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The Effect of Summer Cover Crops and Strawberry Cultivars on the Twospotted Spider Mite, *Tetranychus urticae* (Acari: Tetranychidae) and the Predatory Mite, *Neoseiulus californicus* (Acari: Phytoseidae) in Organic Strawberry Production Systems in Florida

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Abstract

The twospotted spider mite, *Tetranychus urticae* (Koch) (Acari: Tetranychidae), is a key pest of strawberries and many other crops worldwide. Cover cropping, selecting tolerant or resistant cultivars, and biological control are important strategies of an organic management plan. In this study, we examined the effect of summer cover crops and strawberry cultivars on populations of *T. urticae* and a commercially available predatory mite, *Neoseiulus californicus* McGregor (Acari: Phytoseiidae), commonly used for *T. urticae* management in Florida. In the 2013–2014 season, four cover crops and eight strawberry cultivars were screened at the research station and on a commercial organic strawberry farm. The following season, the most promising cover crops (sunn hemp and hairy indigo) and cultivars, 'Sensation', 'Strawberry Festival', and 'Winterstar' were tested at the research station and on two small organic farms. In the 2016–2017, 2017–2018, and 2018–2019 seasons, a 4-way mix of cover crops was compared to sunn hemp and hairy indigo. In 2016–2017, 'Florida Radiance' was added to the three previously selected cultivars. 'Florida Beauty' replaced 'Strawberry Festival' in 2017–2018 and 2018–2019, and 'Florida Brilliance' replaced 'Winterstar' in 2018–2019. The effects of summer cover crops on both *T. urticae* and *N. californicus* were minimal. 'Florida Brilliance', 'Florida Radiance', 'Sensation', 'Strawberry Festival', and 'Winterstar' had lower *T. urticae* populations and higher yields in most seasons at most locations. The establishment and abundance of *N. californicus* was similar on these cultivars and was generally higher where *T. urticae* populations were higher. Implications for organic strawberry production in Florida are discussed.

Key words: twospotted spider mite, predatory mite, cover crop, strawberry, cultivar

Strawberry (*Fragaria* × *ananassa* Duch. (Rosales: Rosaceae)) production is threatened by many arthropod pests and diseases. In Florida, the twospotted spider mite, *Tetranychus urticae* (Koch) (Acari: Tetranychidae), is the primary pest that reduces strawberry yield (Nyoike and Liburd 2013). Twospotted spider mites have not been reported to vector any plant diseases. However, they feed on strawberry leaves by sucking the cell cytoplasm, consequently reducing chlorophyll content, transpiration rate (DeAngelis et al. 1983, Reddall et al. 2004), plant vigor, and yield (Wilson 1993). Twospotted spider mites usually move within and among plants by crawling. Long-distance movement is wind-assisted (Margolies and Kennedy 1985) or by human interference (mechanical tools and clothing).

In organic strawberry production, cultural practices are usually the first line of defense in an integrated pest management (IPM) program against pests and diseases (Carroll and Pritts 2021). This involves cultural tactics such as choosing the plant material, including cultivars. In assessing crop cultivars, host plant resistance is a major strategy in the IPM toolbox (Kogan 1994). The cultivar's relative tolerance or susceptibility to arthropod pests is important in organic strawberry production (Afifi et al. 2010, Underwood et al. 2011) because chemical control is limited to only a few pesticides of botanical or biological origin or synthetics on the National List of Allowed and Prohibited Substances (AMS-USDA 2021).

Generally, cultivar selection for a crop depends on factors such as flavor, shelf life, fruit size, and quality. However, leaf surface and architecture are important factors that could serve as a characteristic or diagnostic feature among cultivars of the same plant species. For instance, leaf architecture can determine the abundance of mites and can influence predator-prey interactions (Walter 1996). Plant cultivars vary in their susceptibility to insect pests (Raina et al. 1984), mite pests (Gilbert et al. 1966, Regev and Cone 1975), diseases (Hershman et al. 1990), and weeds (Zhao et al. 2006, Mahajan and Chauhan 2011). Cultivars differ genotypically, which gives rise to many characteristics, including leaf texture, volatile composition, and yield. This may account for differential levels of arthropod pest establishment. Cultivar differences may also account for variation in plant vigor and rate of transpiration as influenced by the leaf thickness. Strawberry leaves of different cultivars may vary in their abundance of trichomes or leaf hairs, which could serve as a habitat for predatory mites or protect *T. urticae* from predation by insects. Figueiredo et al. (2013) found that the distance traveled by *T. urticae* on strawberry leaves was negatively correlated with the density of glandular trichomes.

Apart from the inherent traits of strawberry cultivars, the choice of cultural practices is an important factor that may influence the susceptibility of crops to pests, weeds, and diseases (White and Liburd 2005). Cropping practices can influence the level of pest infestation and the abundance of natural enemies. For example, Sigsgaard et al. (2014) reported a lower infestation level of *Acleris comariana* (Lepidoptera: Tortricidae) on organically produced strawberry compared with strawberry produced by conventional means. In a study conducted by Iwassaki et al. (2015), the *T. urticae* population was significantly lower on strawberry fields managed with integrated (biological and chemical) control strategies compared with those managed using conventional (chemical) management methods alone. Nyoike and Liburd (2014) found that re-using plastic mulch with or without thatch had no significant effect on plant size, pest populations, and beneficial insects. However, re-using the mulch with thatch suppressed weed growth and increased the incidence of fungal diseases in field-grown strawberries.

Cover crops have become common in sustainable agriculture, especially because of the added fertility inputs, enhanced crop performance, and increased biodiversity (Ingels et al. 1994). Cover crops have been reported to suppress insect pest populations (McNeill et al. 2012), suppress weed growth (Teasdale 1996, Collins et al. 2008), increase soil nutrients thus, soil fertility (Ingels et al. 2005), reduce nematodes (McSorley 1998, 1999), reduce soil-borne pathogens (Hansen et al. 1990), and reduce environmental problems such as soil erosion. Cover crops may affect mite and predator populations. The potential mechanism is that cover crops will improve soil structure and fertility, resulting in more robust strawberry growth and improve plant defense against pests. Another potential mechanism is that cover crops would influence off-season pests and beneficial arthropods in a manner that suppresses *T. urticae*. It has also been reported that there is a positive correlation between the level of synthetic nitrogen fertilization and *T. urticae* population growth (Alizade et al. 2016). However, it is unknown whether cover crops add enough nitrogen to the soil to impact *T. urticae* population growth.

Predatory mites such as *Phytoseiulus persimilis* Athias-Henriott and *Neoseiulus californicus* McGregor (Acari: Phytoseiidae) are effective natural enemies of *T. urticae* (Oatman et al. 1977a, b; Rhodes et al. 2006; Rhodes and Liburd 2006; Fraulo and Liburd 2007). *Neoseiulus californicus* is an effective biological control agent of spider mites (Rhodes and Liburd 2006, Rhodes et al. 2006) and tarsonemid mites like cyclamen mites, *Steneotarsonemus pallidus* Banks, (Acari: Tarsonemidae) (Easterbrook et al. 2001) on various crop plants, including strawberry, without altering the arthropod diversity (Fraulo et al. 2008). *Phytoseiulus persimilis* mites are type I predators that specialize on Tetranychid mites (McMurtry and Croft 1997). They can quickly reduce *T. urticae* populations, but do not persist in the field once the *T. urticae* population crashes (Gilstrap and Friese 1985). In contrast, *N. californicus* is a more generalist predator and can persist in agricultural systems by feeding on pollen and other prey in the absence of *T. urticae* (Croft et al. 1998, McMurtry and Croft 1997), although their intrinsic rate of increase is higher when *T. urticae* is the primary food source compared to other alternate food sources (Khanamani et al. 2017). Gotoh et al. (2004b) found the intrinsic rate of natural increase of *N. californicus* was 0.274 at 25°C; this was lower than the intrinsic rate of 0.336 reported for *T. urticae* by Shih et al. (1976), suggesting that *N. californicus* is reproducing at a lower rate and that the constant availability of *T. urticae* sustains emerging *N. californicus* populations. *Neoseiulus californicus* shows a type II functional response to the consumption of *T. urticae* eggs (Gotoh et al. 2004a, Ahn et al. 2010).

Although several studies have looked at strawberry cultivar preference in *T. urticae* (Costa et al. 2017, Figueiredo et al. 2013, Garcia et al. 2017, Gonzalez-Dominguez et al. 2015, Karlec et al. 2017, Rezaie et al. 2013), none have looked at cultivar preference in Florida organic strawberry production. Also, new varieties are released on a regular basis and need to be evaluated. Only a few studies have examined the influence of host plant cultivar differences on the fecundity of *T. urticae* (McFarlane and Hepworth 1994, Costa et al. 2017). Cultivars bred for conventional production systems may perform differently in organic production systems. This study was conducted to determine the effect of summer cover crop and strawberry cultivar on *T. urticae* and the predatory mite *N. californicus*. We hypothesized that different cover crops would affect mite and predator populations and that strawberry cultivars would differ in their susceptibility to *T. urticae*. The objectives of this study were to evaluate how selected cover crops in organic strawberry affect mite and predator populations. Secondly, to determine how strawberry cultivars selected for organic production affect *T. urticae* and its predator, *N. californicus* populations.

Materials and Methods

Research Station Trials

Study Site

Field trials were conducted at the University of Florida Plant Science Research and Education Unit (PSREU) in Citra, Marion County, FL (29°25′N, 82°9′W) in the 2013–2014, 2014–2015, 2016–2017, 2017–2018, and 2018–2019 seasons. Each trial lasted for an entire strawberry production season from planting in early to mid-October through the end of March or into early April each season. Prior to planting strawberries in all seasons, soil samples were collected and analyzed for nutrient content, sampled for the presence of nematodes, and level of nematode infestation, if any. No nematode infestation was found in any trial year.

In the 2013–2014 and 2014-2015 seasons, an Organic Materials Review Institute approved fertilizer, Nature Safe (10-2-8), all season fertilizer was applied at the rate of 1681 kg/ha before transplanting strawberries. After transplanting, an organic fertilizer (3-0-6; N-P-K, Howard Fertilizers, Orlando, FL) was applied at 8 kg/ha N, and 16 kg/ha K weekly, through the drip irrigation. To manage diseases, organic fungicides Double Nickel, Regalia, and Actinovate (Table 1) were applied in rotations every two weeks through drip irrigation.

In the 2016–2017, 2017–2018, and 2018–2019 seasons, Nature Safe (10-2-8) all season fertilizer was applied at the rate of 1681 kg/ha before transplanting strawberries as in previous seasons. A 50/50 mix of fish fertilizer (5-1-1; N-P-K) and sodium nitrite (3-0-6; N-P-K) was applied weekly at a rate of 0.58 kg/ha. Diseases were managed with organic fungicides (Table 1). Applications were made two days before predicted rain events and included RootShield Plus applied through the drip irrigation in combination with a foliar application of one of the organic fungicides listed in Table 1. In 2017–2018 and 2018–2019, a pre-plant application of RootShield Plus was made by dipping the transplants before planting. On 27 November and 4 December 2018–2019, Cueva was applied as a foliar application to manage an outbreak of angular leaf spot.

Plot Layout and Experimental Design

The experimental design was a split-plot design with the whole plots arranged in a randomized complete block with 4 replications. The whole plot factor consisted of cover crops and the sub-plot factor was strawberry cultivars. Strawberry cultivars were randomized in each whole plot following the termination of the cover crop treatments. There were 5 cover crop treatments in 2013–2014 including: 1) hairy indigo, *Indigofera hirsuta* L. (Fabales: Fabaceae), 2) sunn hemp, *Crotalaria juncea* L. (Fabales: Fabaceae), cv. Tropic Sun, 3) short flower rattlebox, *Crotalaria breviflora* DC (Fabales: Fabaceae), 4) American jointvetch, *Aeschynomene americana* L. (Fabales: Fabaceae), and 5) a no cover crop (weedy) control. Individual whole plots were 6.1 m × 1.5 m spaced at 1.8 m apart, with 7.6 m alley (buffer zone) between blocks. During the 2014–2015 growing season, only three cover crop treatments were evaluated. These treatments included: 1) *I. hirsuta*, 2) *C. juncea*, and 3) weedy control. For the trials in 2016–2017, 2017–2018, and 2018–2019, there were four cover crop treatments: the same three treatments used in 2013–2014 and a four-way mix consisting of hairy indigo, sunn hemp cv. AU Golden, *A. Americana*, and slender leaf rattlebox, *C. ochroleuca* G. Don (Fabales: Fabaceae).

Planting

The cover crops were planted in July during the summer season preceding the strawberry season in all years. The cover crops were terminated using a flail mower in September of all years, in readiness for planting of strawberries.

In 2013, bare root transplants of eight commercial strawberry cultivars: 'Albion', 'Camarosa', 'Strawberry Festival', 'Florida Radiance', 'Treasure', 'Winterstar', Proprietary 1 and 2 were transplanted in October 2013. All the strawberry transplants except for Proprietary 1 and 2 were purchased from C. O. Keddy Nursery Inc., Lakeville, Nova Scotia. Strawberry cultivars were planted on raised beds covered with Guardian plastic mulch (DNM Ag Supply Inc. Calabasas, CA) in alternate double rows, according to standard strawberry planting techniques in Florida (Whitaker et al. 2016). The transplants were spaced at 0.4 m along and between rows. Transplants were watered regularly using the overhead sprinkler system for 24 h for the first five days and for five hours per day for the next five days to allow for plant establishment. The drip irrigation system was used afterward until the end of the season. The drip irrigation was programmed to run for three times each day for 45 min each time, at a flow rate of 1.89 liter/min/30.5 m of drip tape (Chapin).

During the second growing season, October 2014 through April 2015, three strawberry cultivars from the previous growing season that harbored the lowest *T. urticae* population and had high fruit yield were transplanted in the open field. These included 'Winterstar', 'Sensation', and 'Strawberry Festival'. 'Florida Radiance' was replaced by 'Sensation' because the latter had performed well under a high tunnel production system in a separate study (Olaniyi et al. unpublished data). Strawberry plug transplants were used instead of bare root transplants to reduce the water requirements because overhead irrigation is not required for establishment of plugs. Transplant spacing and drip irrigation were the same as in the previous season.

Strawberry plugs, obtained from Production Lareault, Inc. in Quebec, Canada, were also used in the 2016–2017, 2017–2018, and 2018–2019 seasons. Four strawberry cultivars were tested in each season (Table 2). 'Florida Radiance' was included as it is replacing

Table 1. List of organic fungicides used to manage diseases and label rates at which each was applied

Brand Name	Active Ingredient	Application type	Rate	Company
Rootshield Plus WP	*Trichoderma harzianum* Rifai strain T-22 and *T. virens* strain G-41	Pre-plant dip via drip irrigation	47 ml / 100 liter water 1.1 kg/ha	BioWorks Victor, NY
Actinovate AG	*Streptomyces lydicus* WYEC 108	foliar	0.56 kg/ha	Valent USA LLC St. Louis, MO
Double Nickle LC	*Bacillus amyloliquefaciens* strain D747	foliar	3.36 kg/ha	Certis USA LLC Columbia, MD
Regalia	Extract of *Reynoutria sachalinensis*	foliar	2.34 liter/ha	Marrone Bio Innovations Davis, CA
Serenade Optimum	QST 713 strain of *Bacillus subtillis*	foliar	1.5 liter/ha	Bayer Cropscience LP Research Triangle park, NC
Cueva	copper octanoate (copper soap)	foliar	19 liter/ha	Certis USA LLC Columbia, MD

Table 2. Strawberry cultivars planted each season

Treatment #	2016–2017	2017–2018	2018–2019
1	'Strawberry Festival'	'Florida Beauty'	'Florida Beauty'
2	'Florida Radiance'	'Florida Radiance'	'Florida Radiance'
3	'Sensation' 'Florida127'	'Sensation' 'Florida127'	'Sensation' 'Florida127'
4	'Winterstar'	'Winterstar'	'Florida Brilliance'

'Strawberry Festival' as the industry standard. In 2017–2018, 'Florida Festival' was replaced by a newly released cultivar, 'Florida Beauty', to evaluate this new cultivar. In 2018–2019, 'Winterstar' was unavailable and, therefore, replaced by another newly released cultivar, 'Florida Brilliance'. Transplant spacing and drip irrigation were the same as in the previous seasons.

Predatory Mites

Neoseiulus californicus was purchased from Koppert Biological Systems (Howell, Michigan). The predatory mites were packaged in 500 ml bottles with sections of mesh screen on the lid to allow for air circulation. Each bottle contained ~25,000 *N. californicus* at different motile stages mixed with inert materials such as vermiculite. Predatory mites were kept in the laboratory for one to three days before use, depending on the prevailing weather conditions. A viability test was done before release. This involved observing mites in a 5 cm diam. Petri dish to make sure they are active before releasing them in the field. *Neoseiulus californicus* were released by gently shaking containers over *T. urticae* infested strawberry plants.

In 2013–2014 and 2014–2015, *N. californicus* were released onto strawberry plants nine weeks after transplanting at the rate of 1 predatory mite to 10 *T. urticae*. At this time, *T. urticae* populations had established in the field. In 2016–2017, 2017–2018, and 2018–2019, a preventative release of *N. californicus* (1 predatory mite per 25 m^2) was made in mid-November when *T. urticae* populations were low. This was the only release made in 2016–2017 as the *T. urticae* population remained below the threshold of 10 *T. urticae* per leaf throughout the season. In 2017–2018 and 2018–2019, curative releases at the rate of 1 predatory mite per 10 *T. urticae* were made when the threshold of an average of 10 *T. urticae* per leaf was reached. These applications occurred on 11-Jan-2017 and 12-Jan-2018. A curative release of *Phytoseiulus persimilis* at the rate of 20 predatory mites per m^2 was made on 15-Feb-2018 and 1-March-2019 to further reduce *T. urticae* populations. Organic JMS Stylet-Oil (JMS Flower Farms, Inc. Vero Beach, FL) was applied at the rate of 2.3 liter/ha before the release of *P. persimilis* in 2019.

Sampling

Sampling began at four weeks after transplanting when transplants reached the five-trifoliate leaf stage. Plants were sampled weekly by randomly collecting three to five of the older and lower trifoliates of each strawberry variety from every treatment plot (White and Liburd 2005). In the 2018–2019 season, because the effects of cover crops were negligible in all preceding seasons, leaf samples were collected from each variety in only six of the main plots to compare 'Florida Brilliance' to the other cultivars. The collected leaf samples were placed in labeled Ziploc (Racine, WI) bags in a cooler and transported back to the Small Fruits and Vegetable IPM (SFVIPM) laboratory in Gainesville, Florida. Each trifoliate was examined under a stereo microscope (Leica M80, Buffalo Grove, IL) in the SFVIPM laboratory in the Entomology and Nematology Department, at the University of Florida, Gainesville, FL. All arthropods, at different stages of development found on the leaves were identified, counted, and recorded according to the cover crop and strawberry cultivar. The sampling period was approximately 19 wk for each year.

On-farm Trials

In the 2013–2014 season, an on-farm trial was conducted at a commercial organic strawberry farm in Plant City, Hillsborough County, FL. The experiment was conducted at Plant City because it is the major hub for strawberry production in Florida. The trial, including management practices, was identical to the one conducted at the research station except that leaf samples were collected once every two weeks because of the distance from the university.

In the 2014–2015 season, on-farm trials were conducted at two small organic farms, one in west Gainesville, Alachua County, FL. and one in Hawthorne, Alachua County, Florida. The trials on both farms were identical to the trial at Citra with three exceptions involving predatory mite releases, sampling, and yield. A preventative release of *N. californicus* at the rate of 1 predatory mite per 25 m^2 was made on 12-Nov at the Gainesville farm and 13-Nov at the Hawthorne farm. Curative releases at the rate of 1 predatory mite per 10 *T. urticae* were made when the threshold of 10 *T. urticae* per leaf was reached. This occurred on 11 Feb at the Gainesville farm and 16 Jan at the Hawthorne farm. At the request of the growers, leaf samples were collected every other week. Yield data was not collected because the growers were harvesting the fruit to market it.

In 2017–2018 and 2018–2019, on farm trials were again conducted on two small organic strawberry farms, one in Hawthorne, FL where one of the 2014–2015 on-farm trials was conducted and a farm in East Gainesville, FL. In these on-farm trials, the growers managed the research plots the same way they managed the rest of their strawberries. The Gainesville farm followed the standard practice of raised beds with black plastic mulch and drip irrigation, while the Hawthorne farm grew strawberries on bare raised beds with straw mulch and overhead irrigation. At the Gainesville farm, strawberry plugs were planted in both years while at the Hawthorne farm plugs were used in the first year and bare-root transplants were used in the second year. Neither grower released predatory mites at any time, so naturally occurring populations of predatory mites were monitored. The experimental design was the same as that at the research station with a reduced number of cover crop treatments and cultivars. The cover crop treatments included sunn hemp cv. Tropic Sun, hairy indigo, and the four-way mix. In 2017–2018, the three strawberry cultivars evaluated included 'Florida Beauty', 'Florida Radiance', and 'Sensation'. In 2018–2019, 'Florida Beauty' was replaced by 'Florida Brilliance' at the request of the growers. As with the other on-farm trials, leaf samples were collected every two weeks. No yield data was collected because the growers were harvesting the fruit to market it.

Marketable Yield

In each season, harvesting was done once a week in the early season (November–December) when the yield was low, and twice or three times per week during mid and late season (January–March) when the yield was higher. Harvesting was done in all treatment plots. Fruit was considered marketable if it showed no evidence of physical damage such as peck marks, holes, removed achenes (seeds), cat-faced injuries from insect, bird, or animal feeding, rots and mold from disease pathogens, and cracks from frost injury. In addition, small fruits (<10 g) and deformed fruits were not considered marketable, because the defects could be due to nutrient deficiency and inefficient pollination, respectively. Culls (unmarketable fruits) were removed simultaneously from the field to prevent disease incidence. Marketable fruits from each treatment plot were put in separate clamshells and weighed with the aid of a scale (TL 12001, Denver Instrument Company, Arvada CO).

Data Analysis

Open field *T. urticae* data in both locations in 2013–2014 and at the research farm in 2014–2015 were log-transformed and analyzed using PROC MIXED (SAS Institute 2012) to run a two-way analysis of variance (ANOVA) with cover crops and cultivars as the treatment effects. The interaction effect between cover crops and cultivars was also evaluated. Weekly data were pooled, and one-way ANOVA was used to test for differences in the abundance of *T. urticae* and *T. urticae* eggs among cultivars in both locations. Location was used as a factor to test for differences in the population of *T. urticae* motiles on each strawberry cultivar. The *N. californicus* data from both locations in 2013–2014 and from the research farm in 2014–2015 were log-transformed and analyzed using PROC MIXED (SAS Institute 2012) to run a two-way ANOVA with the cover crop as whole plot factor and cultivar as the subplot factor. We found no significant effect on the cover crops and, although repeated measures were initially used, there was no significant effect over time because the populations of *N. californicus* motiles and eggs were too low and not found on some treatment plots.

Research station trial *T. urticae* and *N. californicus* motile and egg data from 2016–2017, 2017–2018, and 2018–2019 were log-transformed to normalize the data and equalize variances. Both *T. urticae* and *N. californicus* populations were low in 2016–2017, so weekly data were pooled and analyzed using a split-plot ANOVA with cover crop and cultivar as the main and subplot factors, respectively, PROC GLM (SAS Institute 2012). In 2017–2018 and 2018–2019, *T. urticae* data were analyzed with repeated measures ANOVA with cover crop and cultivar as the main and subplot factors, respectively, in 2017–2018, and cultivar as the treatment in a one-way ANOVA in 2018–2019. *Neoseiulus californicus* data were pooled in both 2017–2018 and 2018–2019 and analyzed using a split-plot ANOVA in 2017–2018 and a one-way ANOVA in 2018–2019 because the population was too small in both years for repeated-measures analysis.

For the on-farm trials in 2014–2015, 2017–2018, and 2018–2019, weekly data were pooled for analysis and log-transformed to normalize the data and equalize variances. *T. urticae* and *N. californicus* motile and egg data in 2014–2015, *T. urticae* motile and egg data in 2017–2018 and 2018–2019, and native predatory mite data from the Gainesville farm in 2018–2019 were analyzed using a split-plot ANOVA with cover crop and cultivar as the main and subplot factors, respectively, using PROC GLM (SAS institute 2012). Natural populations of predatory mites on both farms in 2017–2018 and on the Hawthorne farm in 2018–2019 were sporadic and too small for statistical analysis.

Marketable yield for the open field production system in 2013–2014 was analyzed using PROC MIXED (SAS Institute 2012).

Tukey's multiple comparison procedure was used to perform the mean separation tests where a significant difference was observed ($P < 0.05$).

Total marketable yield weight in 2014–2015, 2016–2017, and 2017–2018 were analyzed using a split-plot ANOVA with cover crop and cultivar as the main and subplot factors, respectively, using PROC GLM (SAS institute, 2012). In 2018–2019 total marketable yield data was analyzed using a one-way ANOVA with cultivar as the treatment factor.

Results

Research Station Trials

In the 2013–2014 growing season, data were initially analyzed using repeated measures but there were no significant differences among the treatments over time. Therefore, weekly data were pooled together to examine treatment effects over the entire season. At the PSREU location, there was no significant interaction between cover crops and cultivars for *T. urticae* motiles, *N. californicus* motiles, or *N. californicus* eggs (all $F \le 1.4$; df = 28, 116; $P \ge 0.12$), but the interaction between cover crops and cultivars was significant for *T. urticae* eggs ($F = 1.18$; df = 28, 104; $P = 0.0197$). There was no significant difference among the cover crop treatments (Fig. 1a) for *T. urticae* motiles, *T. urticae* eggs, or *N. californicus* motiles (all $F \le 1.4$; df = 4, 116; $P \ge 0.28$). However, there were significant differences in *N. californicus* eggs among cover crops ($F = 3.18$; df = 4, 116; $P = 0.02$). There were significant differences among the cultivars in the population density of *T. urticae* motiles ($F = 2.60$; df = 7, 116; $P = 0.0158$) and eggs ($F = 2.98$; df = 7, 104; $P = 0.0068$). The cultivars 'Florida Radiance', 'Winterstar', and 'Strawberry Festival' had significantly lower *T. urticae* motile populations than the other cultivars evaluated (Fig. 2a). At the Citra PSREU, the populations of *T. urticae* motiles on the cultivars were significantly lower than Plant City ($F = 5.34$; df = 7, 200; $P < 0.0001$). Overall, 'Albion' and Proprietary 1 harbored significantly more eggs than' Festival', 'Winterstar' and 'Florida Radiance' ($F = 2.80$; df = 7, 202; $P = 0.0084$). In the *A. americana*, *C. breviflora*, and weedy control treatments, there were no significant differences in *T. urticae* eggs among cultivars (all $F \le 1.22$, df = 7, 104, $P \ge 0.3$). In the hairy indigo treatment, Proprietary 1 had significantly higher mites compared with all the other treatments ($F = 4.43$; df = 7, 104; $P = 0.0002$), while in the sunn hemp treatment 'Camarosa' had significantly higher numbers of eggs compared with 'Radiance', 'Treasure', and Winterstar'($F = 2.65$; df = 7, 104; $P = 0.01$). Also, the number of eggs on each cultivar were generally higher in Plant City compared to Citra, except for Proprietary 1, which had slightly higher *T. urticae* eggs. The population of *N. californicus* motiles was significantly different among the strawberry cultivars ($F = 5.76$; df = 7, 103;

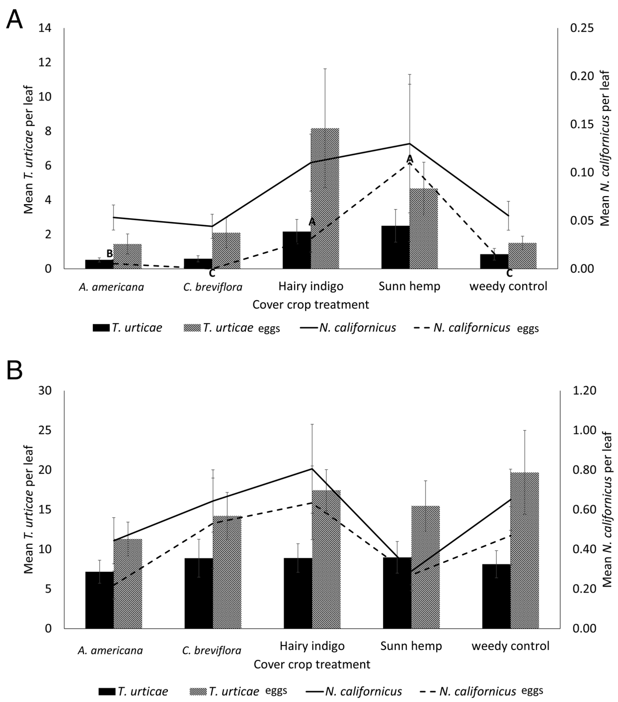

Fig. 1. Mean weekly *T. urticae* motiles and eggs (bars) and *N. californicus* motiles and eggs (lines) in each cover crop for the 2013–2014 strawberry season at (a) PSREU Citra and (b) Plant City, FL. Means were not different at the $P < 0.05$ level according to split-plot ANOVA and least significant difference (LSD) tests except for *N. californicus* eggs at Citra as indicated by the bold capital letters which indicate differences at the $P < 0.05$ level.

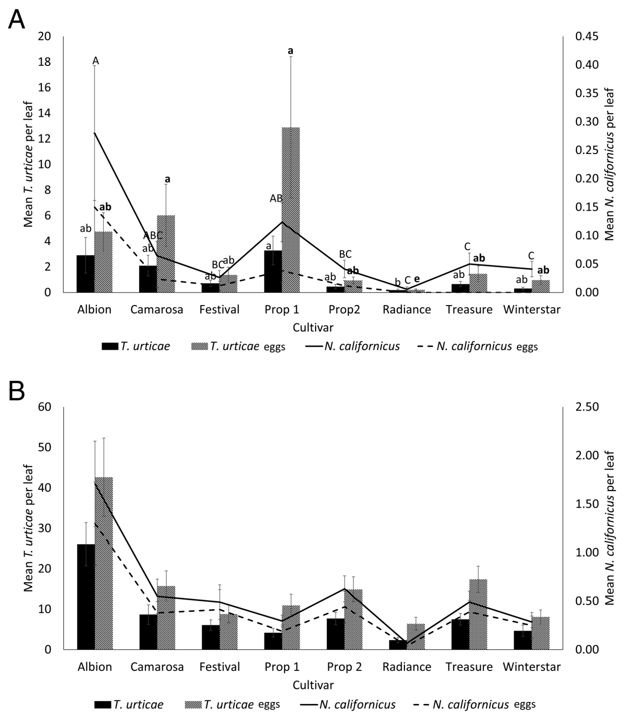

Fig. 2. Mean weekly *T. urticae* motiles and eggs (bars) and *N. californicus* motiles and eggs (lines) on each cultivar (Prop = Proprietary) for the 2013–2014 strawberry season at (a) PSREU Citra and (b) Plant City, FL. Means with the same letter were not different at the $P < 0.05$ level according to split-plot ANOVA and LSD tests. Each data set was analyzed separately as indicated by the different letter types (lower case for *T. urticae* motiles, lower case bold for *T. urticae* eggs, and upper case for *N. californicus* motiles.

$P < 0.0001$; Fig. 2a). However, the number of eggs oviposited by predatory mites on the strawberry cultivars was generally low and, unlike the motiles, there was no significant difference among cultivars ($F = 1.71$; df = 7, 116; $P = 0.1128$).

In 2014–2015, the interaction effects between cultivars and cover crops were significant in relation to the population of *T. urticae* motiles ($F = 3.57$; df = 4, 18; $P = 0.0260$), although there were no significant differences in *T. urticae* motile populations on strawberry cultivars ($F = 0.86$; df = 2, 18; $P = 0.4382$; Fig. 3) and cover crops ($F = 0.75$; df = 2, 6; $P = 0.5100$; Supp Fig. 1 [online only]). In the hairy indigo treatment, there were significantly higher numbers of *T. urticae* motiles in 'Strawberry Festival' compared with 'Winterstar' ($F = 4.4$; df = 2, 18; $P = 0.03$), while there were no significant differences among cultivars in the sunn hemp and weedy control cover crop treatments (both $F \leq 2.06$; df = 2, 18; $P \geq 0.16$). There were no significant interaction effects between cover crops and cultivars for *T. urticae* eggs, *N. californicus* motiles, and *N. californicus* eggs (all $F \leq 1.6$; df = 4, 18; $P \geq 0.22$).Also, no significant differences were observed for *T. urticae* eggs, *N. californicus* motiles, and *N. californicus* eggs among cover crops (all $F \leq 0.71$; df = 2, 6; $P \geq 0.53$; Fig. 4) and cultivars ($F \leq 1.69$; df = 2, 18; $P \geq 0.21$; Fig. 3).

In 2016–2017, there was no interaction between cover crop and cultivar for *T. urticae* motiles, *T. urticae* eggs, *N. californicus* motiles, or *N. californicus* eggs (all $F \leq 1.7$; df = 9, 36; $P \geq 0.12$). Both *T. urticae* and *N. californicus* populations were low throughout the season. There were no differences in *T. urticae* motiles, *T. urticae* eggs, *N. californicus* motiles, or *N. californicus* eggs among cover crops (Supp Fig. 2a [online only], all $F \leq 1.2$; df = 3, 9; $P \geq 0.35$). There were no significant differences in *T. urticae* motile numbers among cultivars (Fig. 4a, $F = 2.2$; df = 3, 63; $P = 0.1$) but higher

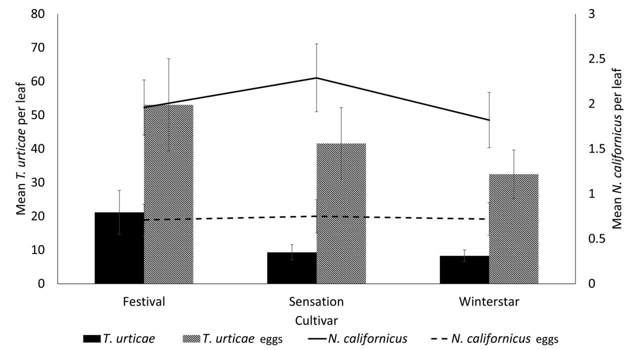

Fig. 3. Mean weekly *T. urticae* motiles and eggs (bars) and *N. californicus* motiles and eggs (lines) on each cultivar for the 2014–2015 strawberry season at Citra PSREU. Means were not different at the $P < 0.05$ level according to split-plot ANOVA and LSD tests.

numbers of *T. urticae* eggs were found on 'Florida Radiance' compared with 'Sensation' and 'Winterstar' ($F = 3.1$; df = 3, 63; $P = 0.03$). Significantly fewer *N. californicus* motiles were collected from 'Florida Radiance' compared with the other three cultivars ($F = 14.9$; df = 3, 63; $P < 0.0001$). However, there were no differences in *N. californicus* egg numbers among cultivars ($F = 1.6$; df = 3, 63; $P = 0.2$).

In 2017–2018, there was no interaction between cover crop and cultivar for *T. urticae* motiles, *T. urticae* eggs, *N. californicus* motiles, or *N. californicus* eggs (all $F \leq 1.7$; df = 9, 36; $P \geq 0.12$). There was also no interaction between cover crop and cultivar over time for *T. urticae* motiles or eggs (both $F \leq 0.9$; df = 63, 252; $P \geq 0.7$). There were no differences in *T. urticae* motiles, *T. urticae* eggs, *N. californicus* motiles, or *N. californicus* eggs among cover crops (Supp Fig. 2b [online only], all $F \leq 1.0$; df = 3, 9; $P \geq 0.4$). There was no interaction between week and cover crop for *T. urticae* motiles or eggs (both $F \leq 1.0$; df = 21, 252; $P \geq 0.7$). Overall (Fig. 4b), there were significantly higher numbers of *T. urticae* motiles ($F = 9.5$; df = 3, 63; $P < 0.0001$) and eggs ($F = 5.01$, df = 3, 63; $P = 0.0053$) on 'Florida Beauty' compared with the other cultivars. There was also a significant interaction between week and cultivar for both *T. urticae* motiles ($F = 4.5$; df = 21, 252; $P < 0.0001$) and eggs ($F = 4.3$; df = 21, 252; $P < 0.0001$). Numbers of *T. urticae* motiles and eggs were higher in 'Florida Beauty' from 19 Dec 2017 to 5 Feb 2018 (Fig. 5a and b). Significantly higher numbers of *N. californicus* motiles (Fig. 4b) were collected from 'Florida Beauty' compared with the other three cultivars ($F = 8.3$; df = 3, 63; $P = 0.0002$). Significantly higher numbers of *N. californicus* eggs (Fig. 4b) were collected from 'Florida Beauty' compared with 'Florida Radiance' and Winterstar ($F = 3.1$; df = 3, 63; $P = 0.04$).

In 2018–2019, there were significant differences in *T. urticae* motiles ($F = 9.0$; df = 3, 15; $P = 0.001$) and eggs ($F = 8.2$; df = 3, 15; $P = 0.002$) among cultivars and a significant interaction between week and cultivar for both *T. urticae* motiles ($F = 4.0$; df = 24, 120, $P < 0.0001$) and eggs ($F = 3.4$; df = 24, 120; $P = 0.001$). Like the results obtained in 2017–2018, 'Florida Beauty' had significantly higher populations of both *T. urticae* motiles and eggs compared with the other three cultivars (Fig. 4c). Significantly fewer *T. urticae* motiles and eggs were collected from 'Sensation' compared with 'Florida Brilliance'. The pattern over time was like the previous season (Fig. 5b) with 'Florida Beauty' having higher *T. urticae* motile and egg numbers from 2 Jan 2019 to 11 Feb 2019. The *N. californicus* population was much lower this season and there were no significant differences in motile ($F = 0.68$; df = 3, 15; $P = 0.6$) or egg ($F = 1.1$; df = 3, 15; $P = 0.4$) numbers among cultivars (Fig. 4c).

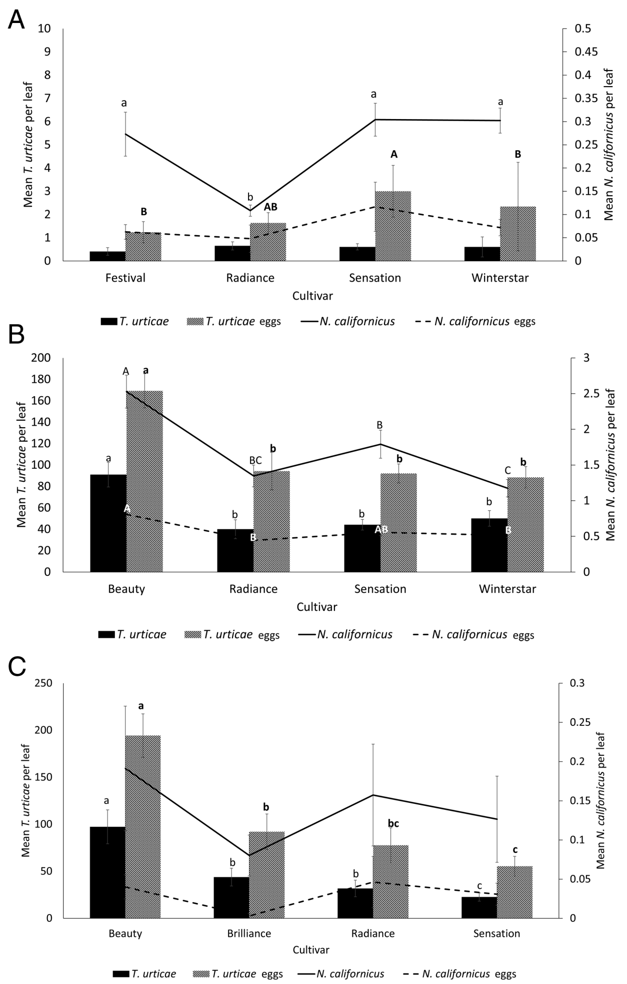

Fig. 4. Mean weekly *T. urticae* motiles and eggs (bars) and *N. californicus* motiles and eggs (lines) in each cultivar for the a) 2016–2017, b) 2017–2018, and c) 2018–2019 strawberry seasons at Citra PSREU. Cultivars with the same letter are not different from each other at the $P \leq 0.05$ level according to split-plot ANOVA (2016–2017), repeated measures split-plot ANOVA (2017–2018), or one-way ANOVA (2018–2019) and LSD tests. Each data set was analyzed separately as indicated by the different letter types (lower case for *T. urticae* motiles, lower case bold for *T. urticae* eggs, upper case for *N. californicus* motiles, and upper case white for *N. californicus eggs*.

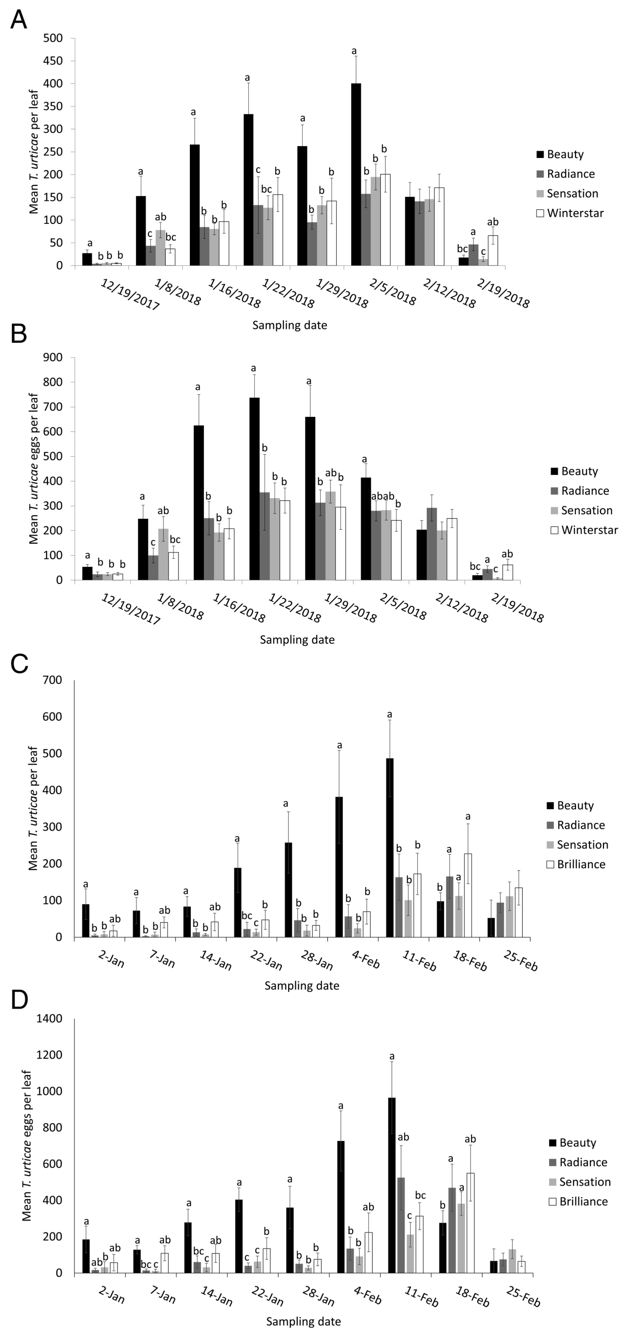

Fig. 5. Mean *T. urticae* in each cultivar each week with significant differences among cultivars: a) *T. urticae* motiles in 2017–2018, b) eggs in 2017–2018, c) motiles in 2018–2019, and d) eggs in 2018–2019. Cultivars each week with the same letter are not different from each other at the $P \leq 0.05$ level according to one-way ANOVA and LSD tests.

On-farm Trials

In 2013–2014 at the Plant City location, the result was like that obtained at the Citra research station. There was no significant interaction between cover crop and cultivars for *T. urticae* motiles, *T. urticae* eggs, *N. californicus* motiles, and *N. californicus* eggs (all $F \leq 1.6$; df = 28, 105; $P \geq 0.06$) and no differences among cover crops (all $F \leq 1.07$; df = 4, 12; $P \geq 0.41$). However, the differences in populations of *T. urticae* motiles on the strawberry cultivars (Fig. 1b) were significant ($F = 10.57$; df = 7, 105; $P < 0.0001$) with 'Strawberry Festival', 'Winterstar' and 'Florida Radiance' harboring the lowest populations The populations of *T. urticae* eggs on the cultivars were significantly different ($F = 6.38$; df = 7, 105; $P < 0.0001$), and were lowest on the same cultivars that harbored the lowest *T. urticae* motile populations (Fig. 2b). The population of *N. californicus* was lowest on 'Florida Radiance' and 'Winterstar'($F = 9.01$; df = 7, 105; $P < 0.0001$). Similar results were obtained for *N. californicus* eggs ($F = 4.23$; df = 7, 105; $P = 0.0004$; Fig. 2b).

We compared the population of *T. urticae* at both the research farm and the Plant City location and found that there were interaction effects between location and cultivar for *T. urticae* motiles ($F = 6.60$; df = 7, 198; $P < 0.0001$). Location had a significant effect on the population of *T. urticae* ($F = 210.25$; df = 1, 21.5; $P < 0.0001$). In both locations, the cultivars performed differently, and this was significant for *T. urticae* motile ($F = 8.75$; df = 7, 198; $P < 0.0001$) and egg populations ($F = 2.98$; df = 7, 104; $P = 0.0068$).

In 2014–2015 at the Hawthorne farm there were no significant differences in *T. urticae* motiles, *T. urticae* eggs, *N. californicus* motiles or *N. californicus* eggs (Table 3) among cover crops (all $F \le 6.4$; df = 2, 4; $P \ge 0.06$) or cultivars (all $F \le 2.2$; df = 2, 26; $P \ge 0.15$) and there was no interaction between cover crops and cultivars (all $F \le 1.1$; df = 4, 12; $P \ge 0.4$). At the west Gainesville farm (Table 4) there were also no significant differences in *T. urticae* motiles, *T. urticae* eggs, *N. californicus* motiles or *N. californicus* eggs among cultivars (all $F \le 3.2$; df = 2, 26; $P \ge 0.08$) and no interaction between cover crop and cultivar (all $F \le 0.54$; df = 4, 12; $P \ge 0.71$). There were significantly higher numbers of *T. urticae* motiles ($F = 32.2$; df = 2, 4; $P = 0.003$), *T. urticae* eggs ($F = 26.9$; df = 2, 4; $P = 0.005$), *N. californicus* motiles ($F = 13.3$; df = 2, 4; $P = 0.02$), and *N. californicus* eggs ($F = 8.8$; df = 2, 4; $P = 0.03$) in the sunn hemp cover crop treatment compared with the other two.

In 2017–2018 on the Hawthorne farm (Table 5) there were no significant differences in *T. urticae* motiles or eggs among cover crop treatments (both $F = 0.6$; df = 2, 4; $P = 0.6$). Significantly higher numbers of *T. urticae* motiles ($F = 10.4$; df = 2, 17; $P = 0.01$) were collected from 'Florida Beauty' compared with the other two cultivars and significantly higher numbers of *T. urticae* eggs ($F = 5.3$; df = 2, 17; $P = 0.05$) were collected from 'Florida Beauty' and 'Florida Radiance' compared with 'Sensation'. The interaction between cover crop and cultivar was significant for *T. urticae* motiles ($F = 4.9$; df = 4, 6; $P = 0.04$) but not for eggs ($F = 2.9$; df = 4, 6; $P = 0.1$). For *T. urticae* motiles, in the hairy indigo cover crop, 'Florida Beauty' had the highest number of *T. urticae* (5 ± 4) followed by 'Florida Radiance' (4 ± 0) and then 'Sensation' (1 ± 1). In contrast, in the sunn hemp cover crop, 'Florida Radiance' had the highest numbers of *T. urticae* motiles (5 ± 1) followed by 'Sensation' (2 ± 0) and then 'Florida Beauty' (1 ± 1). In the four-way mix treatment, 'Florida Radiance' (8 ± 7) and 'Sensation' (9 ± 8) had similar numbers of *T. urticae* motiles while 'Florida Beauty' had the lowest numbers (0 ± 0). Six-spotted thrips, *Scolothrips sexmaculatus* Pergande (Thysanptera: Thripidae), were the main *T. urticae* predators seen on leaves along with a few native predatory mite species.

On the east Gainesville farm, *T. urticae* populations were much higher than those on the Hawthorne farm. There were no significant differences in *T. urticae* motile or egg numbers among cover crop treatments (both: $F \le 0.7$; df = 2, 4; $P \ge 0.6$) or cultivars (both: $F \le 4.7$; df = 2, 4; $P \ge 0.06$) and there was no interaction between cover crop and cultivar for either *T. urticae* motiles or eggs (both $F \le 0.2$; df = 4, 6; $P \ge 0.95$). High numbers of six-spotted thrips were collected along with a few native predatory mites.

In 2018–2019, as in the previous season, on the Hawthorne farm (Table 5) there were no significant differences in *T. urticae* motiles or eggs (both $F \le 3.4$; df = 2, 4; $P \ge 0.2$) among cover crop treatments. Unlike the previous season, there were no significant differences in *T. urticae* motiles and eggs (both $F \le 1.1$; df = 2, 17; $P \ge 0.4$) among cultivars and there was no interaction between cover crop treatment

Table 3. Mean ± SEM *T. urticae* and *N. californicus* motiles and eggs at the Hawthorne farm in 2014–2015

	Cover crop			Cultivar		
	Hairy indigo	Sunn hemp	Weedy control	'Strawberry Festival'	Semsation	Winterstar
T. urticae motiles	6 ± 2	14 ± 2	5 ± 1	10 ± 3	6 ± 1	8 ± 3
T. urticae eggs	14 ± 5	25 ± 4	12 ± 2	20 ± 4	13 ± 4	17 ± 4
N. californicus motiles	0.4 ± 0.1	0.6 ± 0.1	0.4 ± 0.0	0.4 ± 0.1	0.6 ± 0.1	0.4 ± 0.1
N. californicus eggs	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0

Means were not significantly different at the $P < 0.05$ level according to split plot ANOVA tests.

Table 4. Mean ± SEM *T. urticae* and *N. californicus* motiles and eggs at the West Gainesville farm in 2014–2015

	Cover crop			Cultivar		
	Hairy indigo	Sunn hemp	Weedy control	'Strawberry Festival'	Semsation	Winterstar
T. urticae motiles	2 ± 1b	9 ± 3a	3 ± 2b	5 ± 2	7 ± 3	4 ± 1
T. urticae eggs	8 ± 4b	27 ± 8a	10 ± 4b	11 ± 4	16 ± 7	18 ± 7
N. californicus motiles	0.2 ± 0.0b	0.5 ± 0.1a	0.3 ± 0.1b	0.2 ± 0.1	0.5 ± 0.1	0.3 ± 0.1
N. californicus eggs	0.2 ± 0.1b	0.4 ± 0.1a	0.1 ± 0.1b	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1

Means with the same letter were not significantly different at the $P < 0.05$ level according to split plot ANOVA and least significant difference (LSD) tests.

Table 5. Mean ± SEM *T. urticae* motiles and eggs at the Hawthorne farm in 2017–2018 and 2018–2019

		Cover crop			Cultivar			
		Hairy indigo	Sunn hemp	4-way mix	'Florida Beauty'	'Florida Brilliance'	'Florida Radiance'	Sensation
2017–2018	*T. urticae* motiles	1 ± 0	4 ± 2	1 ± 0	3 ± 1 a	/	2 ± 1 b	1 ± 1 b
	T. urticae eggs	1 ± 1	3 ± 1	4 ± 2	4 ± 2 a	/	4 ± 1 a	1 ± 0 b
2018–2019	*T. urticae* motiles	5 ± 1	8 ± 2	12 ± 3	/	11 ± 4	5 ± 2	9 ± 1
	T. urticae eggs	5 ± 1	11 ± 3	14 ± 2	/	11 ± 4	9 ± 2	11 ± 3

Means with the same letter were not significantly different at the $P < 0.05$ level according to split plot ANOVA and LSD tests.

and cultivar for either *T. urticae* motiles or eggs (both $F \leq 0.4$; df = 4, 6; $P \geq 0.8$). Six-spotted thrips were the main *T. urticae* predators seen on leaves along with a few native predatory mite species.

On the east Gainesville farm (Table 6), *T. urticae* populations were, again, much higher than those on the Hawthorne farm. There were no significant differences in *T. urticae* motile or egg (both $F \leq 0.8$; df = 2, 4; $P \geq 0.3$) numbers among cover crop treatments and there was no interaction between cover crop and cultivar for either *T. urticae* motiles or eggs (both $F \leq 1.2$; df = 4, 6; $P \geq 0.4$). There were significantly higher numbers of *T. urticae* motiles in 'Sensation' compared with 'Florida Radiance' ($F = 5.3$; df = 2, 17; $P = 0.05$) but no significant differences in *T. urticae* egg numbers among cultivars ($F = 3.6$; df = 2, 17, $P = 0.1$). The six-spotted thrips population was lower than in the previous season but a population of *Phytoseiulus macropilis* (Banks) (Acari: Phytoseiidae) was present in high enough numbers for statistical analysis. There were no differences in *P. macropilis* motiles or eggs (both $F \leq 5.7$; df = 2, 4; $P \geq 0.2$) among cover crop treatments and there was no interaction between cover crop and cultivar for either *P. macropilis* motiles or eggs (both $F \leq 2.3$; df = 4, 6; $P \geq 0.2$). There were significantly higher numbers of *P. macropilis* motiles ($F = 7.0$; df = 2, 17; $P = 0.03$) and eggs ($F = 18.2$; df = 2, 17; $P = 0.003$) in 'Sensation' compared with the other two cultivars and significantly higher numbers of *P. macropilis* eggs in 'Florida Brilliance' compared with 'Florida Radiance'.

Marketable Yield

In the open field production system at Citra for the growing season 2013–2014, the interaction effects between cover crops and cultivars for marketable yield were not significantly different ($F = 0.78$; df = 28, 105; $P = 0.7755$). However, the total marketable yield (Fig. 6) was significantly different among cultivars ($F = 11.91$; df = 7, 105; $P < 0.0001$), but cover crops had no significant effect on marketable yield ($F = 0.43$; df = 4, 12; $P = 0.7819$). 'Camarosa' and 'Florida Festival' had the highest marketable yields while 'Albion' and Proprietary 2 had the lowest yields. For cover crops, yield ranged from 1.6 ± 0.1 kg in the *A. americana* and weedy control treatments to 1.8 ± 0.1 kg in the hairy indigo treatment. Yields in the *C. breviflora* and sunn hemp treatments were 1.7 ± 0.2 kg and 1.8 ± 0.2 kg, respectively.

At Plant City, during the same growing season (2013–2014), there was no significant interaction between cultivars and cover crops ($F = 0.70$; df = 28, 105; $P = 0.8563$). Significant differences were observed among cultivars ($F = 23.13$; df = 7, 105; $P < 0.0001$) for the total marketable weight (Fig. 6), but not for cover crops ($F = 3.04$; df = 4, 12; $P = 0.0605$). 'Radiance' had the highest yield while 'Albion' and Proprietary 2 had the lowest yields. In the cover crop treatments, yield ranged from 5.5 ± 0.3 kg in the *A. americana* treatment to 6.6 ± 0.4 kg in the *C. breviflora* and weedy control treatments. Yields in the sunn hemp and hairy indigo treatments were 5.8 ± 0.4 kg and 6.1 ± 0.4 kg, respectively.

For the 2014–2015 season at Citra, there was no interaction between cover crop and cultivar for marketable yield ($F = 1.3$; df = 4, 35; $P = 0.3$) and there were no differences among cultivars ($F = 2.6$; df = 2, 35; $P = 0.1$). There was a mean of 19.7 ± 1.1, 17.1 ± 0.8, and 18.7 ± 0.6 kg total marketable yield in 'Strawberry Festival', 'Sensation', and 'Winterstar', respectively. Total marketable yield in sunn hemp (20.3 ± 0.6 kg) was significantly higher compared with 16.7 ± 0.6 kg in the weedy control ($F = 31.9$; df = 2, 6; $P = 0.0006$). At 18.5 ± 1.1 kg, total marketable yield in hairy indigo was not statistically different from either sunn hemp or the weedy control.

Marketable yield (Fig. 7) was similar among the 2016–2017, 2017–2018, and 2018–2019 seasons. In 2016–2017, marketable yield was significantly lower on 'Florida Radiance' compared with

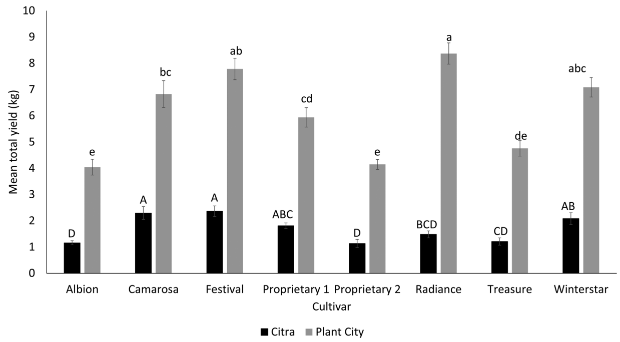

Fig. 6. Mean total marketable yield from the 2013–2014 season per cultivar from Citra PSEU and Plant City. Means with the same letter (Citra upper case and Plant City lower case are not different from each other at the $P \leq 0.05$ level according to split-plot ANOVA and LSD tests.

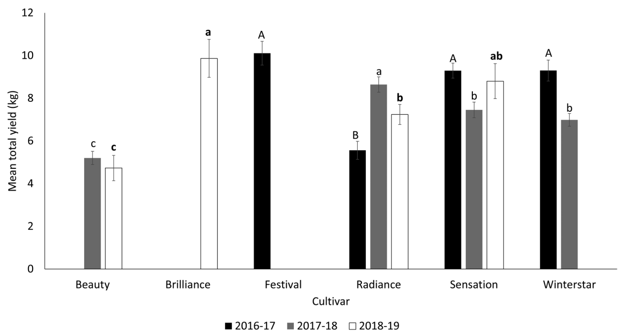

Fig. 7. Mean total marketable yield from the 2016–2017, 2017–2018, and 2018–2019 seasons per cultivar. Means each season with the same letter are not different from each other at the $P \leq 0.05$ level according to split-plot ANOVA (2016–2017 and 2017–2018) or one-way ANOVA (2018–2019) and LSD tests.

Table 6. Mean ± SEM *T. urticae* and *P. macropilis* motiles and eggs at the East Gainesville farm in 2017–2018 and 2018–2019

		Cover crop			Cultivar			
		Hairy indigo	Sunn hemp	4-way mix	'Florida Beauty'	'Florida Brilliance'	'Florida Radiance'	Sensation
2017–2018	*T. urticae* motiles	28 ± 6	31 ± 9	23 ± 8	42 ± 9	/	14 ± 2	25 ± 5
	T. urticae eggs	41 ± 6	56 ± 14	37 ± 12	65 ± 15	/	33 ± 7	37 ± 6
2018–2019	*T. urticae* motiles	18 ± 4	17 ± 4	16 ± 4	/	19 ± 2ab	10 ± 3b	23 ± 4a
	T. urticae eggs	16 ± 3	35 ± 7	28 ± 6	/	26 ± 5	17 ± 3	40 ± 8
	P. macropilis motiles	0.1 ± 0.1	0.9 ± 0.2	0.3 ± 0.1	/	0.2 ± 0.1b	0.1 ± 0.1b	0.8 ± 0.2a
	P. macropilis eggs	0.1 ± 0.0	0.5 ± 0.1	0.2 ± 0.1	/	0.2 ± 0.0b	0.1 ± 0.0c	0.5 ± 0.1a

Means with the same letter were not significantly different at the $P < 0.05$ level according to split plot ANOVA and LSD tests.

the other three cultivars ($F = 22.0$; df = 3, 63; $P < 0.0001$). In 2017–2018 ($F = 19.4$; df = 3, 63; $P < 0.0001$) and 2018–2019 ($F = 9.3$; df = 3, 23; $P = 0.001$), 'Florida Beauty' had significantly lower marketable yield compared to the other three cultivars evaluated in those years. In 2017–2018, 'Florida Radiance' had the highest yield while in 2018–2019, 'Florida Brilliance' had the highest yield. In 2016–2017 and 2017–2018 there was no interaction between cover crop and cultivar (both $F \leq 0.7$; df = 9, 36; $P \geq 0.7$) and no significant difference among cover crop treatments (both $F \leq 1.02$; df = 3, 9; $P \geq 0.43$). Yields in the hairy indigo, sunn hemp, 4-way mix, and weedy control, respectively, were 8.1 ± 0.6 kg, 9.5 ± 1.1 kg, 8.2 ± 0.7 kg, and 8.4 ± 1.4 kg in 2016–2017 and 7.5 ± 0.4 kg, 6.9 ± 0.4 kg, 7.0 ± 0.5 kg, and 6.9 ± 0.5 kg in 2017–2018.

Discussion

We saw no direct effects of the cover crops with respect to mite abundance on strawberries except on the west Gainesville farm in 2014–2015, where higher *T. urticae* populations were found on strawberries grown where sunn hemp had been planted as a summer cover crop. Overall, the *T. urticae* population on this farm was low, well below the 10 *T. urticae* per leaf threshold throughout the season. When *T. urticae* populations were high, the effect of cover crops was negligible. Even when cover crops were planted in the same plot through three successive seasons, 2016–2017, 2017–2018, and 2018–2019, at Citra there was no evidence of a cumulative effect on *T. urticae* populations. It is possible that the cover crops' contribution of nitrogen to the soil is negligible compared with the organic fertilizers applied pre-plant and throughout the growing season. Li et al. (2020) found that incorporation of Sunn hemp led to increased nitrogen availability for only two to three weeks after incorporation.

In the 2013–2014 season, 'Strawberry Festival', 'Winterstar' and 'Florida Radiance' had the lowest *T. urticae* population in the open field production system. Garcia et al. (2017) noted differences in cultivar performance under different strawberry production systems in Arkansas. 'Strawberry Festival', 'Florida Radiance', 'Sensation', and 'Winterstar' continued to perform well on the research farm and on-farm trials. 'Florida Brilliance', added in 2018–2019 in place of 'Winterstar', performed similarly to the original four cultivars. In contrast, *T. urticae* populations increased to extremely high numbers on 'Florida Beauty' in 2017–2018 and 2018–2019. This emphasizes the importance of testing new cultivars. Gonzalez-Dominguez et al. (2015) tested three newly developed cultivars for Mexico. They found that a higher density of *T. urticae* developed on the cultivar CP0615 compared with CPLE-7 and CPJacona. The survivorship of *T. urticae* to adulthood and leaf injury were reduced on CPLE-7 compared with the other two evaluated. Previous studies have reported that cultivars of a plant species might vary in their ability to tolerate pests (McFarlane and Hepworth 1994, Romeih et al. 2013). For example, in a study conducted by Rhainds et al. (2002), 'Honeoye' was recommended as the most suitable strawberry cultivar for organic production in the Northeastern region because of its tolerance to tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), and high yield. Rezaie et al. (2013) found that among the strawberry cultivars they tested, 'Sequoia' and 'Marak' were the most preferred by *T. urticae*, while 'Gaviota' was least preferred. Whether strawberry cultivars are tolerant or have some form of resistance to arthropod pests has not been well studied. Karlec et al. (2017) found evidence of antibiosis resistance against spider mites in the cultivars 'Camarosa', 'Florida Festival', 'IAC Campinas', and 'Sabrosa'.

In 2013–2014, the population of *T. urticae* was higher at the commercial grower's farm in Plant City compared to the research station at Citra. The higher *T. urticae* was likely due to the fact that the commercial farm has been producing strawberries in the same location for decades while the planting location used at Citra was virgin land (for strawberry production). However, the overall population of *T. urticae* was higher in the second growing season (2014–2015) at Citra, probably because of weather conditions and overwintering adults from the previous season. The *T. urticae* population continued to be low in 2016–2017 and then increased in 2017–2018 and 2018–2019. This was likely due to the combination of planting strawberries in the same area year after year and 'Florida Beauty's' high susceptibility. Due to the proximity of different cultivars to each other, it is highly possible that *T. urticae* moved from 'Florida Beauty' into the other cultivars, especially when the infested Florida Beauty plants began to deteriorate.

The *T. urticae* population was higher on the Hawthorne farm in 2014–2015 compared with the west Gainesville farm. In contrast, the *T. urticae* population was higher on the east Gainesville farm compared with the Hawthorne farm in 2017–2018 and 2018–2019. This can be attributed to different management practices on the Hawthorne farm. In 2017–2018 and 2018–2019, the strawberries in the experimental plots on both farms were managed by the growers along with their other strawberries. At the Hawthorne farm, strawberries were grown on straw mulch and frost protection was not used until mid to late February even if temperatures warranted it before that to prolong the harvesting season into June. The lack of frost protection early in the season may have kept the *T. urticae* population in check. Nyoike and Liburd (2013) found that the rate of increase of *T. urticae* on 'Florida Festival' strawberries was correlated with the accumulation of degree days.

In general, cultivars like 'Albion', Proprietary 1, 'Camarosa', and 'Florida Beauty', which harbored high *T. urticae* populations, also had the highest mean populations of *N. californicus*. It appears as if the populations of *N. californicus* on the cultivars may have been guided by the abundance of *T. urticae* on the leaves and not by leaf morphology and characteristics, such as pubescence, waxiness, and trichomes as reported by previous studies for other predatory mites on other crops (Sabelis et al. 1999, Loughner et al. 2008). This is consistent with previous research on *N. californicus* preying on *T. urticae* in strawberries. Ahn et al. (2010) found that the presence of non-glandular trichomes did not affect the functional response of *N. californicus* to *T. urticae*. The hairiness of strawberry leaves also didn't affect *N. californicus* fecundity nor consumption of *T. urticae* (Ottaviano et al. 2013).

At the PSREU location in 2013–2014, the mean populations of *N. californicus* eggs were almost zero, except in areas that were cover cropped with sunn hemp and hairy indigo. However, in Plant City, the populations of *N. californicus* motiles and eggs were significantly higher compared with Citra. The difference in population density could be due to the higher prey (*T. urticae*) density at Plant City. It could also be due to the diverse vegetation that could serve as an alternate food source for *N. californicus*.

In 2016–2017 at the Citra PSREU, only a preventative release of *N. californicus* was needed, as the *T. urticae* population remained low throughout the season. In 2017–2018 and 2018–2019, curative releases were needed. Interestingly, native predators were able to manage *T. urticae* populations on the two organic farms in 2017–2018 and 2018–2019. Naturally occurring *N. californicus* mites along with other native *Amblyseius* spp. and/or *Neoseiulus* spp. were noted on leaf samples along with *P. macropilis* predatory mites and six-spotted thrips. Populations of these naturally occurring predators were higher on the organic farms than at the research station. Both organic farms have diverse cropping systems, and this may contribute to an increase in the diversity and abundance of natural enemies.

In 2013–2014, the marketable yield varied among cultivars in both locations. Cultivars differ genotypically, which may affect fruit characteristics such as shelf life, size, skin thickness/ penetration force (by insects) that affect fruit marketability. 'Strawberry Festival' and 'Florida Radiance' had the highest marketable weights in Citra and Plant City, respectively. In Plant City, 'Strawberry Festival' produced a slightly lower yield than 'Florida Radiance'. The marketable yield produced by 'Florida Radiance' was quite low in Citra, but it produced the highest yield in Plant City. Differences in fertility programs, weather conditions (such as less rain and frost), adaptability differences, and management tactics (fencing to prevent animals like rodents and birds from eating ripe strawberries) may be responsible for the higher yield obtained at the grower's farm in Plant City. Also, the overall higher yield reported of cultivars in Plant City may vary due to the implementation of a different fertility program compared to Citra. Apart from 'Strawberry Festival' and 'Camarosa', all cultivars at Citra had higher cull weight compared to the marketable fruit yield. At both locations, fruits were harvested solely for the fresh market with more stringent requirements at the grower's organic farm in Plant City because the harvested fruits were marketed to a bigger strawberry firm.

A regression analysis was not run to measure the relationship between *T. urticae* population and marketable fruit weight. However, the cultivars with the lowest *T. urticae* population ('Strawberry Festival', 'Winterstar', and 'Florida Radiance') had the highest marketable fruit weight in Plant City in 2013–2014 though not at the Citra PSREU. The mite population at the research station was well below the threshold throughout the season and may have had minimal effects on yield for this reason. In 2017–2018 and 2018–2019, 'Florida Beauty' had the highest *T. urticae* population and the lowest yield. Other factors can also cause yield differences. For example, high disease pressure in the 'Florida Radiance' transplants in 2016–2017 likely resulted in the reduced yields seen in that cultivar that season.

Throughout the research station and on-farm trials, cover crops had minimal impacts on *T. urticae* and their natural enemies. Therefore, growers can focus on other factors, such as soil nutrition, weed management, and nematode suppression when choosing a cover crop. In terms of cultivars, results indicated that 'Florida Brilliance', 'Florida Radiance', 'Sensation', 'Strawberry Festival', and 'Winterstar' appear to be good options for organic strawberry production in Florida from a *T. urticae* management perspective. Establishment of the predatory mite *N. californicus* was not significantly affected by cultivar. Selecting cultivars that harbor lower populations of *T. urticae*, conserving naturally occurring predators, and releasing *N. californicus* are all useful tactics in an organic *T. urticae* management program in Florida strawberries.

Supplementary Data

Supplementary data are available at *Journal of Economic Entomology* online.

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