EVALUATION OF PREDACEOUS MITE RELEASES FOR SPIDER MITE MANAGEMENT

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Abstract

Predatory mite releases can be an effective means to manage spider mites in many perennial cropping systems, yet little research has been performed in annual cropping systems. In earlier research, large scale releases of the western predatory mite *Galendromus occidentalis* in cotton at low release rates were unsuccessful in reducing spider mites. Here, we describe two experiments that evaluate: (1) predaceous mite releases under conditions of high initial spider mite densities, high predatory mite release rates, and low hemipteran predator densities; and, (2) the relative impact of generalist insect predators *Geocoris* spp., *Orius tristicolor*, and *Frankliniella occidentalis* on the persistence of the western predatory mite *Galendromus occidentalis* and how these predator-predator interactions influence spider mite control. The first experiment showed that predatory mite releases can increase predatory mite populations; these predator populations can increase their abundance through recruitment; and they can suppress spider mite populations. We do not know if similar results can be obtained under unmanipulated field conditions where the environment may be less optimal for predatory mite population growth. The second experiment demonstrated that hemipteran predators can have a negative impact on predatory mite persistence but can improve spider mite suppression. No detectable impact of *F. occidentalis* was observed on either *G. occidentalis* or spider mite populations.

Introduction

Spider mite management in cotton is based on multiple strategies. These strategies include the use of selective acaricides such as abamectin (Zephyr¨) or dicofol (Kelthane¨), conservation of naturally occurring spider mite predators (i.e. avoidance of broad spectrum insecticides), and cultural practices such as removal of weeds that host spider mites or the application of water to roads to reduce dust. Though many growers use multiple strategies for managing spider mites, the primary control practice remains the application of acaricides (Leigh 1985).

The potential and realized problem of acaricide resistance development has promoted research on non-chemical alternatives to acaricides. Inoculative releases of predaceous phytoseiid mites for spider mite control have been shown experimentally to reduce spider mite densities in many perennial crops (Oatman *et al.* 1968, Flaherty & Huffaker 1970; Croft & McMurtry 1972, Hoy *et al.* 1982; Croft & MacRae 1992b; Nyrop et al 1998) and some annual row crops such as cotton (Tijerina-Chavez 1991) and field corn (Pickett & Gilstrap 1986, Pickett *et al.* 1987). Naturally occurring phytoseiid mite populations tend to be more abundant in perennial agricultural systems where conditions are considered to be more conducive for population persistence (these sites have less disturbance and more abundant overwintering sites; McMurtry 1981). For this reason, phytoseiid mite releases have been used primarily in perennial systems and have only recently been considered for annual systems. In cotton, naturally occurring phytoseiid mite populations are generally present at very low densities (perhaps due to a lack of overwintering sites), and are not important for spider mite control (van den Bosch and Hagen 1966). More recent research by Tijerina-Chavez (1991) found that inoculative releases of the western predatory mite *Galendromus* (=*Metaseiulus*) *occidentalis* in small experimental plots could provide control of spider mites.

In 1996, we evaluated large scale releases of *G. occidentalis* under grower field conditions (both organic and conventionally grown cotton). Predatory mites were released at 5000 per hectare into 18 two-hectare plots during May (early release) and 11 two-hectare plots from June to August (late release) within grower fields in regions ranging from Kern Co. to Madera Co. All the releases except for one were performed using a mechanical release device that was originally developed by Giles *et al.* (1995) and modified by Warren Sargent (Ag Attack, Visalia, CA). Although 5000 predatory mites per hectare is a very low release rate compared to rates used in more valuable crops (e.g. in strawberries release rates are commonly near 75000 per ha), it was selected because the cost of the predatory mites at this rate was similar to that of an acaricide application. Our experimental method tested the efficacy of predaceous mites in many locations and at a wide range of initial spider mite densities and release dates (Table 1).

Statistical analysis (2-way ANOVA for each sampling date with main effects for mite release and block {field}) found no significant differences in spider mite, *G. occidentalis*, or thrips abundance between the treatments (see Table 2). In these trials, releases of *G. occidentalis* were ineffective in reducing populations of spider mites, because predatory mite numbers were not augmented sufficiently by the releases.

There are several possible explanations for the failure of the predaceous mite releases to increase the density of the predaceous mites, including: (i) release rates were too low; (ii) generalist insect predators fed on predatory mites and consequently limited their population growth; (iii) insectary-reared predatory mites were not adapted to the field

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conditions of the cotton environment; (iv) predatory mites suffered from high mortality during the release process due to the small size of the cotton plants (the mites that fell onto the ground during the release may not have found the small cotton plants) and (v) attributes of the cotton plant (physical or chemical) prevented predatory mite populations from increasing to higher densities. In this manuscript, we describe two experiments, one evaluating the influence of increasing the predatory mite release rate and the second evaluating manipulations of the generalist insect predator community. These two experiments are part of a larger research effort to identify the factor(s) contributing to the failure of released predatory mites to establish populations capable of suppressing spider mites in cotton. Next, we describe some background information that motivated these experimental objectives.

In order to increase the predatory mite population size through augmentative releases, it is necessary to use release rates that are numerically substantial in comparison to the natural background density of predatory mites. As stated above, predaceous mites are generally present at very low densities in cotton, probably because cotton lacks the overwintering sites that perennial crops provide for predatory mites (i.e. refugia in the bark). These observations imply that predaceous mite populations could be substantially increased in cotton by performing early-season, low-rate releases. However, phytoseiid mite species such as *G. occidentalis* that primarily specialize on tetranychid mites may require fairly high densities of spider mites to maintain their populations. These conditions may not always be available early in the cotton season. If spider mite populations reach high densities, then the release rate of predatory mites relative to the density of spider mites must be high enough for the predatory mites to reduce spider mite populations (McMurtry 1981). If these considerations are important, predaceous mite releases may be most effective at reducing spider mite populations when (i) spider mites are at high densities and (ii) release rates are sufficiently high to adjust the predator to prey ratio. In experiment 1, we evaluate predaceous mite releases under conditions of high initial spider mite densities, high predatory mite release rates, and low hemipteran predator densities.

Are the generalist predators found in cotton likely to feed on other predators and in particular predatory phytoseiid mites? Evidence from the literature and a laboratory experiment we conducted suggests that predator-predator interactions may be widespread. First, field experiments examining cotton aphid biological control showed that green lacewings (*Chrysoperla carnea*) could suppress aphid population growth in treatments lacking hemipteran predators. However, aphid suppression was disrupted when lacewing larvae were tested in treatments also containing hemipteran predators such as *Zelus renardii*, *Nabis* spp., and *Geocoris* spp. Lacewing survivorship decreased by 90% in the presence of these hemipteran predators (Rosenheim *et al.*, 1993). Second, predation upon phytoseiid predatory mites, like *G. occidentalis*, has been studied (either directly or indirectly) in experiments conducted under laboratory conditions (Gillespie and Quiring 1992; Cloutier and Johnson 1993; Croft and Croft 1996; Croft *et al.* 1996; MacRae and Croft 1996, Wittmann and Leather 1997), greenhouse conditions (Ramakers 1993; Brodsgaard and Enkegaard 1997) and field conditions (Croft and MacRae, 1992 a, b, 1993; Croft 1994; Walde *et al.* 1997). Croft and MacRae (1992a) showed that predation by the generalist predatory mite *Zetzellia mali* generally displaced *G. occidentalis* populations, which sometimes led to increases in phytophagous mite populations. Finally, in a recently conducted laboratory experiment, we found that larvae of the western flower thrips *Frankliniella occidentalis*, an important mite predator in cotton, consumed approximately equal numbers of the eggs of *G. occidentalis* and *T. urticae* when both were presented at equal densities (Figure 1).

In experiment 2 and part of experiment 1, we evaluate the relative impact of generalist insect predators *Geocoris* spp., *Orius tristicolor*, and *F. occidentalis* on the persistence of the western predatory mite *Galendromus occidentalis* and evaluate the possible influence of predator-predator interactions on spider mite control.

Materials and Methods

Experiment 1

Experiment 1 was designed to quantify (1) the impact of *G. occidentalis* mite releases on *Tetranychus urticae* abundance under high predator and prey densities and (2) the impact of *F. occidentalis* on spider mite and predatory mite abundance. The experiment was conducted from 31 May to 25 June, 1997 in a 0.4 ha experimental planting of *Gossypium hirsutum* cv. "Maxxa" at the UC Davis Plant Pathology Fieldhouse, Davis, CA. Plants were grown on rows separated by 76 cm following standard commercial practices except that no acaricides or insecticides were used. Plants were small (approximately 8 mainstem nodes) and not yet flowering when the experiment was initiated.

The experimental unit was a single plant. On 31 May, plants were randomly selected and thoroughly sprayed with an insecticidal soap (Safer¨ Inc.) at the labeled rate (20 mL soap/ L H_2O) to reduce resident populations of western flower thrips and other insects. Plants were then enclosed in cylindrical cages composed of a plastic PVC base and No-Thrips® mesh (Greentek® Inc.; pore size ca. 150 µm)(cage dimensions: height 45 cm, diameter 30 cm). Cage bases were imbedded in the ground to prevent arthropod movement. All seams in the cages were sewn closed.

On 1 June, plants were randomly assigned to one of four treatments, each replicated 14 times: (1) spider mites alone (*T. urticae*), (2) spider mites plus western predatory mites, (3) spider mites plus western flower thrips and (4) spider mites, predaceous mites, and western flower thrips. Spider

mites were added to all replicates by placing two spider mite infested seedlings from a laboratory culture onto each plant; this delivered 471 ± 45 (mean ± 1 SE) spider mites to each replicate. Approximately 10 thrips adults were added to each replicate in the thrips treatments. About half of the thrips adults were collected from a laboratory culture, while the other half were collected from the cotton field where the experiment was conducted. Western predatory mites were purchased from Biotactics® Inc. (Riverside, CA) and were released within two days of receipt. On 1 June, approximately 10 adult predatory mites were added to each replicate of the predatory mite treatments. On 7 June, a second release of 68 ± 16 predator mites in a corn-cob grit carrier was added to each replicate in the predatory mite treatments to adjust the predator to prey ratio. This second release was performed because we originally underestimated the number of spider mites added to the plants.

On 15 June, 9 out of the 14 replicates from each treatment were sampled destructively (census 1). The remaining five replicates of each treatment were collected on 25 June (census 2). All leaves from these replicates were collected into plastic bags, preserved with 70% ethanol, and stored at 4ºC. All arthropods were later removed from the leaf material using a leaf washing method developed by Leigh *et al.* (1984). To reduce the time necessary to quantify samples, we counted only the larger stages of mites. Mite stages were separated by using two mesh sieves: an 88 mesh sieve to collect adult and larger immature mite stages (i.e. deutonymphs) and a 210 mesh sieve to collect all other smaller stages (i.e. eggs, larvae, protonymphs). By quantifying all mobile stages (eggs were not counted) in both sieves and using linear regression through the origin, we developed a relationship between the proportion of spider and phytoseiid mites found in each sieve (spider mites: bottom sieve = top sieve x 0.937, $r^2 = 0.927$, $p < 0.0001$; phytoseiid mites: bottom sieve = top sieve x 0.358, $r^2 = 0.853$, $p < 0.0001$). Thus, the regression analysis allowed us to quantify only the larger stages of mites but obtain an estimate of the total number of mobile mites. All arthropods were quantified using a dissecting stereomicroscope.

Experiment 2

Experiment 2 was designed to quantify the individual impact of the insect predators *Geocoris* spp. (*G. punctipes* and *G. pallens*), *O. tristicolor*, and *F. occidentalis* on spider mite and predatory mite abundance. The experiment was conducted from 14 August to 30 August, 1997 in a 0.2 ha experimental planting of *G. hirsutum* cv. "Maxxa" at the UC Davis Agronomy Field Plots, Davis, CA. Plants were grown on rows separated by 76 cm following standard commercial practices with exception that no acaricides or insecticides were used. Plants had approximately 20 mainstem nodes and were setting squares and bolls.

The experimental unit was a single mainstem leaf located at the fifth node from the plant terminal. From 14 -15 August, plants were randomly selected and the fifth node mainstem leaf was thoroughly brushed (3.75 cm width paint brush; Ace Hardware Co.) to reduce resident populations of western flower thrips and other insects. Leaves were then enclosed in square cages composed of No-Thrips® mesh (Greentek® Inc.; pore size ca. 0.15 mm; cage dimensions: length and width 22.7 cm). Two seams were closed using plastic folder bindings to facilitate easy entry into cages; the petiole-side seam was closed using double sided mounting tape, Duck® tape, and rope caulk weather-stripping (Ace Hardware Corp.).

On 21-22 August, cages were re-opened and brushed a second time to remove insects that emerged from egg stages embedded in the leaf tissue, such as *F. occidentalis* and *O. tristicolor*. We waited 7 days before re-opening cages in anticipation that this would be sufficient time for all eggs to hatch. This removal technique was effective for *O. tristicolor* but only partially effective for *F. occidentalis*. Once brushed, caged leaves were randomly allocated to one of five treatments, each replicated 18 times: (1) spider mites alone (*T. urticae*, 147 ± 15 per leaf), (2) spider mites plus *G. occidentalis* (10.6 ± 0.7 per leaf), (3) spider mites, predaceous mites, and *O. tristicolor* (4 first to third instar nymphs per leaf), (4) spider mites, predaceous mites, and *Geocoris* spp. (1 first to third instar nymph per leaf), and (5) spider mites, predaceous mites, and *F. occidentalis* (ca. 12 adults per leaf) (densities were chosen to reflect natural densities of predators in cotton when spider mite densities are high; J. A. Rosenheim, unpublished data). *T. urticae* and *F. occidentalis* were collected from laboratory cultures, *G. occidentalis* was purchased from Biotactics¨ Inc. (Riverside, CA), and *Geocoris* spp. and *O. tristicolor* were hand collected in or near the cotton field where experiment 2 was conducted. Predatory mites were delivered to cages in a corn-cob grit carrier.

The duration of this experiment was 7 days (approximately the generation time for the spider mites, predaceous mites, and thrips). From 28-30 August, replicates were collected, cages were opened, and all herbivorous and predatory arthropods were quantified in the laboratory with the aid of a dissecting stereomicroscope. Spider mite and predatory mite counts included both motile and egg stages (in contrast to experiment 1 where only mobile stages were quantified).

Statistical Analyses

For experiment 1, we analyzed the influence of predatory mite and thrips releases on final spider mite and predatory mite abundance using several 2-way ANOVA's for the census 1 treatments and Kruskal-Wallis rank-sum tests for the census 2 treatments. Final spider mite and predatory mite abundances were log transformed to equalize variances between treatments for the 2-way ANOVA's. However, the tables and figures present untransformed data. Kruskal-

Wallis rank-sum tests were also used to determine if thrips treatment manipulations were successful. For experiment 2, we analyzed the influence of different predators on spider mite and predatory mite abundance using Kruskal-Wallis rank-sum tests and planned-paired comparisons using two-tailed Wilcoxon rank-sum tests. For both experiments 1 and 2, the critical P value was adjusted for the number of pairwise comparisons to maintain an overall α value equal to 0.05.

Results

Experiment 1

Addition of predatory mites greatly enhanced the number of predatory mites found in the census 1 treatments in comparison to treatments without predatory mite releases (2-way ANOVA, release effect, $F_{1, 33} = 21.4$, $P < 0.0001$; Figure 2), with release treatments having predatory mite densities 75 times greater than the control. However, 8 days after release the predaceous mite per capita population growth from the initial release rate of 78 per plant was slightly negative (per capita growth = [final density - release rate]/ [release rate] = -0.33). In the census 2 treatments, the difference in predatory mite abundance in the release and control treatments remained very large (Kruskal-Wallis Test, $\chi^2 = 13.6$, $P = 0.0002$). The predaceous mite per capita growth from the initial release rate was positive (per capita growth = 0.624), indicating the predatory mite population had grown by more than 60 % from the release date (Figure 2). Regression analysis of the predaceous mite treatments for both census dates showed that predatory mite numbers were strongly correlated with spider mite densities (simple linear regression, $r^2 = 0.705$, $F_{1,27} = 64.7$, $P < 0.0001$; Figure 3), suggesting that predatory mites have greater recruitment under high spider mite densities.

Manipulation of the *F. occidentalis* thrips population was somewhat successful in the census 1 treatments, but many thrips invaded the control treatment (38.4 ± 6.5; $\chi^2 = 7.48$, $P = 0.0062$; Table 3). This treatment manipulation disappeared after 18 days of experimentation ($\chi^2 = 0.282$, $P = 0.595$; Table 3). The lack of a thrips manipulation in the 18 day treatments convinced us to drop the thrips treatment from the spider mite and predatory mite analysis.

In the census 1 treatments, spider mite population abundance was significantly reduced by the predatory mite releases (predatory mite release, 296 ± 108; control, 782 ± 111; release effect, $F_{1, 34} = 6.3$, $P = 0.017$; Figure 4) but not by the thrips additions (thrips addition, 550 ± 110; control, 512 ± 113; thrips addition effect, $F_{1, 33} = 0.118$, $P = 0.734$). The predatory mite release treatment continued to reduce spider mite abundance after 18 days of experimentation (predatory mite release, 2639 ± 1021; control, 6932 ± 1215; $\chi^2 = 5.61$, $P = 0.0179$; Figure 4). Predatory mites reduced spider mite abundance to 38% of the level reached in the controls for both the census dates. Despite this impact of predatory mites on spider mites, spider mite population densities increased greatly in both treatments over the duration of the experiment. Averaging over treatments, spider mite populations were approximately 7.8 times larger after 18 days of experimentation compared to the 8 day treatments.

Increasing the thrips density did not negatively affect predatory mite abundance (thrips addition, 27.6 ± 7.3; control, 26.8 ± 7.7; $F_{1, 34} = 0.160$, $P = 0.691$) within the census 1 treatments.

Experiment 2

After 7 days of experimentation, the manipulations of all of the generalist insect predators were successful, with much higher densities in treatments where predators were added in comparison to the controls (Table 4). Like experiment 1, *F. occidentalis* was somewhat of an exception, because thrips was not completely excluded from the control treatment. Despite this problem, the thrips addition treatment had significantly higher thrips densities compared to the control (Kruskal-Wallis Test, $\chi^2 = 6.67$, $P = 0.0098$; Table 4).

Predatory mite releases greatly enhanced the predaceous mite density (Table 4, Figure 5a). Final densities of predatory mites were, however, lower than the release rate (release rate, 10.6 ± 0.7; final predator density; 3.7 ± 0.8), which resulted in a negative per capita population growth (per capita growth = -0.65). This result is similar to the census 1 predatory mite release treatment in experiment 1 where there was also negative per capita population growth.

The addition of hemipteran predators had a negative impact on predatory mite abundance (Figure 5a). Predatory mite abundance significantly decreased from 3.67 ± 0.78 in the predatory mite alone treatment to 0.83 ± 0.35 in the predatory mite + *Geocoris* treatment ($\chi^2 = 9.83$, $P = 0.0017$) and 0.0 in the predatory mite + *O. tristicolor* treatment ($\chi^2 = 22.81$, $P < 0.0001$). In concurrence with experiment 1, the addition of *F. occidentalis* did not have an impact on predatory mite abundance ($\chi^2 = 0.400$, $P = 0.527$; Figure 5a).

The addition of predatory mites reduced the spider mite density to 47% of the density reached in the control (control, 161.3 ± 23.4; release, 75.1 ± 15.5; $\chi^2 = 7.58$, $P = 0.0059$; Figure 5b). The addition of predatory mites + thrips or predatory mites + *Geocoris* did not produce significant enhanced mite suppression compared to that seen in the predatory mites alone treatment ($\chi^2 = 0.40$, $P = 0.527$; $\chi^2 = 2.45$, $P = 0.117$, respectively); both predatory mites + thrips and predatory mites + *Geocoris* significantly suppressed spider mite abundance compared to the control ($\chi^2 = 12.9$, $P = 0.0003$; $\chi^2 = 15.39$, $P < 0.0001$, respectively). The addition of predatory mites + *O. tristicolor* lowered spider mite abundance below both the control and the predatory mites alone treatment levels ($\chi^2 = 26.86$, $P < 0.0001$; $\chi^2 = 21.70$, $P < 0.0001$, respectively). Note that all stated

significant P values are below the Bonferroni adjusted critical P value (P = 0.05/7 = 0.0071).

Discussion

The outcomes of experiment 1 and 2 differ from that observed in our 1996 large scale predatory mites releases. First, using high release rates, we were able to greatly increase the predatory mite population compared to the naturally occurring background population. This effect was probably increased by our experimental preparation of replicates (spraying of insecticidal soap and brushing of plant material), which may have reduced the background level of predatory mites in these replicates. Nevertheless, densities of *G. occidentalis* were much higher in the release treatments than we have observed in any unmanipulated cotton field (R. G. Colfer, unpublished data).

The second important difference from 1996 is that released predatory mite populations increased at least 60% above the initial release rates under conditons of high spider mite availability, low predation, and a sufficiently long duration (this result was only observed after 18 days following predatory mite release in experiment 1; this calculation is excluding eggs so the actual population increase was likely to be well above 60%). This result is important in that it demonstrates that *G. occidentalis* populations can grow in cotton. Regression analysis of the predatory mite release treatments revealed that predatory mite densities were highly correlated with spider mite densities. This result suggests that predatory mites show the greatest recruitment on plants that had the highest spider mite densities. Whether *G. occidentalis* mites need these high spider mite densities to recruit new offspring in cotton remains unknown at this time.

In experiments 1 and 2, predatory mite densities appeared to decline over the first 7-8 days after the initial release. One explanation for this observation is that a portion of the predatory mites delivered to cages did not move from the corn-cob grit to the plant surface (we were careful not to spill the corn-cob grit during mite delivery). Other potential explanations include the possibility that some initial mite mortality occurred from the stresses of changing environments (from the greenhouse environment to the cotton field environment) or the stresses of being transported in corn-cob grit.

The third major difference from 1996 is that the predatory mite releases consistently reduced spider mite abundance to 38 - 47% of the level reached in the controls. This result suggests that, under the correct conditions, predatory mite releases could help control spider mites in cotton. However, in experiment 1 spider mite populations continued to build from day 8 to day 18 in the predatory mite release treatments, suggesting that predatory mites may be capable of suppressing but not controlling spider mite populations in cotton in the short term. Predatory mites may have been capable of adequately controlling spider mites had the predator to prey ratio been higher or had the experimental duration been longer.

An important outcome of experiment 2 is its demonstration that generalist hemipteran predators, such as *Geocoris* and *O. tristicolor,* can have negative impacts on *G. occidentalis* persistence. The addition of *Geocoris* and *O. tristicolor* reduced predatory mite densities to 23% and 0%, respectively, of the density observed in the predatory mite alone treatment. These hemipteran predators may have reduced the predatory mite density either by direct predation, by exploitative competition for spider mites, or by both of these mechanisms. The combination of direct predation and indirect exploitative competition for a shared resource is known as intraguild predation (Polis and Holt 1992; Holt and Polis 1997). The negative effects that *Orius* spp. can have on predaceous phytoseiid mites have been studied in the laboratory (Gillespie and Quiring 1992; Cloutier and Johnson 1993; Wittmann and Leather 1997) and in greenhouse nurseries (Ramakers 1993; Brodsgaard and Enkegaard 1997) where both *Orius* spp. and phytoseiids are used as biological control agents. However, we know of no studies that have documented predator interactions between *Orius* and phytoseiid mites under field conditions or predatory interactions between *Geocoris* and phytoseiids under any conditions. Both of these hemipteran predators are very common in cotton and are important naturally occurring spider mite predators (Wilson *et al.* 1991). It is uncertain at this time whether the presence of these hemipteran predators prevents predatory mites from becoming abundant under natural field conditions.

Although the simultaneous addition of predatory mites and hemipteran predators had negative effects on predatory mite persistence, it did not interfere with spider mite suppression. Indeed, the suppression of spider mites was strongest in the *O. tristicolor* + predatory mite treatment. These results are in contrast to some other arthropod systems where predator-predator interactions occur. For instance, predation by hemipteran predators on lacewing larvae can disrupt cotton aphid control (Rosenheim *et al.* 1993), and predation by *Zetzellia mali* on *G. occidentalis* can disrupt control of *Panonychus ulmi* (Croft and MacRae 1992a).

One spider mite predator that does not appear to have negative effects on *G. occidentalis* is the western flower thrips *F. occidentalis*. This result is surprising given the results of our laboratory experiment, where thrips larvae fed on eggs of both *G. occidentalis* and *T. urticae*. Perhaps thrips densities have to be much greater for this source of predation to be important.

In experiment 1, *F. occidentalis* had no detectable impact on spider mite populations. This result is surprising given that earlier laboratory work by Trichilo and Leigh (1986) and regression analyses of arthropod population dynamics (Wilson *et al.* 1991; R.G. Colfer, unpublished data) suggest

that thrips are important early season mite predators in cotton. Two caveats regarding our experimental results are that we were unable to increase thrips densities to levels commonly seen in early season cotton, where thrips:spider mite ratios can be near 1 (Table 2), and we were somewhat unsuccessful in excluding thrips from the control cages. Further work is needed to better evaluate the impact of *F. occidentalis* on spider mite populations in cotton.

In summary, we found that predatory mite releases can increase predatory mite populations; these predator populations can increase their abundance through reproductive recruitment in the field; and they can suppress spider mite populations. It is still unclear whether spider mites can be suppressed below economic thresholds. Furthermore, it is unknown whether these results can be observed under conditions that are less optimal for predatory mite population growth. *Geocoris* and *O. tristicolor* can have a negative impact on predatory mite persistence but can improve spider mite suppression, at least in the short-term. No detectable impact of *F. occidentalis* was observed on either *G. occidentalis* or spider mite populations.

Future research will evaluate alternative hypotheses that could explain why large scale releases of predatory mites at low rates were not successful in suppressing mites. We will compare how predatory mite population growth and persistence is affected by: (1) host plant (plants that predatory mites are known to perform well on, such as grapes and soybeans, will be compared with cotton plants); and, (2) different predatory mite sources (mites collected from grape fields vs. purchased from an insectary). We will also continue to evaluate how generalist insect predators impact predatory mites.

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Beltwide Tables and Figures

Table 1. Predatory mite release sites, dates and initial percent of leaves infested with spider mites.

Site #	County	Early Release (ER) date	Late Release (LR) date	% plants Infested (ER, LR)*
Conv. 1	Kern	5/03/96	none	25
Conv. 2	Kern	5/03/96	none	30
Conv. 3	Kern	5/03/96	none	30
Conv. 4	Kern	5/03/96	none	25
Conv. 5	Kern	5/04/96	none	20
Conv. 6	Merced	5/25/96	6/19/96	25, 85
Conv. 7	Merced	5/25/96	none	25
Conv. 8	Merced	5/25/96	6/25/96	30, 50
Organ. 1	Merced	5/10/96	6/06/96	25, 95
Organ 2	Madera	5/10/96	6/06/96	45, 100
Organ 3	Madera	5/10/96	6/07/96	45, 100
Organ 4	Madera	5/11/96	6/12/96	25, 100
Organ 5	Madera	5/24/96	6/20/96	20, 100
Organ 6	Madera	5/24/96	6/20/96	20, 90
Organ 7	Madera	5/24/96	6/12/96	60, 100
Organ 8	Madera	5/11/96	6/12/96	20, 65
Organ 9	Madera	5/25/96	none	35
Organ 10	Madera	5/25/96	none	45
Organ 11	Kern	none	8/7/96	35

*Includes plants that were only infested with mite eggs.
Conv. = Conventional; Organ. = Organic

Table 2. Mean (± S.E.) seasonal arthropod numbers per 80 leaves.

Farming Practice	Treatment	Spider mites	Thrips	Predatory mites
Conventional	Control	41 ± 10	119 ± 32	0.4 ± 0.2
Conventional	Early Release	49 ± 10	148 ± 34	0.2 ± 0.2
Organic[1]	Control	187 ± 41	128 ± 18	0.5 ± 0.3
Organic[1]	Early Release	185 ± 43	138 ± 19	0.5 ± 0.3
Organic[2]	Control	282 ± 72	132 ± 28	0.9 ± 0.6
Organic[2]	Early Release	249 ± 80	131 ± 31	1.0 ± 0.6
Organic[2]	Late Release	327 ± 76	105 ± 30	1.8 ± 0.6

1 - Range of dates from early release to end of season
2 - Range of dates from late release to end of season

Table 3. Thrips treatment manipulations in experiment 1.

Duration of Experiment	Census 1	Census 2
Control	38.4 ± 10.1	105 ± 29.8
Thrips Addition	82.3 ± 9.8	112 ± 20.4

Table 4. Arthropod treatment manipulations in experiment 2.

Treatment	Control	Predator Addition
Predatory Mites	0	3.7 ± 0.8
Thrips	7.7 ± 1.7	13.0 ± 1.5
Geocoris	0	0.5 ± 0.1
Orius	0.2 ± 0.1	1.1 ± 0.3

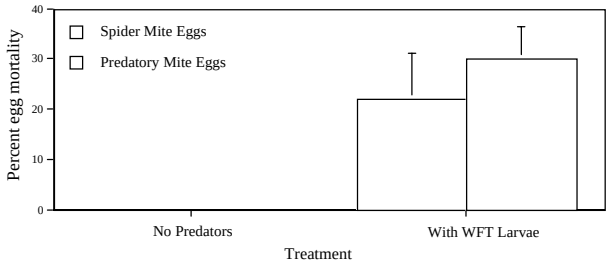

Figure 1. Percent of *T. urticae* and *G. occidentalis* egg predation by western flower thrips (WFT) larvae. Controls were leaf disks containing eggs but no WFT larvae; all eggs in controls were undamaged after the 24-hr assay period. Egg predation rates were similar for *T. urticae* and *G. occidentalis* eggs (student t-test, Prob>|t| = 0.49).

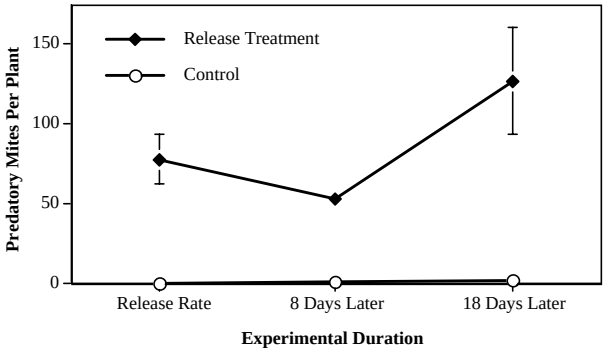

Figure 2. Releases increased predatory mite numbers far above numbers occurring on control plants.

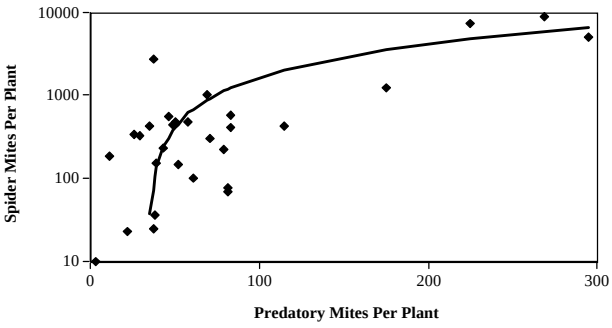

Figure 3. Predatory and spider mite abundance for plants in the release treatment. Numbers of spider and predatory mites were strongly correlated ($r^2 = 0.705$, $F_{1,27} = 64.7$, $P < 0.0001$). The line represents the "line-of-best-fit" from simple linear regression. Note that spider mite abundance is on a $\log_{10}$ scale.

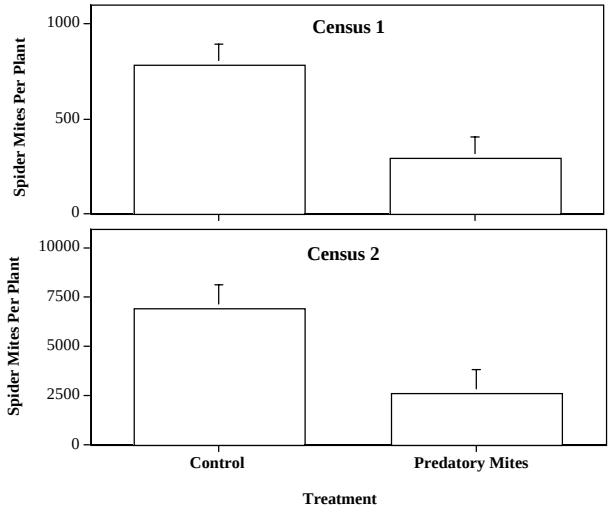

Figure 4. Releases of *G. occidentalis* reduced spider mite densities to less than 40% of the densities in the control plants at both day 8 and day 18 of experiment 1. Spider mite density continued to increase in all treatments from day 8 to day 18 despite predatory mite releases.

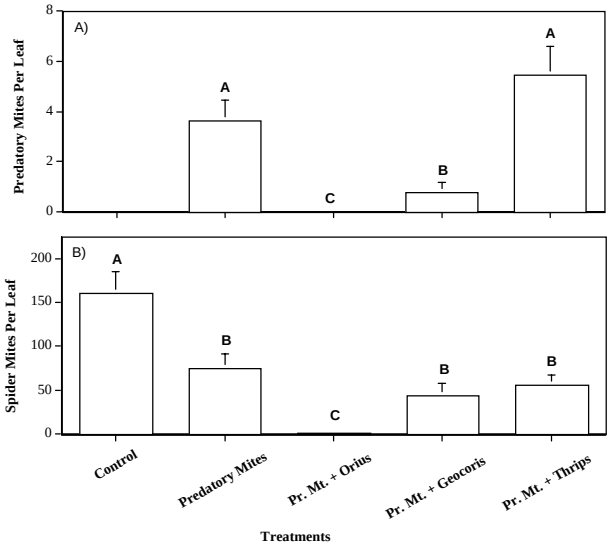

Figure 5. Influence of predatory mites and generalist insect predators on (A) western predatory mite, *Galendromus occidentalis*, abundance per leaf and (B) twospotted spider mite, *Tetranychus urticae*, abundance per leaf in experiment 2. Different letters above bars represent significant differences between treatments at $\alpha = 0.05$.