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Effect of *Tetranychus urticae* (Acari: Tetranychidae), on Marketable Yields of Field-Grown Strawberries in North–Central Florida

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ABSTRACT Understanding the impact of a pest species on a particular crop is critical for the success of a pest management program. Field studies were conducted to determine the effect of the twospotted spider mite, *Tetranychus urticae* Koch, on marketable yield of strawberries during the 2008/2009 and 2009/2010 growing seasons. Low, medium, and high mite infestation levels were established by initial inoculations of 5, 10, and 20 twospotted spider mites per strawberry leaf, respectively. A control treatment maintained at near zero mites through applications of an acaricide, bifenazate (Acramite 50 WP), was also included. Weekly records of motile twospotted spider mites were obtained over 13 and 16 wk during the 2008/2009 and 2009/2010 growing seasons, respectively. Degree-days and weather parameters were monitored to determine their effect on mite population. In addition, mite-days were calculated for each year from weekly mite counts to determine the effect of mites on marketable yield of strawberries. In both years, twospotted spider mite population increased throughout the growing seasons. More degree-days were accumulated during the 2008/2009 growing season, and mite population was higher in 2008/2009 than in 2009/2010. Mite population density per leaf increased up to 278 motiles per leaf in 2008/2009 growing season as compared with 137 in 2009/2010 within the high-infestation-level treatment. The divergence in mite population between the two growing seasons was attributed mainly to temperature differences between the two seasons that affected mite population development and establishment. During both growing seasons, the high mite infestation level had lowest marketable yield. A negative correlation between cumulative mite-days and harvested marketable yields was detected in both seasons, but it was only significant during the 2008/2009 growing season. Strawberry yield reduction was detected when plants attained 80 mites per leaf in 2008/2009 and 50 mites per leaf in 2009/2010 within the high mite infestation treatment. Factors that affect mite population establishment and management for twospotted spider mites on strawberries are discussed.

KEY WORDS *Fragaria ananassa*, action threshold, degree-day, mite-day, six-spotted thrip

The market value of strawberries (*Fragaria ananassa* Duchesne) depends on the quality of fruits produced, which is influenced by a number of factors, including physical injuries from insect pests and pathogens. Management strategies that will reduce strawberry injury from pests and pathogens are therefore critical in enhancing the quality of strawberries produced. Such efforts require adequate knowledge of the strawberry pest complex and beneficial insects and their biology.

The twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), is one of the most damaging and persistent mite pests that affect field-grown strawberry in Florida (Poe 1971; Mossler and Nesheim 2003, 2007; Chandler et al. 2008) and elsewhere (Oatman and McMurtry 1966, Sances et al. 1982, Walsh et al. 1998, Greco et al. 2005, Sato et al. 2007). The piercing and removal of cell contents from strawberry leaves by spider mites (Tomczyk and Kropczyńska 1985) results in loss of chlorophyll and reduced photosynthetic rates, leaving the leaf with white or yellow spots, a condition termed as "stippling" (Sances et al. 1979, DeAngelis et al. 1982, Park and Lee 2005). At high infestation rates, twospotted spider mites can suppress flower and leaf development, and ultimately affect the quality and quantity of berries produced (Sances et al. 1982, Fraulo et al. 2008). The economic loss caused by twospotted spider mites and associated damage is enormous, making it a major target for integrated pest management (IPM) in strawberry systems (Sances et al. 1982, Liburd et al. 2007).

The principles of IPM demand that pest management actions be delayed until it is economically sound to implement them. The term economic threshold (ET) is used to define the pest population density level at which management actions should be applied to avoid economic losses (Pedigo 1996). Thresholds are determined based on the relationship between pest population levels and the damage they cause to a crop. Once the ET level is known, management tactics

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are applied at this level to prevent the pest from reaching economically damaging levels.

ET levels for twospotted spider mites in strawberry vary from region to region, cultivar, stage of crop growth, time of the season, control options, and market prices (Pedigo 1996, Walsh and Zalom 1996). An ET of 150 mites per trifoliate leaf was reported for a short-day strawberry variety in California (Wyman et al. 1979) compared with one mite per leaf for the day-neutral cultivar, Selva (Walsh et al. 1998). Similarly, an ET of 15 mites per mid-tier trifoliate leaf was reported during the first 5 mo of growth in winter compared with 30 mites per mid-tier trifoliate leaf in summer and 60 mites per trifoliate leaf after harvest was initiated (Walsh and Zalom 1996). Finally, twospotted spider mite densities higher than 15 mites per trifoliate leaf during the early growth stages of strawberry can negatively affect the number of berries produced and hence the overall yield (Sances et al. 1982, Gimenez–Ferrer et al. 1994).

Mite densities, and therefore the ET levels, are also sensitive to prevailing weather conditions that influence mite growth, survivorship, and fecundity, including temperature, rainfall, and relative humidity (Boyne and Hain 1983, Bounfour and Tanigoshi 2001, White and Liburd 2005). Developmental period for twospotted spider mites decreased from 25 to 6.5 d and the intrinsic rate of increase rose from 0.08 to 0.321 when the temperature was increased from 15 to 30°C (Bounfour and Tanigoshi 2001). Temperature is also known to affect the fecundity and longevity of twospotted spider mites (Herbert 1981). Therefore, these factors should be considered when developing pest management programs for spider mites on strawberries.

In Florida, several different types of sampling programs are used to determine when management action is needed for twospotted spider mites in field-grown strawberry. A survey conducted in north-central Florida between 2008 and 2010 revealed that the majority (>60%) of growers' management decisions were based on presence/absence sampling programs (unpublished data). Presence or absence sampling programs have been used successfully to detect if the pest is present in the field or not. A major drawback with this approach is that growers tend to spray more often than required because management decisions are not based on mite levels that would cause economic losses but rather if mites are present in the field. In south–central Florida, ET levels for twospotted spider mites are based on percent infestation per leaf (Mossler and Nesheim 2003). However, this approach may be interpreted differently by individuals because the different life stages of spider mites offer varying risks to the strawberry plant. For instance, a threshold based on egg population is not the same as one based on the adult stage, especially where the population of females is high. To standardize Florida's approach, it would be advisable to base thresholds on motile stages (all stages except eggs) that are already causing injury to the plant. In addition, our aim was to use weekly harvest to determine when strawberry yield began to be affected by mite densities to estimate a threshold. Our ultimate goals were to determine the mite numbers that would cause economic losses on field-grown strawberries in north–central Florida, and to quantify how various environmental factors influenced mite populations. Twospotted spider mite densities were manipulated in strawberries under field conditions, and their effect on marketable yields of strawberries were quantified.

Materials and Methods

Twospotted Spider Mite Colony. Twospotted spider mites were obtained from the Small Fruit and Vegetable IPM Laboratory colony at the University of Florida, Gainesville, FL. The colony was maintained on bean (*Phaseolus vulgaris* L.) plants and strawberry transplants contained in 3.8-liter polyethylene pots for ≈5 mo before the start of each experiment. The plants were kept under two 60-watt incandescent bulbs with a photoperiod of 14:10 (L:D) h and 60% relative humidity (RH). Old mite-damaged plants were replaced with new bean plants every other week. Plants were watered manually three times per week or as needed.

Field Experiment Study Site. The study was conducted at the University of Florida, Plant Science Research and Education Center located in Citra, Marion County, FL, during the 2008/2009 and 2009/2010 strawberry growing seasons. The growing season in north–central Florida runs from mid-September to March or April the following year, depending on the environmental conditions. Experimental plots were 7.3 by 6.1 m with 11-m buffer zones between plots. Each plot had six double rows of strawberries (six beds) spaced at 0.35 m between plants (along the row) and between the two rows on the bed. Two weeks before planting, a soil fumigant consisting of a mixture of methyl bromide and chloropicrin (50:50) (Hendrix and Dail, Palmetto, FL) was applied to the beds at the rate of 36.5 liters/ha. During land preparation and bed formation, fertilizer (10-10-10; N-P_2O_5-K_2O) (Southern States CO-OP, Cordele, GA) was applied at the rate of 563 kg/ha on the center of the beds before placing a black plastic mulch (Johnny's Selected Seeds, Winslow, ME) cover. Bare-root green-top strawberry transplants of the variety, 'Festival', were used during both growing seasons. Over-head irrigation was used for plant establishment for the first 3 wk of the growing season and drip irrigation was adopted thereafter. Other growing practices, including fertilizer program, weeding, plant care, and removing runners, were done according to the standard production practices in north–central Florida (Peres et al. 2006).

With the exception of *Bacillus thuringiensis* (Dipel, Valent BioSciences Corporation, Libertyville, IL), no other insecticide was applied to the strawberry plants. When needed, *B. thuringiensis* was applied ≈3–4 wk after transplanting strawberries to control cutworms. Several fungicides including Abound (azoxystrobin) (Syngenta Crop Protection, Greensboro, NC), Aliette (aluminum tris) (Bayer Crop Science, Research Triangle Park, NC), Serenade (*Bacillus subtilis*) (Agraquest, Davis, CA), and Cabrio EG (pyraclostrobin) (BASF Corporation Research Triangle Park, NC) were rotated weekly to control common fungal diseases, including Botrytis fruit rot (*Botrytis cinerea*), anthracnose crown rot (caused by *Colletotrichum acutatum* and *Colletotrichum gloeosporides*), and powdery mildew (*Podosphaera aphanis*).

Experimental Design. Experimental design was a completely randomized block with four treatments (twospotted spider mite infestation levels), and five and four replicates per treatment in 2008/2009 and 2009/2010 growing seasons, respectively. The reduction in number of replicates used in 2009/2010 was because of increased labor costs and subsequent land charges. Treatments consisted of a high (20 spider mites per leaf), medium (10 spider mites per leaf), and a low infestation (five spider mites per leaf) rate, alongside a control (zero mites). Bifenazate (Acramite, Chemtura, Middlebury, CT) at the rate of 0.89 kg/ha was used to maintain mite population at close to zero spider mite/leaf on the control plots. Bifenazate is one of the recommended miticides for twospotted spider mites on strawberries in Florida, and well-timed applications of Acramite successfully control populations of *T. urticae* on strawberries (Rhodes and Liburd 2006, Liburd et al. 2007).

To achieve the three twospotted spider mite infestation levels, spider mites were introduced into the plots from the laboratory colony reared on bean plants. The number of twospotted spider mites introduced per plot was determined based on the number of fully grown leaves per strawberry plant per plot in each season. Twospotted spider mite-infested bean leaves were clipped onto strawberry leaves with plastic paper clips (Vinyl paper clips, Wal-Mart stores, Inc. Bentonville, AR) to allow the mites to crawl/walk onto the new hosts. During the 2008/2009 growing season, 5,760, 2,880, and 1,440 mites were introduced per plot, whereas in the 2009/2010 growing season, 4,320, 2,160, and 1,080 mites per plot for the high, medium, and low treatments, respectively. Plants in the 2009/2010 growing season were smaller and had fewer leaves than those in 2008/2009, and therefore, fewer mites were introduced per plot.

In both seasons, spider mites were introduced in the field 4 wk after transplanting the strawberry plants. On the control plots, bifenazate application varied slightly depending on the twospotted spider mite population build up. Control plots received two applications of bifenazate in 2008/2009 and only one in 2009/2010 to maintain mite populations at or near zero. Before the treatment applications, 10 mature trifoliate leaves were collected from each plot to determine if there were preexisting (natural infestations) spider mite populations in the field.

Sampling. The sampling of twospotted spider mites was conducted between 12 December 2008 and 2 March 2009 for the 2008/2009 field-season and between 17 December 2009 and 8 April 2010, for the 2009/2010 field-season. These sampling periods began 2 wk after initial infestation and continued to the end of the growing seasons. Each week, 10 mature trifoliate leaves were randomly collected from 10 plants in each replicate. Leaves were placed in Ziploc bags (Racine, WI) and transported to the laboratory under cool conditions and examined for twospotted spider mites by using a dissecting microscope (Leica MZ 12 5, Leica Microsystems, Houston, TX). From these leaves, twospotted spider mite motiles (all stages except eggs), insect pests and beneficial insects, were recorded.

Marketable Yield. Strawberries were harvested twice per week from the two inner alternate rows that were not used for leaf sampling. Marketable fruits consisted of berries that weighed >10 g and without physical evidence of injury. Berries <10 g or berries showing spider mite injury or other types of injury, including bird damage, weather-related injury (freezing, frost), or fungal diseases, were considered unmarketable. Harvesting was conducted from 30 December 2008 to 2 March 2009 and from 29 December 2009 to 12 April 2010.

Weather Factors. Weather data for Citra, FL, was downloaded from Florida Automated Weather Network (University of Florida 2011). Daily minimum and maximum temperatures and total rainfall received were obtained for the two growing seasons and used to compute weekly average temperature and total rainfall.

Data Analysis. Data analysis was accomplished by using SAS statistical package (SAS Institute 2002), and mite numbers per leaf were log-transformed to $ln(x + 1)$ to normalize the distribution and homogenize the variances. Differences in mite numbers between the four infestation levels (high, medium, low, and control) were compared by using a two-way repeated-measure analysis of variance, whereas differences in accumulated marketable yield and insect pests and beneficial insects were evaluated by using a one-way ANOVA. Significant means differences were separated with Tukey–Kramer's test, and means were considered significant when $P \leq 0.05$.

Mite-days were calculated for each year from the weekly mite counts to determine the effect of mite injury on marketable yield of strawberries. Mite-day combines both mite density and the duration of mites feeding on the host (Sances et al. 1981) and therefore is a good indicator of the effect of mite injury on marketable yield of strawberries. Accumulative mite-days were calculated by using equation 1 (Park and Lee 2005).

$$\sum [(x_i + x_{i+1})/2 \times \Delta t] \qquad [1]$$

where x_i is the number of mites at week i of sampling, x_{i+1} is the mite population the following week of sampling, Δt is days of the sampling interval, that is, 7 d, and the results are summarized over the total number of weeks. Regression analysis by using PROC REG (SAS Institute 2002) was used to determine the effect of accumulated mite-days on strawberry leaves on marketable yield. A multiple regression was used to test the effect of rainfall and temperature (weather factors) on spider mite population densities in both seasons.

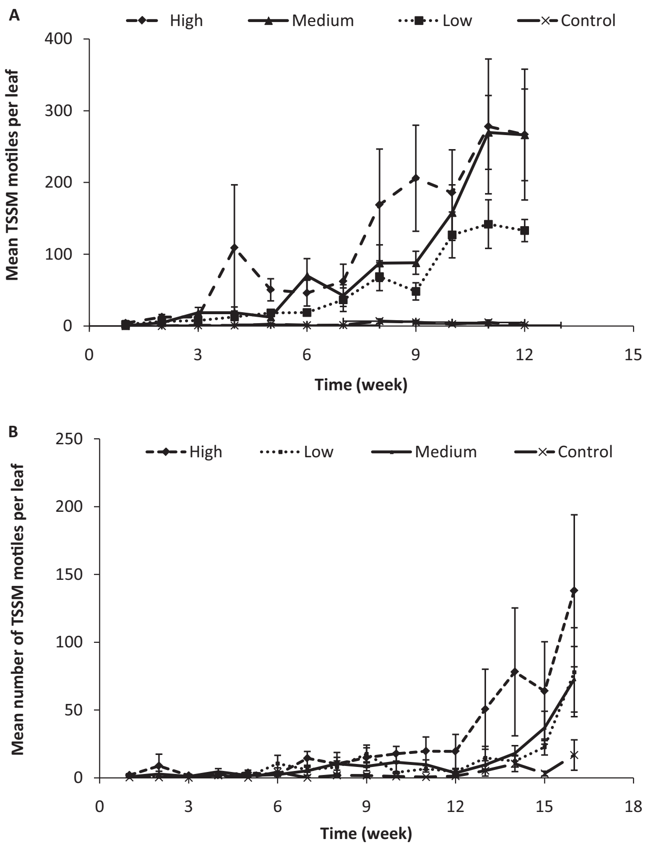

Fig. 1. Mean population of *T. urticae* per strawberry leaf at four infestation levels in (A) 2008/2009 and (B) 2009/2010 strawberry growing seasons.

To compare spider mite population growth between the two growing cycles, cumulative degree-days (DD) for twospotted spider mites were calculated for each year by using the daily mean temperature minus 10°C, the minimum threshold for twospotted spider mite development (Shih et al. 1976, Herbert 1981). In addition, the rate of twospotted spider mite increase was calculated by regressing $ln(x + 1)$ against the time of exposure, where x is the mean number of mites per sampling time, and time of exposure is equivalent to the difference between when the mites were introduced to the field and sampling time (Wilson 1993).

Results

Twospotted Spider Mite Population. Weekly mite counts per strawberry leaves in 2008/2009 were significantly influenced by interaction between infestation levels and time ($F = 3.08$; df = 30, 160; $P < 0.0002$) [with Greenhouse–Geisser adjustment] (Fig. 1A). Mite population remained low early in the growing season with a sudden increase in the high infestation level, where mite population increased up to an average of a 100 motiles per leaf by week 4. Treatment differences were recorded on all sampling dates, except week 1. On almost all the sampling dates, the high infestation level had significantly higher mite numbers than all the other treatments. On all the treatments, mite population growth was more obvious after week 8 (Fig. 1A). The highest average motiles counted per strawberry leaf were observed on week 11. The numbers were 278, 269,142, and 5 mites for high, medium, low, and control infestation levels, respectively. Overall, minimal mite population growth over time was recorded in the control plots.

In the 2009/2010 strawberry growing season, mite numbers per strawberry leaf were significantly influenced by infestation levels ($F = 4.22$; df = 3, 12; $P < 0.03$), and time ($F = 22.55$; df = 14, 168; $P < 0.0001$) but not their interaction ($F = 1.19$; df = 42,168; $P > 0.29$) (Fig. 1B). Mite population remained relatively low (<20) motiles per leaf on all infestation levels until week 12, when the population started to increase. At the end of the growing season, the high infestation level had significantly higher mite numbers per leaf than the control but similar to the medium and the low infestation levels.

Marketable Yield. Significantly more marketable yields were recorded during the 2009/2010 growing season compared with 2008/2009 ($t = -5.1$, $P < 0.002$). For both 2008/2009 and 2009/2010 growing seasons, marketable yields from strawberry plants

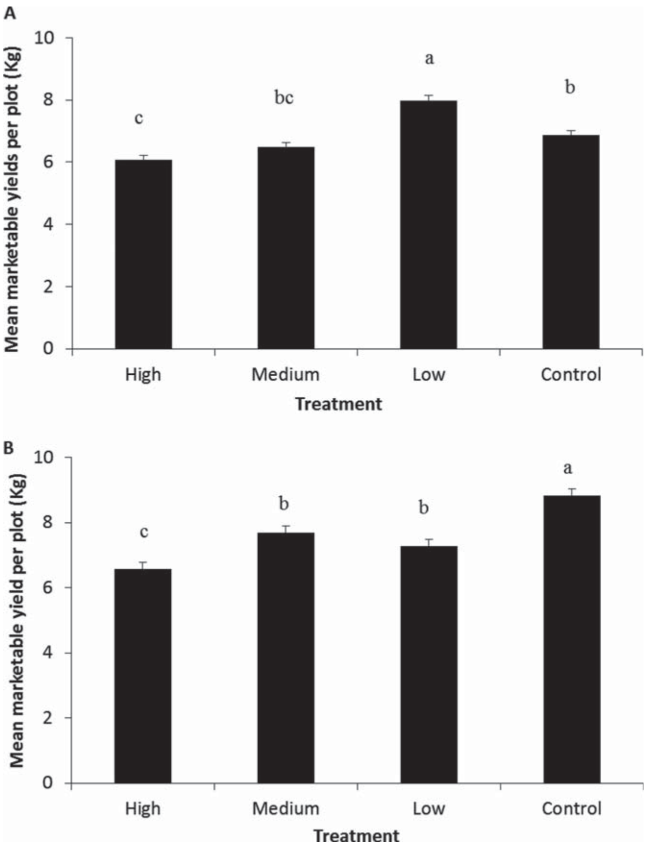

Fig. 2. Mean harvested marketable yield from different *T. urticae* densities on field-grown strawberries for the (A) 2008/2009 and (B) 2009/2010 growing seasons. Columns with same letters are not significantly different ($P \leq 0.05$).

were significantly influenced by mite infestation levels (2008/2009, $F = 22.83$; df = 3, 288; $P < 0.0001$; 2009/2010 and $F = 20.12$; df = 3, 192; $P < 0.0001$) (Fig. 2A and B). For the 2008/2009 growing season, the low-infestation-level treatment had the highest mean marketable yield (mean = 8.0 kg; Tukey's test; $P = 0.05$) that was significantly different from all other treatments. The high mite infestation level had lowest marketable yield (mean = 6.1 kg), which was significantly different from control (mean = 6.9 kg) but similar to medium (mean = 6.5 kg). In the 2009/2010 growing season, marketable yields were highest in control treatments (8.8 kg), intermediate in low (7.3 kg) and medium (7.7 kg) infestation levels, and lowest in high infestation level (6.6 kg).

Effect of Accumulated Mite-Days on Marketable Yield of Strawberries. Total accumulated mite-days for the entire season were 9,042, 6,460, 4,056, and 200 mite-days for the high, medium, low, and control mite infestation density levels, respectively, in the 2008/2009 growing season. During the 2009/2010 growing season, fewer mite-days were accumulated on the strawberry plants in comparison with the previous season. At the end of the growing season, the strawberry plants had accumulated 2,646, 1,140, 1,059, and 280 mite-days on the high, medium, low, and control infestation levels, respectively. There is a decrease in marketable yields as the mite-days increase (Fig. 3). Regression analysis revealed that there was a significant effect of mite-days on strawberry marketable yields ($F = 5.55$, df = 1, 18; $P < 0.0030$; $y = 12.59 - 0.244x$; $R^2 = 0.24$) in 2008/2009 but not in 2009/2010 ($F = 3.13$; 1, 14; $P = 0.09$; $y = 18.62 - 1.21x$; $R^2 = 0.18$). During the 2008/2009 growing season, the effect of mite populations on marketable yields was observed from week 9 until the end of the season when strawberry plants had accumulated 4,924 mite-days on the high-infestation-level treatment. In 2009/2010, a significant effect of twospotted spider mites on the marketable yields was only recorded on the last two sampling dates.

Effect of Weather Factors on Twospotted Spider Mite Population Dynamics. Temperatures were lower early in the 2009/2010 season (December and January) than in the 2008/2009 growing season (Fig. 4A). There were more days below the freezing temperature in the 2009/2010 growing season than in the 2008/2009 season in the months of January and February. For 13 consecutive days in January, temperatures remained below freezing point in 2010. Accordingly, more DD were accumulated during the 2008/2009 growing season as compared with the 2009/2010

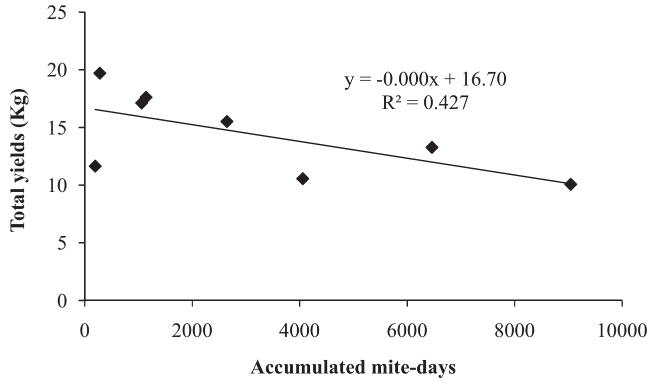

Fig. 3. Relationship between overall yield and accumulated mite-days on strawberry plants for the two strawberry growing seasons combined.

season (Fig. 5) by using a basal temperatures of 10°C (Herbert 1981). At day 34 (10 January 2010), hardly any DD were accumulated during the 2009/2010 growing season as compared with 233 DD generated during the previous year at the same time. Accumulated DD remained <100 for most of the growing season in 2009/2010, and a notable increase was observed after day 91 (Fig. 5).

In total, 352.3 mm of rainfall was recorded in the 2009/2010 growing season as compared with 123.7 mm in the previous season. The highest rainfall recorded was 34.5 and 83.6 mm in the 2008/2009 and 2009/2010 growing seasons, respectively (Fig. 4B). Regression analysis revealed that rainfall and temperature, respectively, were significant negative and positive predictors on mite-days in the 2009/2010 growing season (rainfall; $t = -1.99$, $P = 0.04$; temperature; $t = 7.77$, $P < 0.0001$; $y = 310 - 3.59x_1 + 67.09x_2$; $R^2 = 0.20$) but not the 2008/2009 growing season (rainfall $t = -1.58$, $P = 0.11$; temperature; $t = 0.27$, $P = 0.79$; $y = 2{,}014 - 24.7x_1 + 12.57x_2$; $R^2 = 0.0092$), where x_1 is the rainfall and x_2 is the temperature.

Results from the regression analysis ($ln(x + 1)$ against the time of exposure) are as follows: 2008/2009: $F = 356.70$; df = 1, 178; $P < 0.0001$; $y = 0.06x + 0.53$;

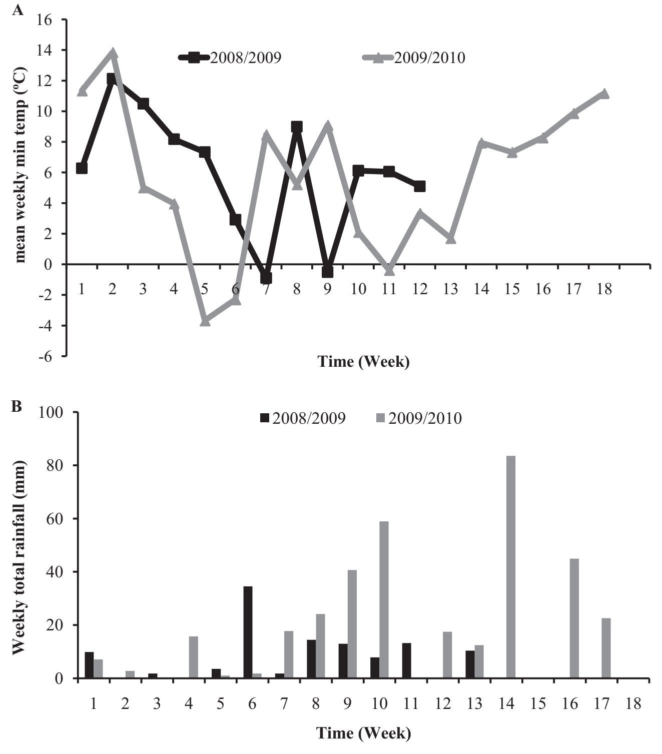

Fig. 4. Weather parameters including (A) mean weekly minimum temperatures in °C and (B) weekly total rainfall recorded during the 2008/2009 and 2009/2010 strawberry growing seasons at Citra, FL.

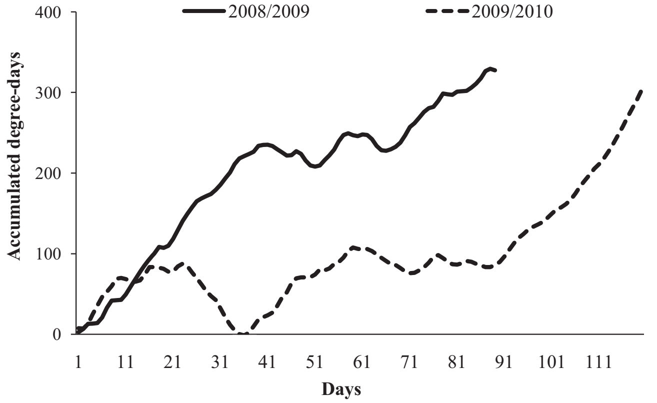

Fig. 5. Accumulated degree-days for twospotted spider mites on strawberries during the 2008/2009 and 2009/2010 growing seasons. Day 1 indicates when the spider mites were introduced on strawberry plants in the field.

$R^2 = 0.67$; and 2009/2010: $F = 177.12$; df = 1, 190; $P < 0.0001$; y = 0.03x – 0.36; $R^2 = 0.48$, an indication that the rate of increase of twospotted spider mites was higher during the 2008/2009 growing season than in 2009/2010 (0.06 vs. 0.03).

Insect Pests and Beneficial Insects. In both years in addition to mites, two other pests recorded on strawberry leaves were melon aphids, *Aphis gosspyii* Glover, and whiteflies *Bemisia tabaci* (Gennadius) (immature). For both the 2008/2009 and 2009/2010 growing seasons, there were no significant differences in mean number of aphids (2008/2009; $F = 2.38$; df = 3, 195; $P = 0.07$; 2009/2010; $F = 0.74$; df = 3, 268; $P = 0.53$) and whiteflies (2008/2009; $F = 1.30$; df = 3, 195; $P = 0.28$; 2009/2010; $F = 0.38$; df = 3, 268; $P = 0.76$; Table 1) among the treatments.

The two main beneficial insects recorded were six-spotted thrips, *Scolothrips sexmaculatus* (Pergande), and big-eyed bugs (*Geocoris* spp.). In 2008/2009, the control had significantly lower numbers of six-spotted thrips compared with high and medium infestation levels ($F = 3.12$; df = 3, 195; $P = 0.02$; Table 1), whereas no significant differences were recorded across the treatments in 2009/2010 ($F = 2.37$; df = 3, 268; $P = 0.07$). No significant differences were observed in big-eyed bugs eggs recorded between treatments during the 2008/2009 growing season ($F = 1.28$; df = 3, 195; $P = 0.28$). However, in the 2009/2010 field-season, the number of big-eyed bugs recorded in the high mite infestation treatment was significantly higher than the control ($F = 3.66$; df = 3, 268; $P = 0.01$) (Table 1).

Table 1. Mean number of insect pests and beneficial insects recorded on field-grown strawberries in the 2008/2009 and 2009/2010 growing seasons in Citrus County, FL

Treatment	Mean ± SEM			
	Insect pests		Beneficial insects	
	Aphid	Whitefly nymph	Sixspotted thrips	Big-eyed bugs egg
2008/2009				
High	6.8 ± 0.9	1.2 ± 0.3	2.3 ± 0.5a	1.6 ± 0.3
Medium	9.3 ± 0.9	0.7 ± 0.3	1.7 ± 0.5a	1.3 ± 0.3
Low	7.6 ± 0.9	1.3 ± 0.3	1.5 ± 0.5ab	1.2 ± 0.3
Control	5.7 ± 0.9	0.6 ± 0.3	0.3 ± 0.5b	0.8 ± 0.3
(*F*; *P*)	2.38; 0.07	1.30; 0.28	3.12; 0.02	1.28; 0.28
2009/2010				
High	1.6 ± 0.6	3.6 ± 0.9	0.4 ± 0.1	1.9 ± 0.3a
Medium	1.3 ± 0.6	2.9 ± 0.9	0.3 ± 0.1	1.5 ± 0.3ab
Low	2.4 ± 0.6	4.3 ± 0.9	0.4 ± 0.1	1.9 ± 0.3a
Control	2.1 ± 0.6	3.8 ± 0.9	0.02 ± 0.1	0.8 ± 0.3b
(*F*; *P*)	0.74; 0.53	0.38; 0.76	2.37; 0.07	3.66; 0.01

Means in columns with the same letter are not significantly different ($P = 0.05$); df were 3, 195 and 3, 268 in 2008/2009 and 2009/2010 strawberry growing seasons, respectively.

Discussion

Twospotted Spider Mite Population. Spider mite population increased with time during the growing seasons, with noticeable growth observed when the temperature began to increase above 20°C after mid-February in 2008/2009 and in March in 2009/2010. More DD were accumulated during the 2008/2009 growing season than in the 2009/2010 season. As a result, the rate of increase was higher as compared with the rate observed in 2009/2010. It takes 169.8 DD for twospotted spider mites to complete a generation (Herbert 1981), and therefore, 27 d after spider mites' introduction in the field, mite population could have potentially completed a generation in the 2008/2009 growing season. In contrast, this was much later in the season (day 101) in 2009/2010 when 168 DD were achieved. Developmental period for twospotted spider mites is temperature-dependent (Shih et al. 1976, Bounfour and Tanigoshi 2001, White and Liburd 2005). The optimum developmental temperature range for twospotted spider mites is 23–29°C for a period of 7–12 d to complete its lifecycle from egg to adult.

January and February were the coldest months of the growing season with 13 and 9 d below freezing temperatures, respectively, in 2009/2010 compared with only 9 and 4 d, respectively, in 2008/2009. During 2008/2009 season, the 9 d of freezing temperatures were sporadic, occurring at different times in the month of January; however, in 2009/2010, the 13 d of freezing temperatures occurred consecutively around mid-January. As a result of the low temperatures, twospotted spider mites' development in 2009/2010 was heavily impacted in January, and no treatment differences were recorded in all sampling dates during that month. The mite population barely reached 15 motiles per strawberry leaf as compared with mite levels recorded in January during the previous season that had reached up to 108 mite/leaf on the high-infestation-level treatment.

More rainfall was recorded during the 2009/2010 growing season than in the 2008/2009 season. The maximum rainfall received per week during the 2008/2009 growing season was 34.5 mm and a weekly average of 10.5 mm for the entire season as compared with a maximum of 83.6 mm and weekly average of 20.4 mm in the 2009/2010 growing season. Direct effects of high rainfall include washing off or flooding the mites on the strawberry leaves. Over-head irrigation has been previously used to "wash off" mites on ornamental plants, including roses and carnations. Boyne and Hain (1983) achieved up to 93% reduction in Spruce spider mite (*Oligonychus ununguis* Jacobi) population on Fraser fir, *Abies fraseri* (Pursh) Poir, in comparison with the control plants by using simulated rainfall (2.54 cm per day) in a greenhouse study.

Rainfall patterns can also affect soil moisture levels, which are known to influence twospotted spider mites' population levels in field-grown strawberries. White and Liburd (2005) found three times as many eggs and motiles on strawberry plants exposed to low or moderate soil moisture levels compared with high soil moisture. In our study, we presumed that these two weather-related factors may have contributed to the differences observed in twospotted spider mites' population during the two growing seasons. Weather parameters will not only affect the twospotted spider mites' population physiologically and mechanically but also indirectly through host quality changes (Knapp et al. 2006).

Two predatory insects, six-spotted thrips and big-eyed bugs, were recorded during the two growing seasons and tended to be positively associated with twospotted spider mites' populations. These predatory insects are generalists in their feeding behavior, a factor that has been cited as a limitation for their use in biological control programs against twospotted spider mites (Oatman and McMurtry 1966). In our studies, these predatory insects did not contribute to a significant reduction in the number of twospotted spider mites, as the high-infestation-level treatment also had the highest number of spider mites at the end of the experiment. Six-spotted thrips and big-eyed bugs have been reported previously in field-grown strawberry associated with high mite populations (Oatman et al. 1985, Raworth 1990, Fraulo et al. 2008). Laboratory studies evaluating the predatory ability of big-eyed bugs among other predatory insects on twospotted spider mites concluded that big-eyed bugs preferred to feed on other plant insects such as aphids as opposed to spider mites (Rondon et al. 2004).

Aphids and whiteflies were present in the early growing seasons, but their numbers decreased as the temperatures decreased. These two pests were not present in significant numbers in either growing seasons, and therefore, it is likely they did not affect the marketable yield of strawberries.

Marketable Yield. Strawberry yields were higher in the 2009/2010 growing season than in 2008/2009. Differences in yield could partially be attributed to differences in mite populations between the two seasons. In addition, the 2009/2010 season was cooler and a longer flowering period was observed, increasing plant productivity. Strawberry plants did not produce any flowers or fruits for most of January, and therefore, the plants had the reserves available and subsequently produced flowers/fruits for a longer period. A significant yield reduction was detected on the high-infestation-level treatment when mite population on the strawberry leaves was 206 ± 74 (mean ± SE) in mid-February during the 2008/2009 growing season. Yield on these plots was 25% lower than the low-infestation-level treatment that had the highest yield and 15% lower than the control plots. The high yields in the low-infestation-level treatment could be related to high crop vigor within those plots and low mite population (<100 mites per leaf). During the 2009/2010, the effect of mite on marketable yields was recorded late in the season. The average mite per leaf was 78 ± 47 on the high-infestation-level treatment, and the plots had 21% lower marketable yield than the control plots. Strawberry yield recorded at this point was affected by the mite numbers on the leaves at the time of flower initiation (≈2.5 wk before). At high infestation, twospotted spider mites' injury can suppress flower and leaf development (Sances et al. 1982). Accordingly, it can be deduced that the effect of mites on the marketable yields on strawberries was realized when strawberry plants had reached ≈80 and 50 mites per leaf at the end of January in 2008/2009 and mid-March 2009/2010 growing seasons, respectively. Yield reduction from this time progressed slowly to the end of the season, even though mite population densities per leaf was much higher than 80 or 50 by the end of the season in 2008/2009 and 2009/2010 growing seasons, respectively.

It has been shown that yield reduction because of twospotted spider mites' feeding is as a result of a decrease in the number of berries produced per strawberry plant but not the fruit size (Sances et al. 1981, Walsh et al. 1998). Removal of chloroplasts (hence chlorophyll) through spider mites' feeding results in a decrease in the use of radiant energy with consequent reduction in vegetative growth and yield (Sances et al. 1981, 1982; Kielkiewicz 1985). However, strawberry plants have been reported to have a high tolerance to mite damage as compared with other fruit crops such as apples because of the plant response to mite feeding (Campbell et al. 1990). Twospotted spider mites' feeding causes damage to epidermal cells on the lower surface and spongy and palisade parenchyma cells (Sances et al. 1979, Campbell et al. 1990). In studies to investigate the cellular damage caused by twospotted spider mites feeding on strawberry leaves, scans and electron microscopy images showed that spider mite penetration during feeding caused distortion of chloroplast only in penetrated cells but not in the neighboring cells (Sances et al. 1979), suggesting these plants tolerate mite injury in comparison with other fruits crops (Campbell et al. 1990).

Previous studies have reported lower or higher mite densities per leaf as the level that causes yield reduction in strawberries because of mite injury. Walsh et al. (1998) reported that detectible yield reduction occurred at mite densities >3 per strawberry leaf on a day-neutral strawberry variety 'Selva' in California. On a short-day strawberry variety 'Tufts,' plants tolerated up to 150 mites per leaf before yield reduction was detected (Wyman et al. 1979). These numbers seem to vary with strawberry variety, season, prevailing weather conditions, and the time of mite infestation. In our study, weather differences between the two growing seasons affected the time of mite population increase. Mite populations during the 2009/2010 growing season remained low during early growing period and only increased toward the end of the season hence less damage was realized from mites over the course of that season. Sances et al. (1981) showed that the time of mite infestation on strawberry leaves can affect the amount of damage from mite injury. High mite numbers would be required to cause damage when infestation occurs late in the season.

In practice, management decisions for twospotted spider mites in Florida are influenced by market prices. Strawberry prices remain high until strawberry fruits from California become available on the market. Market prices have a great impact on growers' decision to spray or not to spray against mite populations. In some cases, the grower might decide to leave the plants without spraying for mites if the prices are not too favorable for fresh market. Management decision may also be affected by other factors such as crop condition (vigor) and targeted markets (fresh vs. processing berries).

Our study confirmed that control of twospotted spider mites on field-grown strawberries is important in preventing yield losses. As we observed, there was a decrease in yields as the mite-days increase. In addition, we showed that early infestation coupled with favorable temperatures for twospotted spider mites will result in economic losses starting from the mid-season. Therefore, early treatment of spider mites is necessary on field-grown strawberries to prevent yield losses later in the season. Because of the variation between the two growing seasons, we cannot determine an ET for twospotted spider mites in strawberries, but we can suggest an action threshold based on mite densities in our study. An action threshold level of <80 mites per leaf is recommended for temperatures >18°C. The prevailing weather conditions will not only affect the mite population establishment but also the plant productivity and therefore an important factor to consider when making management decision for twospotted spider mites in strawberries.

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