# THE EVALUATION OF BIOLOGICAL CONTROL OF SPIDER MITES

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## Abstract

The purpose of this research was to evaluate the naturally occurring biological control of spider mites. We focused on the two groups: omnivorous western flower thrips, *Frankliniella occidentalis* and generalist predatory bugs (specifically *Orius tristicolor* and *Geocoris* spp.). We used multiple approaches; including field enclosures and insecticide manipulations, to manipulate predator abundance. We found that western flower thrips were successful in substantially reducing spider mite population growth during the early season, and this, in turn, led to greater seed cotton yields at the end of the season. Also, we observed no yield losses caused from early-season plant feeding by western flower thrips. Generalist predators, especially *O. tristicolor* and *Geocoris* spp., were very effective at suppressing mites. For three different field seasons, we found that predators suppressed spider mite populations to levels 76 - 99 percent below those observed where generalist predator abundance had been reduced. Furthermore, we observed high levels of suppression using multiple techniques to manipulate predators: levels of spider mite suppression were similar in cage and insecticide manipulation experiments. Finally, we found that generalist predators suppressed mites over a fairly wide range of initial spider mite densities. These findings demonstrate the importance of conserving naturally occurring predators of spider mite control; efforts should be made to find replacements for broad-spectrum insecticides that frequently decimate generalist predator populations.

## Introduction

Spider mites, *Tetranychus* spp., are foliar feeders that destroy photosynthetic cells as they feed. High densities of spider mites can lead to the defoliation of plants and can cause severe economic damage to upland cotton, *Gossypium hirsutum,* especially in the San Joaquin Valley of California. While spider mites can be important primary pests, they are especially known as secondary pests: they display rapid rates of population growth following the application of broad spectrum insecticides (carbamates, organophosphates, and pyrethroids) for control of *Lygus* bugs or cotton aphids.

A form of biological control that is frequently underemphasized is the conservation of naturally occurring predators and parasitoids (Barbosa 1998, Pickett & Bugg 1998). Cotton generally fosters high numbers of predators if populations are not disrupted by broad-spectrum chemicals. Research has shown that some of these predators may be important in suppressing spider mites in cotton (Wilson et al. 1991, Trichilo & Leigh 1986). Furthermore, the role of western flower thrips in California cotton is somewhat contentious; some growers consider it a pest while others consider it an important natural enemy of spider mites. A better understanding of the role that these generalist predators and omnivores are playing in reducing spider mite populations will improve our ability to control spider mites.

In this paper we use different techniques to evaluate the impact that generalist predators have on spider mite suppression at different times of the season. First, we use exclusion field cages to evaluate the impact that the western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) has on spider mite populations and cotton plant performance during the early season (presquaring period). Second, we evaluate the impact that the entire generalist predator community has on spider mite suppression during the early and midseason (prior to the boll forming period), with special emphasis on the minute pirate bug *Orius tristicolor* (White) (Heteroptera: Anthocoridae) and the big-eyed bugs, *Geocoris pallens* Stal and *G. punctipes* (Say) (Heteroptera: Lygaeidae). We use both cage and insecticide exclusion approaches to manipulate predators in these experiments.

## Methods and Materials

### Evaluation of Early-Season Control of Spider Mites by Western Flower Thrips

The purpose of these experiments was to quantify (1) the impact of western flower thrips on spider mite population dynamics, (2) to quantify the reciprocal influence of spider mites on thrips population dynamics, and (3) to compare the relative impact of spider mites and thrips on early and late season cotton plant performance.

### 1998 Experiment

This experiment was conducted 18 May to 25 October in a half acre plot of *G. hirsutum* (cv. Acala SJ 2) planted at the UCD Plant Pathology Fieldhouse, Davis, CA. The experimental unit was a pair of cotton plants enclosed in a No-Thrips® mesh cage (Greentek, Inc.; mesh size ca. 150 μm) with a PVC hoop base buried in the ground. The experiment contained the following treatments, each with 40 replicates: (1) plants infested with spider mites (*T. urticae*, ca. 40 mites per plant), (2) plants infested with western flower thrips (ca. 25 thrips per plant), and (3) plants infested with spider mites and thrips. To prevent thrips establishment on non-thrips treatments, cages were set in place before the cotton seeds germinated, thereby slowing the colonization of

seedlings by thrips. Cages were separated by at least 8 ft. Treatments were initiated on 5 June. Replicates were monitored by collecting two fifth-node mainstem leaves after approximately 2 and 4 weeks from the beginning of the experiment (22 June and 5 July). On 5 July cages were removed and plant height and leaf lengths were measured for all plants. Leaf area was estimated using a previously established relationship between leaf length and area determined by regression analysis (leaf area = -2.49 + 0.204(leaf length) + 0.823(leaf length)$^2$, r = .983, P < 0.0001). After the cages were removed, no attempt was made to maintain treatment differences, and plants were allowed to grow to the end of the season. On 25 October, plant yields were estimated by counting the total number of bolls on all plants.

### 1999 Experiment

This experiment was conducted 21 April to 20 October in a five acre plot of *G. hirsutum* (cv. Acala Maxxa) planted at the UC West Side Research and Extension Center, Five Points, CA. This experiment was conducted using the same methods as described for 1998 except as noted here. The experimental unit was three cotton plants enclosed in a cage. The experiment contained the following treatments, each with 40 replicates: (1) plants without herbivores, (2) plants infested with spider mites (*T. urticae*, ca. 25 mites per plant), (3) plants infested with western flower thrips (ca. 25 thrips per plant), and (4) plants infested with spider mites and thrips. The experimental treatments were initiated on 5 May. Replicates were monitored three times by collecting two mainstem leaves (located three nodes below the apex of the plant) approximately 2, 4, and 6 weeks after the beginning of the experiment (19 May, 3 June, and 17 June). After six weeks of experimentation, cages were removed and plant height and leaf area were estimated for all plants. On 20 October, plant yields were measured by collecting and weighing seed cotton yields and quantifying the total number of bolls on all plants.

### Evaluation of Generalist Predators for Control of Spider Mites

The purpose of these experiments was to quantify the impact of generalist predators including the minute pirate bug, *Orius tristicolor,* and the big-eyed bugs, *Geocoris* spp., on spider mites. We used a mixture of experimental designs, including enclosure cages, semi-enclosure cages, and chemical applications. We also evaluate how differences in initial spider mite density influence the ability of generalist predators to suppress spider mites.

### 1998 Generalist Predator Experiment

The experiment was conducted from 23 June to 22 July, 1998 in a three acre plot of *Gossypium hirsutum* cv. "Maxxa" at the UC Cotton Research Station, Shafter, CA. The experimental unit was a single plant enclosed in a No-Thrips® mesh cage with a PVC hoop base buried in the ground. The experiment contained the following treatments, each with 16 replicates: (1) spider mites alone (initiated with ca. 250 mites), (2) spider mites + *Geocoris* (2 adults), (3) spider mites + *Orius* (4 adults), (4) spider mites + 'natural predators'. Experimental plants were thoroughly brushed to remove herbivorous and predatory arthropods before being inoculated with spider mites and predators, except for the 'natural predators' treatment. In this treatment, spider mites were added but predators were neither added nor removed, and some predator movement into and out of the cages was allowed by putting approximately 60 'port holes' (diameter 2 cm) on the sides and the top of the cages (semi-enclosure cage). *Geoocoris* spp. and *O. tristicolor* were the most abundant predators in the 'natural predators' treatment but their abundance was able to fluctuate naturally throughout the duration of the experiment. Treatments were initiated on 1 July, 1998. On 22 July, the experiment was terminated; all arthropods in the cages were quantified by aspirating large, active predators and removing all leaf material from experimental plants (ca. 40 leaves). Leaf material was stored in alcohol and arthropods were removed from the foliage using a leaf-washing procedure (Leigh *et al.* 1984). Arthropods were quantified using a stereomicroscope.

### 1999 Generalist Predator Experiment - Effect of Initial Spider Mite Density

The experiment was conducted from 25 May to 20 July, 1999 in a 2.8 acre plot of *Gossypium hirsutum* cv. "Maxxa" at the UC Cotton Research Station, Shafter, CA. The experimental unit was a single plant enclosed in a No-Thrips® mesh cage with a PVC hoop base buried in the ground. The experiment contained three predator treatments: (1) spider mites alone, (2) spider mites + *Geocoris* (1-2 females) and *Orius* (2 females), and (3) spider mites + 'natural predators'. Predator treatments were crossed with four different densities of spider mites (A = 303 ± 27, B = 601 ± 45 , C = 838 ± 71, D = 1430 ± 117; mean mites per plant ± standard error). Each combination of predator treatment and initial spider mite level was replicated five time except for the natural predator treatment, which had nine replicates. Experimental plants were thoroughly brushed to remove herbivorous and predatory arthropods before being inoculated with spider mites and predators, except for the 'natural predators' treatment in which naturally-occurring predators were retained. Treatments were initiated on 23 June, 1999. On 7 July, spider mite populations were estimated by sampling two mainstem leaves (4-6 nodes below the plant apex) per replicate. On 20 July, the experiment was terminated; all arthropods in the cages were quantified by aspirating larger, active predators and removing all leaf material from experimental plants (ca. 40 leaves).

## 1997 Generalist Predator Experiment – Chemical Manipulation

This experiment was designed to quantify the impact of the generalist predator community on spider mite populations using a chemical manipulation of the arthropod community. The experiment was conducted from 21 May to 15 July, 1997 in a five acre planting of *G. hirsutum* cv. "Maxxa" at the UC Cotton Research Station, Shafter, CA. Experimental units were cotton plots (28m x 12m) surrounded by 3.5m of bare soil. Plots were randomly allocated to one of four treatments, each replicated 14 times: (1) application of acephate (Orthene®) to temporarily reduce generalist predator abundance and (2) no manipulation control. Acephate was sprayed at 4.0 oz ai/ac on 21 May to reduce naturally occurring populations of predators without causing substantial mortality to spider mite populations. Plots were monitored every two weeks using leaf and sweep (20 sweeps/plot) sampling techniques from 21 May to 15 July. Leaf sampling involved randomly collecting 25 mainstem leaves located five nodes below the apex of the plant.

### Statistical Analysis

In all the experiments, we analyzed arthropod and plant performance data using one or two factor analysis-of-variance or repeated measures analysis-of-variance. All the data that did not meet the requirements for ANOVA were log transformed.

### Results

### Evaluation of Early-Season Control of Spider Mites by Western Flower Thrips

Western flower thrips significantly reduced spider mite abundance over the duration of the experiment during both 1998 (Fig. 1a, P=0.0001) and 1999 (Fig. 1b, P<0.0001). During 1998, the magnitude of the impact of thrips was greater after three weeks than after two weeks (Thrips by Time interaction, P = 0.0085). During 1999, the magnitude of the impact of thrips did not substantially change across the three sample dates (Thrips by Time interaction, P = 0.37). Thrips did not, however, completely prevent spider mite population growth during either 1998 or 1999 (Fig. 1), they only reduced it.

Thrips populations benefited by having access to spider mite prey; they were at least twice as abundant in treatments with spider mites compared to treatments with only cotton seedlings available as food during both 1998 and 1999 (Fig. 2a, P < 0.0001; Fig. 2b, P < 0.0001; respectively). Unlike a typical specialist predator, western flower thrips populations did not increase with increasing spider mite prey abundance (i.e. they did not 'track' their prey). Instead, thrips densities were stable during the 1998 experiment and actually declined in density during 1999 (Fig. 2).

We describe plant performance traits separately for the 1998 and 1999 field seasons because both the experimental design and the results were slightly different between the two years. During 1999, we added a treatment containing neither spider mites nor thrips because it allowed us to determine the direct effect of thrips on cotton plant performance.

During 1998, thrips populations had a larger negative effect on plant growth, as measured by total leaf area at midseason (10 July measurement, Fig. 3a), compared to the spider mite populations. However, spider mite damage had a larger negative effect than did thrips damage on cotton yield, as measured by total number of bolls at the end of the 1998 season (Fig. 3b, P = 0.005). Note that this effect was observed even though treatment differences were only enforced until 10 July. In 1998, cotton yields were slightly, but non-significantly, higher in the spider mites + thrips treatment compared to the spider mites alone treatment.

During 1999, plant performance was more strongly influenced by spider mites than thrips during the early/midseason (16 June measurement) and the end of the season (20 October). Spider mites significantly reduced total leaf area while thrips did not (Fig. 4a, P = 0.005, P = 0.96, respectively). Both spider mites and thrips caused substantial damage to leaves (Fig. 4b, P < 0.0001, P < 0.0001, respectively). Even though thrips reduced spider mite numbers throughout the experiment, the percentage of leaf damage was actually slightly increased on plants infested with both spider mite and thrips compared to leaves with spider mites only (i.e. damage by thrips and spider mites was additive; thrips by spider mite interaction, P = 0.22). Plant feeding by thrips did not cause a reduction in seed cotton yields (P = 0.83). In contrast, spider mites reduced seed cotton yields by more than 46 percent (P < 0.0001). Most importantly, when thrips were added to cages containing spider mites, they reduced the negative effects of mites on cotton yield; seed cotton yields in the spider mite + thrips treatment was 30% greater than in the spider mites alone treatment.

### Evaluation of Generalist Predator for Control of Spider Mites

Generalist predators suppressed spider mite populations in all three experiments during 1997 – 1999 which employed both enclosure cage and chemical manipulation techniques. We will review the results of each experiment beginning with the 1998 cage experiment, then the 1999 cage experiment, and finally the 1997 chemical manipulation experiment.

### 1998 Generalist Predator Experiment

Spider mite populations were suppressed in all three generalist predator treatments compared to the spider mites only treatment (Fig. 5; *Orius*, P = 0.0002; *Geocoris*, P < 0.0001; Natural Predators, P < 0.0001). Spider mite

suppression was strongest in the natural predators treatment where spider mites were reduced by 95% below that of the spider mites only treatment.

### 1999 Generalist Predator Experiment -
### Effect of Initial Spider Mite Density

Spider mite populations were again greatly reduced by generalist predators. Data in this experiment are presented as the percentage that spider mites were suppressed in predator treatments below that observed in the spider mites only treatment. Spider mite suppression was calculated using the following formula: (1 – (# spider mites in a predator treatment/ # spider mites in the spider mites only treatment))*100%. We observed the greatest suppression of spider mites in the natural predators treatment where suppression was even greater than during 1999; spider mites were reduced by more than 99% below that of the spider mites only treatment during both census periods (Fig. 6a & 6b; census 1, P < 0.0001; census 2, P < 0.0001). Spider mite reductions were not influenced by the initial spider mite density in the natural predator treatment (P = 0.18).

The *Geocoris/ Orius* treatment also significantly reduced spider mites during both census periods (Fig. 6a & 6b, census 1, P = 0.0001; census 2, P < 0.0001). However, initial spider mite densities did influence the amount of suppression observed at census 1; greater suppression was seen in treatments with lower initial spider mite densities (Fig. 6a, regression of initial spider mite density by % spider mite suppression, r = 0.45, P = 0.003). However, this relationship reversed by the end of the experiment; the percentage of spider mite suppression was greater at higher initial spider mite densities (Fig. 6b, r = 0.50, P = 0.025). This result is likely due to the higher reproductive recruitment of *Geocoris* in treatments with higher initial spider mite densities (Fig. 7, r = 0.57, P = 0.007).

### 1997 Generalist Predator Experiment –
### Chemical Manipulation

In this experiment, acephate was applied to plots to reduce the densities of naturally occurring generalist predators while minimizing the pesticide-induced mortality on spider mites. The application of acephate was effective at reducing predators; two weeks after the acephate application immature predator abundance (excluding western flower thrips) was reduced by 80 percent (Fig. 8, P = 0.0003), total predator abundance was reduced by 40 percent (P = 0.002), and western flower thrips abundance was reduced by 48 percent (P = 0.079). With the decline in predator abundance, we observed higher spider mite densities in sprayed plots compared to unsprayed plots over the duration of the experiment (Fig. 9, P < 0.0001). Spider mite densities in sprayed plots were 4.2 times greater and 9.8 times greater than the unsprayed plots two and four weeks (6/2 and 6/15) following the acephate application, respectively. Spider

mites declined in both sprayed and unsprayed plots after 2 June, and sprayed and unsprayed plots had similarly low densities of spider mites by 15 July (P = 0.14). The decrease in spider mite populations was correlated with an increase in predator abundance (Spearmans ρ = -0.33, P < 0.0001).

### Discussion

### Evaluation of Early-Season Control of
### SpiderMites by Western Flower Thrips

Our manipulative field experiments showed that western flower thrips consistently reduced spider mite abundance. During both 1998 and 1999, we found that spider mite levels were reduced by more than fifty percent. While earlier work has explored some ecological aspects of spider mite egg predation by flower thrips in the laboratory (Trichilo and Leigh 1986a, 1988, Wilson et al. 1996, Milne & Walter 1997, Agrawal et al. 1999), this study is the first to manipulate thrips densities in the field without insecticides and thereby directly evaluate their utility as biological control agents. Some previous studies have manipulated flower thrips populations using insecticides (Wilson et al. 1991, Wilson et al. 1996). However, these studies are often difficult to interpret because insecticides may have other effects on spider mites (i.e. hormoligosis), and insecticides used to kill thrips frequently kill other spider mite predators.

Spider mite availability had a large positive effect on thrips populations; thrips were at least twice as abundant in treatments where spider mites were available. Other studies have shown that flower thrips gain a fitness advantage by feeding on spider mite eggs (Trichilo and Leigh 1988, Milne and Walter 1997). Our study shows that this fitness advantage translates to increased thrips populations. Unlike most predators, western flower thrips showed limited reproductive recruitment to increasing spider mite populations; thrips populations stayed constant or declined as spider mite populations increased. This aspect of western flower thrips ecology distinguishes it from most other spider mite predators.

While plant feeding by thrips can have fairly large effects on cotton plant performance during the early and midseason (Fig. 3a), this damage did not depress yields. Indeed, in our 1999 experiment, plants infested with both spider mites and thrips had more leaf damage than plants with spider mites only, yet these plants had significantly greater seed cotton yields (Fig. 4c). Furthermore, plant feeding by thrips alone did not reduce seed cotton yields during 1999. These results indicate that western flower thrips are not an early-season pest of cotton when their densities are not exceptionally abundant. Thus, insecticide treatments for thrips control during most years in the San Joaquin Valley of California are likely to be more detrimental than beneficial to the cotton crop, because insecticides used to control thrips generally

disrupt the whole predator complex and this can cause secondary pest outbreaks. However, thrips may cause economic damage to cotton plants when thrips densities are expectionally high and/or early season temperatures are below average. Under these conditions, thrips can kill plant terminals and can cause severe reductions in leave area. Cotton seedlings can be significantly damaged by thrips feeding when they are stunted by cool temperatures (R.G. Colfer, pers. observ.). Further research needs to be done to evaluate the pest status of thrips under these more stressful conditions.

## Evaluation of Generalist Predators for Control of Spider Mites

Generalist predators substantially reduced spider mite abundance during each of the three years of our experimental evaluations of spider mite biological control. We observed predators consistently suppressing spider mite populations to levels 75 - 99 percent below those observed where generalist predators had been removed. Furthermore, we observed this high level of suppression using different techniques to manipulate predators: levels of spider mite suppression were similar between cage and insecticide manipulation experiments.

During 1998 and 1999, we found that the best level of spider mite suppression was observed in the predator treatment containing the whole complex of generalist predators at their natural densities. This treatment was unique for a cage experiment because it did not enclose a fixed number of predators in a cage that prevented movement. We neither added nor removed predators to experimental plants, and the cage design facilitated movement in and out of it while preventing most aerial dispersal by spider mites. While *O. tristicolor* and *Geocoris* spp. treatments in our experiments were effective at suppressing spider mite populations, the natural predator treatment consistently had lower spider mite densities than these treatments. There was a marked difference between the *Orius/ Geocoris* treatment and the natural predators treatment in our 1999 experiment evaluating the ability of these natural enemies to suppress spider mite populations over a range of initial spider mite densities. The natural predator treatment provided rapid and nearly complete suppression of spider mites, while the *Orius/ Geocoris* treatment initially provide only partial control in treatments with high initial spider mite densities. We believe that the primary differences between the *Orius/ Geocoris* treatment and the natural predators treatment were (1) predators were capable of spatially responding to spider mite populations in the natural predator treatment (i.e., predators moved into the cages) and (2) predator diversity was greater in the natural predator treatment; although *O. tristicolor* and *Geocoris* spp. were still the most abundant species, we also found *Nabis* spp., *Notoxus calcaratus, Zelus renardii*, *Chrysoperla* spp., and spiders.

During our 1997 experiment, we found that acephate substantially reduced generalist predators and caused spider mite densities to increase 4.2 to 9.8 times above mite densities in unsprayed plots. There are several potentially important reasons for the secondary outbreak of spider mites following the application of broad spectrum insecticides such as acephate. One of the best supported explanations for this observation is that insecticides decimate naturally occurring generalist predators yet cause little mortality to spider mites (Trichilo & Leigh 1986b, Gonzalez et al. 1982, this study). When spider mite populations are no longer limited by predation they can expand and cause severe foliar damage to cotton plants. Another potential reason for this phenomenon is that broad spectrum insecticides cause spider mite growth rates to increase either directly or indirectly by modifying plant quality. While both of these factors may contribute to spider mite outbreaks, simulation analysis of this system has shown that the reduction in predator abundance is probably more important (Trichilo and Wilson 1993). In this study we employed several techniques of evaluating natural enemy impacts on spider mites. Because the magnitude of the impact of generalist predators on spider mite populations was similar whether predators were excluded with cages or with insecticides, we can more confidently conclude that spider mite population growth following the acephate treatment was primarily due to the suppression of generalist predators.

Cotton is generally inhabited by a diverse and abundant complex of generalist predators (van den Bosch & Hagen 1966). If populations of these predators are conserved, there is the potential to partially or completely control many pests of cotton. One of the most important approaches to conserving predators while controlling key pests is to replace currently used broad spectrum pesticides with selective pesticides (Ruberson et al. 1998). Unfortunately, there are no selective pesticides available to control some key pests such as the *Lygus* bug and the cotton aphid. In these cases, the cost of treating secondary outbreaks of herbivores such as spider mites and lepidopterans should be factored into damage thresholds.

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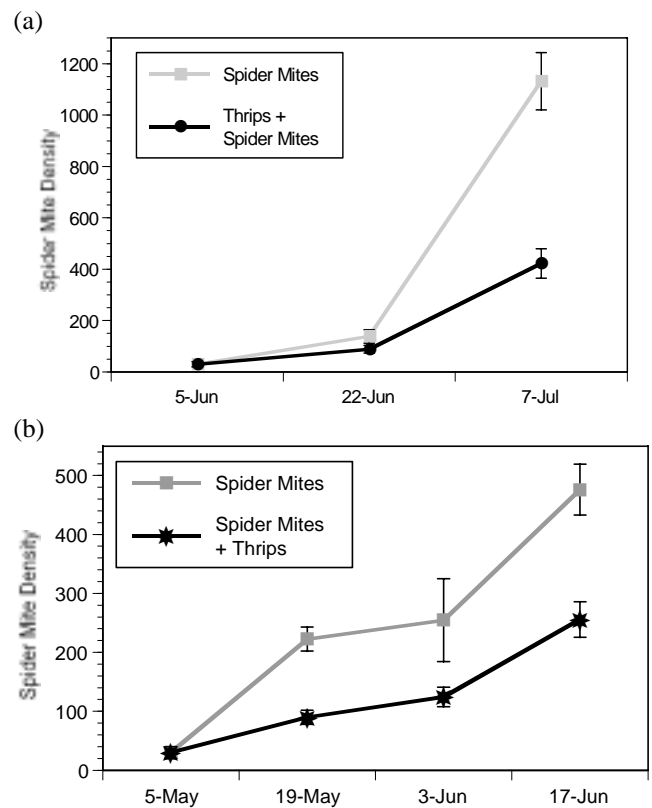
(a)



(b)



Figure 1. Means ± SE (Standard Error) spider mite densities (total number per 2 leaves) during the (a) 1998 and (b) 1999 field experiments, which evaluated the impact of western flower thrips on spider mite populations.
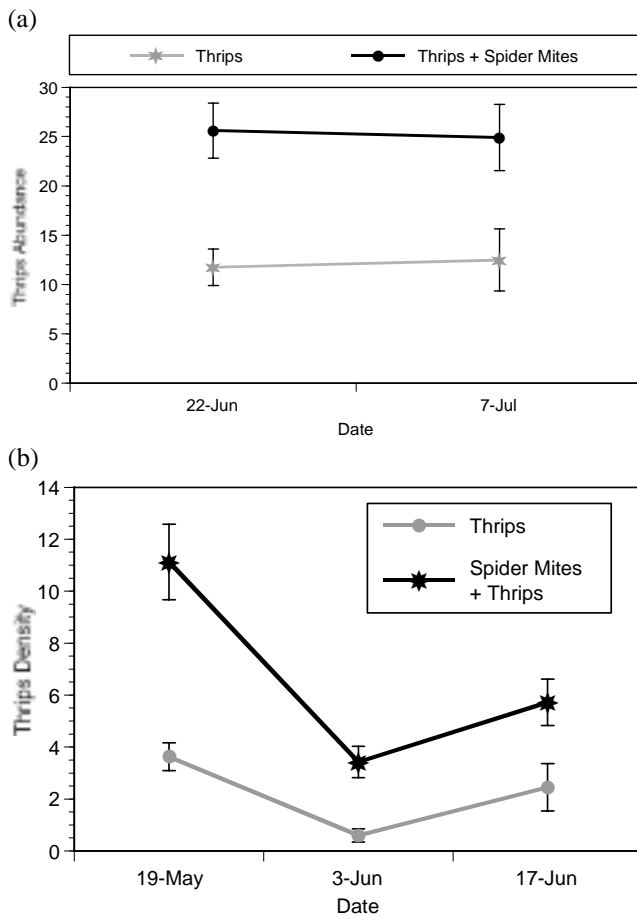
(a)



(b)



Figure 2. Means ± SE western flower thrips densities (total number per 2 leaves) during the (a) 1998 and the (b) 1999 field experiments.
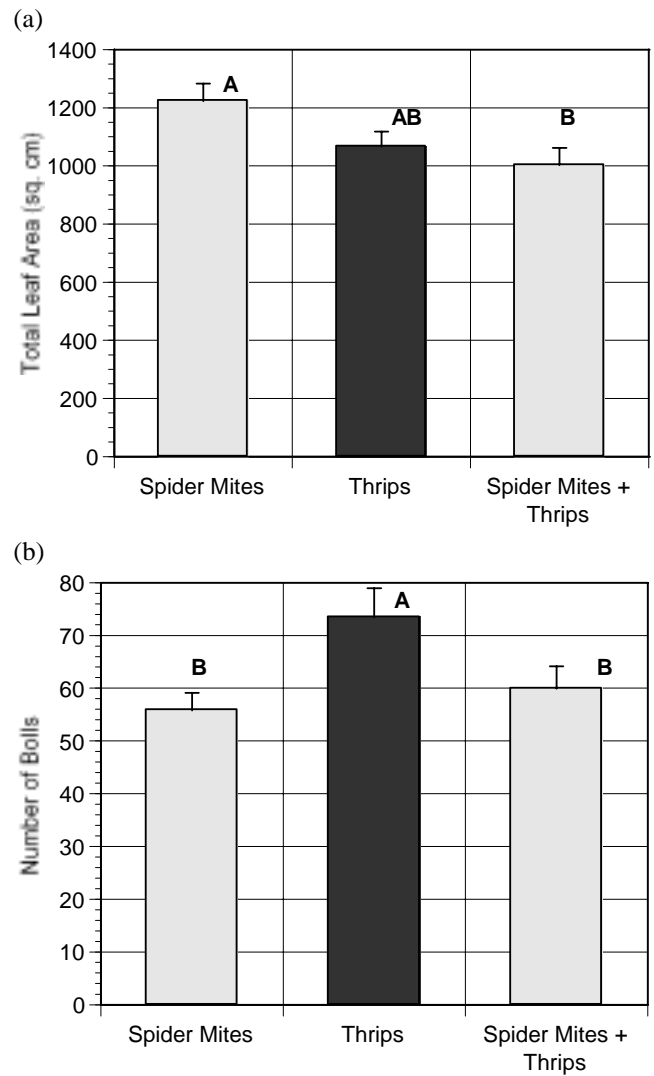
(a)



(b)



Figure 3. Mean ± SE (a) leaf area (measured on 10 July) and (b) number of bolls (measured on 25 October) per 2 plants for the 1998 field experiment. Differences in letters above the bar graphs indicate significant differences between treatments ($\alpha = 0.05$).
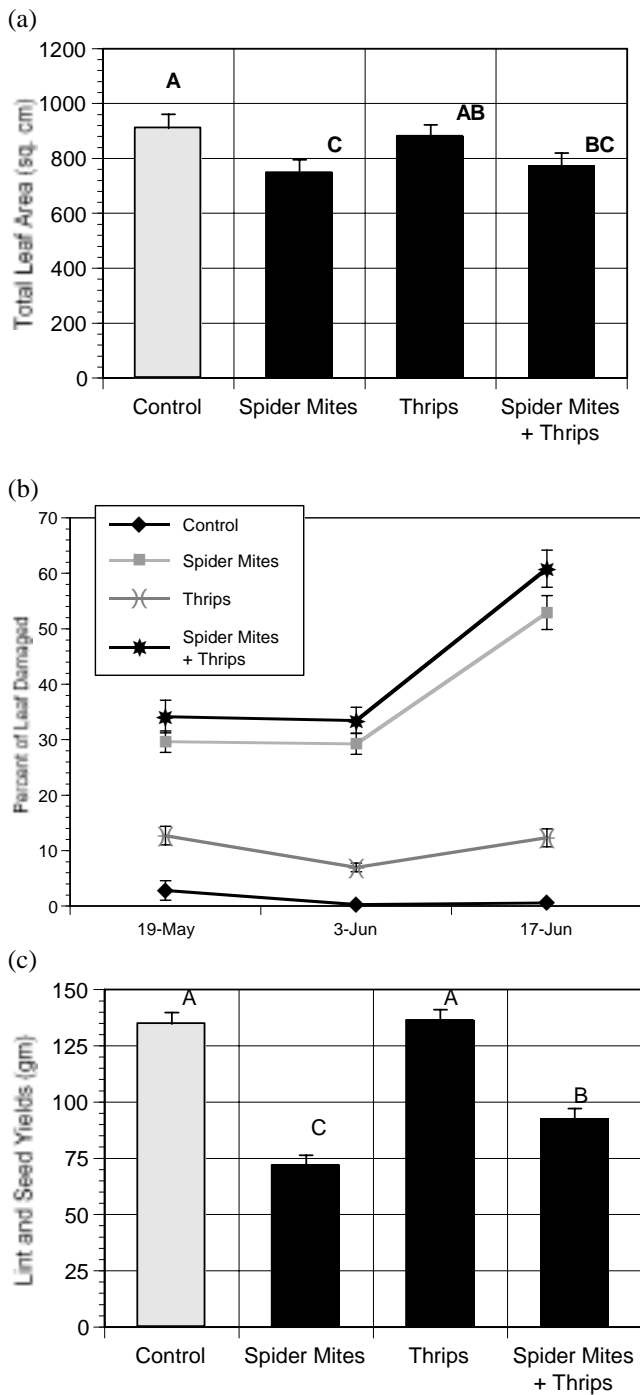
(a)



(b)
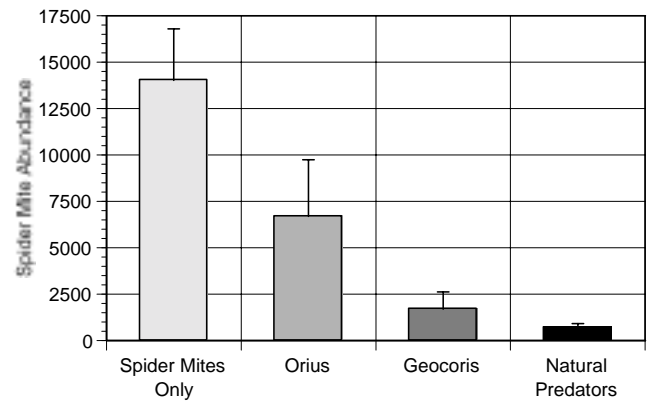


(c)



Figure 4. Mean ± SE (a) leaf area per 3 plants (measured on 16 June), (b) percentage of lower leaf surface damaged by herbivory from spider mites, western flower thrips, or both, and (c) seed cotton yields per 3 plants (measured on 20 October) during 1999 field experiment. Differences in letters above the bar graphs indicate significant differences between treatments (α = 0.05).



Figure 5. Mean ± SE spider mite abundance per plant in the 1998 experiment evaluating the impact of *Orius tristicolor*, *Geocoris* spp., and naturally occurring densities of generalist predators on spider mite suppression.
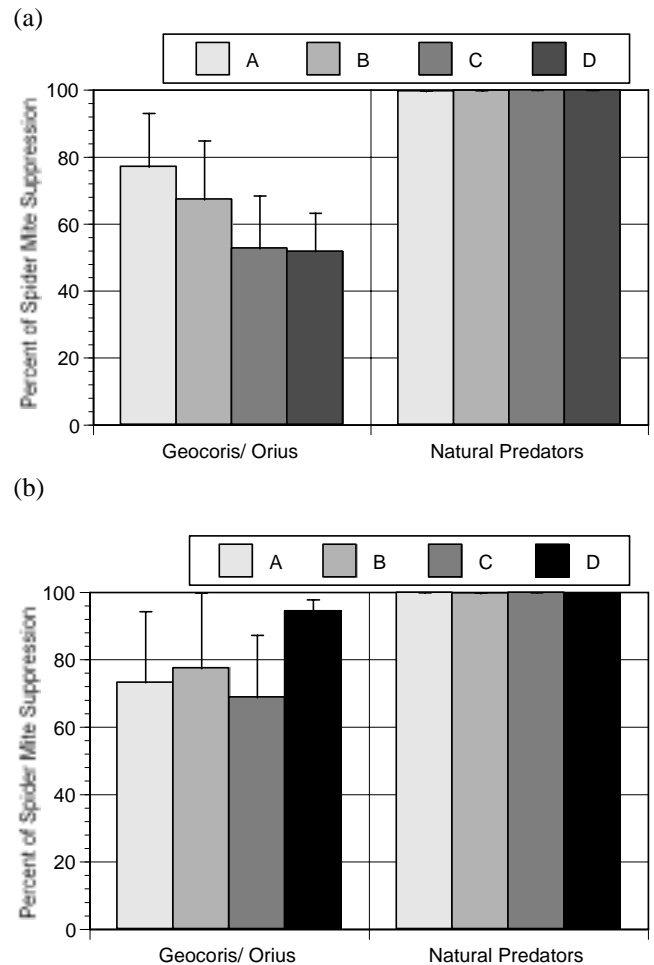
(a)



(b)



Figure 6. Percentage of spider mite suppression (Mean ± SE) provided by a treatment with *Orius tristicolor* and *Geocoris* spp. and a treatment with naturally occurring densities of generalist predators at four different levels of initial spider mite abundance (A = 303 ± 27, B = 601 ± 45 , C = 838 ± 71,

D = 1430 ± 117; mean per plant ± standard error). Spider mite suppression was measured twice: at (a) two weeks and (b) four weeks after the experiment was initiated. This experiment was conducted during the 1999 field season.
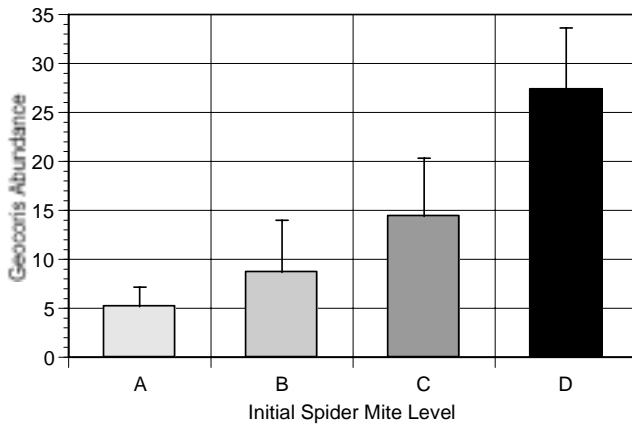


Figure 7. Mean ± SE Geocoris spp. abundance (nymphal and adult stages) four weeks after the experiment was initiated in the four initial spider mite density treatments (A = 303 ± 27, B = 601 ± 45 , C = 838 ± 71, D = 1430 ± 117; mean per plant ± standard error).
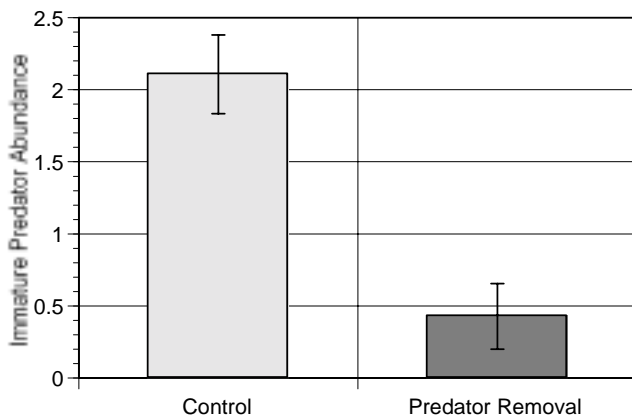


Figure 8. Mean ± SE immature predator abundance (nymphal and larval stages) per 20 sweeps in the 1997 field experiment two weeks following an application of acephate (Orthene®). 'Predator Removal' plots received the acephate application and 'Control' Plots did not.
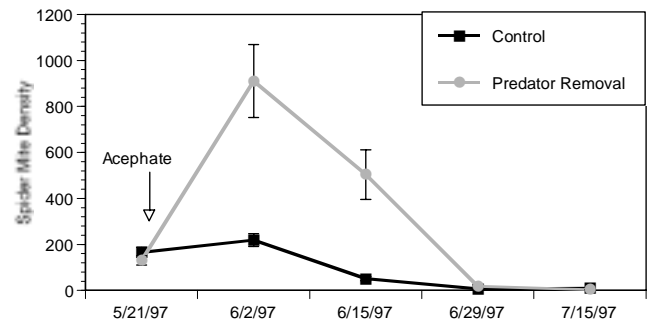


Figure 9. Mean ± SE spider mite densities in treatments that received an application of acephate (Predator Removal) and that were not sprayed (Control). The arrow indicates when the acephate application was made. The acephate application was successful in substantially reducing the abundance of spider mite predators.