is not the case and often TSSM and predatory mites will find areas where the miticide is absent and continue to develop. The problem with using whole plants is that the predatory mites are small and there are many places for them to hide. In addition, they tend to leave the plants making counting extremely difficult and tedious.

Overall, I recommend that growers implement an IPM strategy for the management of TSSM in strawberries. The use of novel compounds combined with the timely release of predatory mites should provide effective control of TSSM populations. I recommend the use of Acramite® followed by a release of *N. californicus* 48 hours after spraying. Acramite® will suppress populations of TSSM and allow *N. californicus* to build up and provide effective control. *Neoseiulus californicus* should also persist in the field when TSSM populations are low due to its generalist feeding habits.

Table 5-1. Effect of miticides on twospotted spider mite (TSSM) mortality (2002)

Treatment	Hours 6 [a]	12 [b]	24 [c]	48 [d]	72 [e]
Acramite	6.75 ± 0.99a	5.42 ± 1.05a	4.50 ± 0.93a	2.25 ± 0.43a	1.33 ± 0.41a
Wipeout	6.83 ± 0.63a	6.00 ± 0.76ab	4.58 ± 0.66ab	3.25 ± 0.57a	3.08 ± 0.56b
Vendex	8.33 ± 0.51b	7.17 ± 0.42bc	6.00 ± 0.56bc	4.75 ± 0.63b	2.92 ± 0.54b
Repel	8.92 ± 0.38b	7.58 ± 0.72c	6.75 ± 0.46cd	6.17 ± 0.49bc	5.00 ± 0.51c
Control	8.75 ± 0.60b	8.25 ± 0.59c	7.50 ± 0.50d	7.08 ± 0.50c	6.58 ± 0.40d

Initially 10 TSSM transferred to each leaf disc
Total mean number of TSSM motiles (±SEM)
Means followed by the same letter are not significantly different (P = 0.05, LSD Test)
[a] $F = 2.88$, df = 4,44, $P = 0.03$ (6 hours)
[b] $F = 2.71$, df = 4,44, $P = 0.04$ (12 hours)
[c] $F = 5.30$, df = 4,44, $P = <0.01$ (24 hours)
[d] $F = 16.60$, df = 4,44, $P = <0.01$ (48 hours)
[e] $F = 19.73$, df = 4,44, $P = <0.01$ (72 hours)

Table 5-2. Effect of miticides on egg production of twospotted spider mite (TSSM) after one week on the plants

Treatment	One Week
Acramite	0.00 ± 0.00a
Wipeout	7.25 ± 4.25ab
Vendex	11.75 ± 4.47ab
Repel	29.00 ± 8.97c
Control	17.83 ± 5.07bc

Initially 10 TSSM transferred to each leaf disc
Total mean number of TSSM eggs (±SEM)
Means followed by the same letter are not significantly different (P = 0.05, LSD Test)
$F = 5.39$, df = 4,44, $P = <0.01$ (one week)

Table 5-3. Effect of Vendex on *Phytoseiulus persimilis* and *Neoseiulus californicus* mortality (2002)

Treatment [a]	Sampling Interval [b]		
Phytoseiulus persimilis			
	1	2	3
0	3.67 ± 1.86ab	2.67 ± 1.45ab	2.33 ± 1.20ab
6	2.33 ± 0.33a	2.67 ± 0.88ab	2.00 ± 1.15a
12	3.33 ± 1.76ab	3.00 ± 2.08ab	2.67 ± 1.45ab
24	3.67 ± 0.33 ab	5.33 ± 0.33a	5.00 ± 0.00 b
48	3.33 ± 0.33ab	2.33 ± 0.88b	2.33 ± 0.88ab
72	5.33 ± 1.33b	4.67 ± 0.33ab	3.33 ± 0.67ab
Neoseiulus californicus			
	1	2	3
0	4.33 ± 0.88ab	3.33 ± 0.88ab	2.67 ± 1.20a
6	4.00 ± 1.73ab	5.33 ± 1.76ab	4.00 ± 2.00a
12	6.67 ± 1.20a	6.67 ± 1.76a	5.67 ± 1.76a
24	3.00 ± 1.73b	2.33 ± 0.88b	2.67 ± 0.33a
48	1.67 ± 1.20b	3.67 ± 1.20ab	3.33 ± 0.67a
72	4.00 ± 1.15ab	5.33 ± 0.33ab	3.33 ± 0.67a

Initially 10 TSSM transferred to each leaf disc followed by 10 predators
Total mean number of predator motiles (±SEM)
Means followed by the same letter are not significantly different ($P = 0.05$, LSD Test)
[a] Treatments are the number of hours at which predator mites were released on the plants after the miticide was applied
[b] Predator mites were counted every 24 hours after released onto the plants

Table 5-4. Effect of Acramite on *Phytoseiulus persimilis* and *Neoseiulus californicus* mortality (2002)

Treatment [a]	Sampling Interval [b]		
Phytoseiulus persimilis			
	1	2	3
0	4.33 ± 0.88a	3.67 ± 1.20a	1.33 ± 1.33a
6	3.33 ± 2.40ab	1.67 ± 1.67b	1.67 ± 1.20a
12	1.67 ± 0.67b	2.33 ± 0.88ab	1.67 ± 0.67a
24	5.33 ± 0.88a	2.33 ± 1.33ab	1.67 ± 1.67a
48	3.67 ± 0.88a	2.00 ± 0.58ab	0.33 ± 0.33a
72	1.00 ± 1.00b	0.67 ± 0.67b	0.33 ± 0.33a
Neoseiulus californicus			
	1	2	3
0	4.00 ± 3.06a	2.33 ± 2.33a	2.67 ± 1.20a
6	1.33 ± 0.88b	1.33 ± 0.88a	0.33 ± 0.33ab
12	1.00 ± 0.58b	2.00 ± 2.00a	1.67 ± 1.67ab
24	1.00 ± 0.58b	2.00 ± 1.00a	1.33 ± 0.88ab
48	1.67 ± 1.67ab	1.00 ± 1.00a	1.33 ± 1.33ab
72	0.67 ± 0.33b	0.67 ± 0.67a	0.00 ± 0.00b

Initially 10 TSSM transferred to each leaf disc followed by 10 predators
Total mean number of predator motiles (±SEM)
Means followed by the same letter are not significantly different ($P = 0.05$, LSD Test)
[a] Treatments are the number of hours at which predator mites were released on the plants after the miticide was applied
[b] Predator mites were counted every 24 hours after released onto the plants

CHAPTER 6
SUMMARY AND CONCLUSIONS

Twospotted Spider Mite Rearing Procedures

Most laboratory colonies of twospotted spider mites (TSSM), *Tetranychus urticae* Koch, are reared on various types of beans, *Phaseolus* spp., because of the biology of this plant and how well TSSM has adapted to it. Bean seeds are often cheap and can be found at any local gardening store. In a greenhouse, bean plants can germinate, grow large enough to support TSSM feeding and then be disposed of all in one month. These factors allow for TSSM to be reared quickly and efficiently without much interference from predators. However, once predators invade a colony of TSSM they are difficult to remove and many times the colony needs to be destroyed.

Strawberry plants, *Fragaria x Ananassa* Duchesne, have a very different biology when compared with beans. Strawberries are cool weather plants that do not grow well in the warmer months. It is hypothesized that the nutritive value of the leaf changes in the warmer months and is often not as desirable to TSSM during these months. More research is needed to determine whether this hypothesis is true.

Strawberry plants are not carried by local stores and usually have to be mail ordered in lots containing more than 100 individuals. When plants arrive they must be planted within a week. Transplants usually arrive as bare-roots, green-tops and require plenty of water at transplanting. It often takes 2-3 months before the plants are large enough to support a large TSSM colony. This allows the plant to release defensive kairomones to attract predators that can invade the colony. Due to the small size of many of these predators they are often difficult to keep out of the colony and often the plants need to be disposed of because of predator invasion. These factors make rearing TSSM on strawberries a difficult task.

We adapted our rearing protocol to allow for these factors in several ways. During the cooler months when strawberries grew well we placed plants in a small, isolated greenhouse and inoculated them with TSSM. These colonies reproduced rapidly and gave us a large enough colony to conduct our experiments. The cool season in north-central Florida starts in late October but TSSMs usually do not become abundant until late February. This allows a 3-4 month period to complete any involved TSSM laboratory experiments. Any experiments involving large numbers of TSSM (over 50 per plant) will need to be completed from November through mid-February when these colonies are robust.

Colonies of TSSM need to be examined weekly for predators. If any predators invade the colonies, plants hosting predators will need to be removed from the colony. Depending on the predator, insecticides can be applied to suppress the population. For insect predators, reduced-risk insecticides can be applied at a low rate. Mite susceptibility should be checked before application. If predatory mites invade the colony, carbaryl (Sevin®) can be used to eliminate the population. It has been reported that TSSM seems to reproduce faster in the presence of this chemical and it has a negative effect on predatory mites.

From the end of the field season (late April-early May) until mid-October, TSSM colonies are difficult to rear on strawberries. They will occur naturally on the plants in very low numbers and often, since it is warmer, predators are much more common. In addition, the physiology of the plant changes and fruits are no longer produced. Instead, the plant produces runners. The plants need to be kept alive during this time and pruned for the upcoming field season. Experiments involving small TSSM numbers (10 or fewer TSSM per leaf) may be completed between May and October but once the colony is harvested it is difficult to obtain high enough numbers for its re-establishment.

Predator Mite Protocols

Most experiments that are completed in the laboratory using predatory mites are done using leaf disc methods. This method is extremely artificial and it may be difficult to make field assumptions based on results from leaf discs. Therefore, I avoided this method in our laboratory experiments by using whole, potted strawberry plants. I attempted to test the effects of soil moisture and temperature on *Phytoseiulus persimilis* Athias-Henriot and *Neoseiulus californicus* McGregor using similar methods to those in the TSSM protocol. I placed 10 TSSM on the plants and allowed them to reproduce for one week and then released 10 predator mites onto the plants and monitored their activity over time.

Two problems arose when trying to use the "whole-plant" protocol. The first was that the predatory mites tended to find places on the plants to hide or left the plant. Due to their small size, I was unable to locate the predators after a few days on the whole plant. The other problem was that the predatory mites tended to move towards the clusters of TSSM on the plants irrespective of the treatments. I was unable to develop a protocol that would allow for equal amounts of TSSM on all plants throughout the experiment while subjecting the predatory mites to each individual treatment. I noticed that after a few days the treatments that did not support TSSM development had very few mites. Consequently, the predatory mites would leave the host plant. This, I believe, was due to the low numbers of TSSM and not due to the treatment. More research needs to be done to develop an effective whole plant protocol for testing the effects of environmental conditions on predatory mites using TSSM as the food source.

Conclusions

The purpose of my Master's research was to develop IPM strategies for controlling TSSM in strawberries in north-central Florida. My two main goals were to document the effects of soil moisture and temperature on TSSM and to evaluate the direct and residual effects of different miticides on TSSM and its associated predatory mites. I also sampled TSSM populations on two farms in Alachua county to determine the population dynamics as well as the strategies growers were using to control this pest. The populations dynamics and effectiveness of different IPM strategies have been well documented in California and southern Florida but little has been done in north-central Florida.

One aspect of IPM is the use of cultural practices to help maintain pest populations at manageable levels. My results illustrated that low soil moisture and high temperature promote TSSM reproduction. In the laboratory there was a three-fold increase in TSSM motiles in both the low soil moisture and high temperature when compared with the high soil moisture and low temperature, respectively. Early in the field season I also documented that low soil moisture promoted TSSM reproduction but as the season progressed and temperatures increased (above 27^{o}C) soil moisture no longer played a role. My research showed that in the field, temperature seems to play a more important role in TSSM reproduction when compared with soil moisture. The soil moisture results have applications in the field by recommending to growers to keep their strawberry plants well watered. Also, establishing plants during the cooler months will allow slower development of TSSM throughout the field season.

Another important aspect of IPM is the use of pesticides as a last resort to control pest populations. There has been a lot of focus on miticides with regards to TSSM due to the high level of resistance that has been documented. In my studies the conventional miticide Vendex® was shown to be less effective than Acramite® in controlling TSSM. Acramite® not only killed active motiles but had a long residual effect on egg production. Vendex® killed most of the motiles but had less of a residual effect on mites.

Predatory mites, *P. persimilis* and *N. californicus*, demonstrated low levels of susceptibility to residual Vendex® and Acramite® with *N. californicus* appearing to be slightly more susceptible. Irrespective of this susceptibility, both predatory mites recovered within 48 hours of release. I would recommend that growers wait a minimum of 48 hours after spray application to release predatory mites in the field.

The last aspect of this thesis was to monitor strawberry grower farms in Alachua county to document TSSM population dynamics and to survey the growing practices these farmers use. I found that the farm that used a strict spraying regime and watered the plants daily had less of a problem with TSSM populations compared with the farm that did not have a spray regime and watered the plants as the grower saw fit. In the farm that was managed using a strict spray regime, the mite populations did not peak until late April after the bulk of the strawberries was harvested. Since the plants were not producing enough fruit to support chemical control tactics, the plants were plowed under. At the farm that did not use a strict spray regime TSSM populations peaked in mid-February. I sprayed Vendex® at the recommended rate and released *P. persimilis* one week after spray application. An acceptable level of control of TSSM was achieved using these control practices. Therefore, applying a strict spray regime and watering the plants daily, a grower may delay TSSM populations enough so that control tactics are not warranted.

The research completed in this thesis has advanced the knowledge of successful IPM tactics that are required to control TSSM in strawberries in north-central Florida. By keeping strawberry plants well watered and planting them during the cooler months growers may be able to maintain low levels of TSSM. If the populations should multiply and reach economic threshold levels, novel acaricides such as Acramite® and releasing *N. californicus* 48 hours after spray application should help control populations of TSSM.

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BIOGRAPHICAL SKETCH

Jeffrey Carl White was born in Dover, NJ, on November 29, 1978. Within a year he was living in Newton, NJ, which is where he graduated high school. While in high school he was a member of the National Honors Society and played soccer, basketball and baseball.

In August of 1997 he started his B.S. at Rutgers University in New Brunswick, NJ. After his first year he decided to major in biological sciences and at the end of his third year he had discovered his future in entomology. He then worked a summer internship at Philip Alampi Beneficial Insect Laboratory (PABIL) in Trenton, NJ. Here he worked on recovering field release data on the predatory coccinellid beetle, *Pseudoscymnus tsugae* Sasaji and McClure, and its effectiveness against the hemlock woolly adelgid, *Adelges tsugae* Annand.

After graduating Rutgers University in August of 2001 with his B.S. in biological sciences, he continued his internship at PABIL, while he was applying to the University of Florida. He was accepted to Florida in October of 2001 and started his master's on the twospotted spider mite, *Tetranychus urticae* Koch, in strawberries, in January of 2002. After the completion of this degree he will be continuing his education by enrolling in a doctoral program at Rutgers University where he will conduct research on the oriental beetle, *Exomala orientalis* (Waterhouse), in blueberries.