Arthropod Pest Management in the Lower San Joaquin Valley

Project No.: **17-ENTO6-Haviland**

Project Leader:
David Haviland
Entomology Farm Advisor
UCCE - Kern County
1031 S. Mount Vernon
Bakersfield CA 93307
661.868.6215
dhaviland@ucdavis.edu

Project Cooperators and Personnel:
Stephanie Rill, UCCE- Kern County

Objectives:

1) Develop practical implications from sixspotted thrips literature
2) Evaluate sticky cards for monitoring sixspotted thrips and predatory beetles
3) Evaluate seasonal sixspotted thrips abundance and activity patterns in almonds
4) Evaluate the impacts of sixspotted thrips on spider mite populations
5) Evaluate the effects of miticides on Pacific spider mite
6) Evaluate the efficacy of four mating disruption products for navel orangeworm control
7) Maintain a University-based research and demonstration orchard for almond pest management research

Interpretive Summary:

During 2017 we conducted research on mating disruption for navel orangeworm (NOW) and biological and chemical control of spider mites.

We evaluated four mating disruption (MD) systems: NOW Puffer (Suterra), Semios NOW (Semios), Isomate NOW Mist (Pacific Biocontrol), and Cidetrak NOW Meso (Trécé). All MD products contain the same active ingredient, but deliver it to the orchard differently. Each product was evaluated using 40-acre plots within an orchard, and the trial was replicated in three Kern County orchards. All four MD systems caused greater than 90% reductions in the capture of males in pheromone traps from April through September. Egg captures during the same time period were reduced by 22% where MD was used. Across all orchard the average percentage of NOW-infested kernels was 2.28% for the no-MD checks compared to 1.13 to 1.33% for the four MD products. When all four MD products are averaged, MD reduced NOW damage by 35% in Nonpareil, 51% in Monterey and 55% in Fritz, with an overall reduction of 46%.

Economic analysis of the data showed that grower returns increased by an average of $112 per acre. This is comparable to the cost of implementing mating disruption. In other words, adding MD to existing management programs on a 40-acre scale pays for itself. In the process, levels of NOW damage for nuts arriving at the huller were cut in half and risks of aflatoxin were reduced. Implementing MD also has the benefit of being considered a ‘green’

and ‘sustainable’ method for pest control that can help with resistance management programs and does not have issues related to residues, re-entry intervals, or pre-harvest intervals.

Research on biological control of Pacific spider mite showed that sixspotted thrips are a key biological control organism. Trap studies identified the yellow strip trap (Great Lakes IPM), small yellow trap (Alpha Scents) and green trap (Alpha Scents) as the most effective at catching sixspotted thrips and spider mite destroyer beetles. When ease of use and cost were also considered we determined that the yellow strip trap was the most effective and practical.

Season-long monitoring for thrips using the large yellow strip trap (6” x 12”) consistently showed a period of adult activity in April and May. At this time the thrips provided excellent control of early-season spider mites as overwintering females attempted to get established in the spring. Growers should avoid ‘preventative’ miticide applications at this time, especially with pesticides that might kill thrips, as a way to improve biological control of spider mites.

Sixspotted thrips had a second period of activity in July and August in response to rapid increases in spider mites after hull split. Approximately two to three weeks after spider mite increases began, thrips populations increased exponentially and eventually caused spider mite populations to crash. In all cases the exponential increase in thrips occurred after spider mites reached current UC treatment thresholds for spider mites. However, in all cases the thrips caused spider mites to crash before mites got to levels that would be considered of economic importance. This suggests that the UC threshold can be increased when thrips are present.

Closer evaluation during periods of peak activity showed that sixspotted thrips has a population doubling time of 3.4 days compared to 7.6 days for Pacific spider mite. Correlations showed that ratios between sixspotted thrips on cards and spider mites per leaf can be used to predict whether or not spider mite populations will increase, decrease, or stay the same one to two weeks later. In a simplified version of this correlation we determined that if pest control advisors catch 25 sixspotted thrips on a 12” x 6” yellow strip trap in one week, that there is a 72.7% likelihood that mite populations will stay the same or decrease within one week, and a 96.6% likelihood that mites will be on the decline at 14 days without the use of a miticide. Experiments on trap size showed that thrips can also be monitored on a commercially-available, smaller version of the yellow strip trap (3” x 5”), called a small yellow strip trap (Great Lakes IPM). If monitoring with the smaller trap, the tentative thrips threshold at which mite populations are predicted to stay the same or decrease within 14 days is 6 sixspotted thrips/trap/week.

In our 2017 miticide trial, evaluations of cumulative mites through 21 days after treatment showed significant reductions in mite density in plots treated with bifenazate (Banter, Vigilant), METI inhibitors (Nealta, Fujimite and Magester) and the growth regulator Envidor. Mite densities in plots treated with Biomite, Kanemite and experimental product (1180AA) were statistically equivalent to the best treatments as well as the untreated check.

Materials and Methods:

Objective 1: Develop practical implications from sixspotted thrips literature

Over the past few years sixspotted thrips has become an increasingly important predator of spider mites in California almonds. However, knowledge about this predator was minimal. A quick review of University of California books and online pest management guidelines reveals many occurrences of sixspotted thrips listed as a predator of spider mites, but very little to no practical information about its life history or biology. Therefore we conducted a literature search to identify previous research done on sixspotted thrips that might be able to fill current gaps in knowledge and identify areas where future research may be needed.

Objective 2: Evaluate sticky cards for monitoring sixspotted thrips and predatory beetles

In order to fully implement integrated pest management practices it is important to have ways to monitor pests and beneficials. In 2016 we documented that yellow sticky cards can be an effective way to quantify densities of spider mite predators, especially sixspotted thrips and spider mite destroyer beetles. These studies showed that the yellow strip trap (Great Lakes IPM) was the most effective trap at capturing both beneficials. However, it was also the largest trap we evaluated. For this reason we repeated the study in 2017, after first cutting all of the traps to the same size, to reassess relative effectiveness. During 2017 we also conducted a trial to evaluate the impact of trap size on capture rates. This was to help develop recommendations for the ideal trap size for use by growers and pest control advisors.

Evaluations of trap type and trap size were conducted in two commercial almond orchards in Kern Co. (Wasco and Lost Hills). The trap type study evaluated nine commercially-available sticky card traps that were each cut to a size of 3” by 5” (**Table 1**). The traps were placed within almond trees on 29 Aug at a height of approximately 6 ft in a randomized complete block design with four blocks. Traps were secured to the tree by attaching them to a binder clip that hooked onto a tree limb with an unwound wire paper clip. Spacing between plots was 8 trees by 4 rows. Traps were collected one week later on 5 Sep and a dissecting scope was used to count the number of sixspotted thrips, spider mite destroyer beetles, green lacewings and minute pirate bugs on each trap.

Table 1. Characteristics of sticky traps

Trap type	Original size of trap (in)	Original trap sticky surface area (in^2) front and back	Sticky surface area (in^2) front and back after cutting	Brand of trap
Green Card	3 x 5	30	30	Alpha Scents
White Card	3.5 x 6	42	30	Alpha Scents
Yellow Whitefly Card	4 x 6	48	30	Seabright Laboratories
Blue Thrips Card	4 x 6	48	30	Seabright Laboratories
Small Blue Strip Card	3 x 5	30	30	Great Lakes IPM
Large Yellow Strip Card	6 x 12	144	30	Great Lakes IPM
Small Yellow Strip Card	3 x 5	30	30	Great Lakes IPM
Large Yellow Card	6 x 9	108	30	Alpha Scents
Small Yellow Card	4 x 6	48	30	Alpha Scents

The second trial (trap size) was organized in the same design as the first trial, except that treatments included 12” by 6” large yellow strip traps (Great Lakes IPM) that were cut to five different sizes including 12” x 6”, 6” x 6”, 6” x 3”, 3” x 3” and 3” x 1.5”. Also included was a commercially available small yellow strip trap (Great Lakes IPM) that came precut to 5” x 3”.

The average number of each beneficial were analyzed by ANOVA using transformed data (square root(x+0.5)) with means separated by Fisher’s Protected LDS (*P*=0.05).

Objective 3: Evaluate seasonal sixspotted thrips abundance and activity patterns in almonds

Seasonal patterns in sixspotted thrips abundance were evaluated in three commercial almond orchards in Kern County (Wasco, Maricopa and Buttonwillow). Every week from mid-March to the end of September we collected twenty random leaves from each of 8 locations in each orchard. Leaves were returned to the laboratory and the total numbers of spider mites on each leaf were counted. Sixspotted thrips were evaluated by placing a large yellow strip trap (Great Lakes IPM) at each location and counting the number of thrips one week later. Data were combined across locations to determine the average number of mites per leaf and thrips per card for each orchard on each evaluation date. Data were presented graphically to display periods of thrips activity compared to when mites were present. They were also used to calculate the population doubling time for each species during periods when population growth appeared optimal during the months of July and August.

Objective 4: Evaluate the impacts of sixspotted thrips on spider mite populations

The ultimate goal regarding thrips monitoring is to determine how to use thrips population information to help make decisions on the need to treat spider mites. In other words, at what number of thrips on a trap, or at what thrips to mite ratio, will spider mite density in the future increase, decrease or stay the same.

This was evaluated using data from three almond orchards in 2016 and seven orchards in 2017. Orchards were all located in Kern County within the vicinities of Wasco, Buttonwillow, Maricopa, Shafter, Lost Hills and Edison. Within each orchard we collected 10-20 leaves from four to 14 different locations and evaluated them for the number of spider mites per leaf each week from July to September in 2016 or from March to September in 2017. Each week we also placed one yellow sticky card (large yellow strip trap 6" x 12") at each location, recovered the trap one week later, and returned to the lab to count the number of sixspotted thrips captured. Calculations of change in mite density were made by dividing the number of mites per leaf in 7 or 14 days by the number of mites/leaf on the current evaluation date. This resulted in a ratio whereby values greater than 1 indicate an increase in mite density, a value of 1 indicates that mite density stayed the same, and values between 0 and 1 (fractions) indicate that mite density decreased.

Data were analyzed by regressing thrips density (thrips/card/week) or thrips-to-mite ratios (thrips/card/week divided by mites/leaf) on the x-axis against the ratio of future to current mite densities (at 7 or 14 days) on the y-axis. Prior to completing these correlations we excluded all data points that were collected the week prior to or week after miticide applications, or where densities of thrips or spider mites did not meet a minimum density of 2 per card or 0.5 per leaf, respectively. After evaluation, a formula to characterize regression lines was made in Excel using the "power" trendline function to account for logarithmic relationships in the data.

During 2016 and 2017 we made 1,865 evaluations of thrips density on yellow sticky cards, mite density, and mite density one week later. Of these, 220 data points met our criteria for use in evaluations looking at the relationships between thrips captures, mite captures, thrips to mite ratios, and relationship between mite densities in 7 or 14 days compared to today.

Objective 5: Evaluate the effects of miticides on Pacific spider mite

During 2017 we conducted a trial in Shafter, CA to evaluate the effects of miticides on the density of Pacific spider mites in almond. The trial was located in a nine year old orchard (20 ft x 22 ft spacing) that contained alternating rows of the varieties Nonpareil and Monterey. Plot size was three trees long by one row wide. The plots were organized into a randomized complete block design with 4 blocks of 12 treatments and one untreated check. Treatments were applied on 8-9 Aug to individual trees with a hand gun at 150 PSI with a water volume of 200 GPA. All treatment included 1% 415 Oil.

Mite densities were evaluated in each plot prior to treatment on 8 Aug and then on 11 Aug (3 DAT), 16 Aug (8 DAT), 22 Aug (14 DAT), and 29 Jul (21 DAT). On each sampling date, 20 leaves were collected per plot. This included six to seven random leaves per tree from each of the three trees per plot. Leaves were transported to a laboratory where mites were counted and converted to average mites per leaf. The number of cumulative mite-days for each plot was calculated by multiplying the number of mites 3 DAT by 3 days, then for the other evaluation dates calculating the average mites per leaf for the current and previous sample date and multiplying by the number of days between evaluations, and then calculating the sum of the mite-days from all evaluation dates. Data were analyzed by ANOVA using transformed data (square root (x + 0.5)) with means separated by Fisher's Protected LSD (P=0.05).

Objective 6: Evaluate the efficacy of four mating disruption products for navel orangeworm control

Navel orangeworm (NOW) is the single most important insect pest of almonds due to its ability to feed directly on the kernel and association with aflatoxins. Management of NOW requires a combination of cultural and chemical controls. Over the past few years, chemical control options have been expanded to include mating disruption (MD). This technique uses mass-dispersal of NOW pheromone in an effort to reduce the likelihood that male moths can find females and mate. There are now four commercially-available mating disruption products available in almonds. They all use the same pheromone, but deliver it in different ways. Our trial evaluated these four products to determine if they work and whether or not using this technique has a good return on investment.

During 2017 we conducted side-by-side comparisons of four mating disruption products at three different Kern County orchards (Buttonwillow, Maricopa and Wasco). Treatments included NOW Puffer, Semios NOW, Isomate NOW Mist and Cidetrak NOW Meso (**Table 2**). As of fall 2018 all products are registered for commercial use. Each experimental orchard was approximately 360 acres that was divided into nine, 40-acre plots. The four treatments and an untreated check (no-MD check) were assigned to five squares in a checkerboard pattern such that they touched at the corners but were not adjacent to each other on the sides. The remaining four plots did not receive MD and served as buffers between the treated plots. The grower cooperators at each orchard grew the crop with commercial standard production practices, including winter sanitation and one to two insecticide sprays between the start of hull split and harvest. Therefore this trial evaluated mating disruption in addition to standard management practices, and not as a replacement for sanitation or chemical spray programs.

Table 2. Characteristics of navel orangeworm mating disruption products

Product	Manufacturer	Type	Dispensers per acre[1]	Release rate
NOW Puffer	Suterra	Aerosol can	2	Static
Semios NOW	Semios	Aerosol can	1	Variable
Isomate NOW Mist	Pacific Biocontrol	Aerosol can	1	Static
Cidetrak NOW Meso	Trécé	Passive dispenser	20	Static

[1] All four products release approximately the same amount of pheromone over the season. For example, products using 2 dispensers per acre have approximately one half the amount of active ingredient per can than products using one dispenser per acre.

Mating disruption products were deployed within each orchard between 27 March and 6 April 2017. Dispensers were placed into the top one third of trees according to grid maps approved by each manufacturer at a height of approximately 15 ft. NOW populations were monitored weekly at six stations within each plot. Two stations were towards the center of each plot with the remaining four at the north, south, east and west edges. Each station had one pheromone and one egg trap. At harvest, two samples of approximately 250-300 nuts were collected at each station for each variety in the orchard. In total, this monitoring effort included weekly readings of 2,700 pheromone traps (30 weeks x 6 traps per plot x 5 plots per orchard x 3 orchards), 2,700 egg traps, and 540 harvest samples (12 samples per plot x 5 plots per orchard x 3 orchards x 3 varieties per orchard). This amounted to approximately 135,000 nuts.

The economic benefit of MD was evaluated using damage calculations from each orchard, assumptions about yield, and a per-pound price guide from Blue Diamond Growers. First, we calculated the percentage of NOW-infested kernels in each variety for all plots. Second, we divided this number in half. This was based on an assumption that half of all nuts damaged by NOW do not make it through the hulling process (such as blowouts during harvest or kernels that are fully eaten by NOW and obliterated during hulling), while the other half of damaged kernels enter the stage where nut quality (including insect damage) is assessed. Third, we made an assumption that each orchard had a yield of 3,000 meat lbs/acre consisting of 1,500 lbs of Nonpareil, 750 lbs of Monterey and 750 lbs of Fritz. This is a typical yield in the southern San Joaquin Valley for mature almond orchard. Fourth, we calculated a yield loss associated with the half of damaged kernels that would be unlikely to complete the huller process. Fifth, we determined a price per pound value for the remaining tonnage by assuming a base price of $2.50/lb for Nonpareil and $2.25/lb for other varieties, and adding premiums to these prices based on a 2017 Blue Diamond Crop Quality Schedule. This schedule provides a sliding scale of up to $0.16 for low damage to Nonpareil and up to $0.08/lb premiums for other varieties. Sixth, calculations were made of the total grower returns after half of all damaged nuts are assessed as a yield loss and the remaining tonnage was multiplied by the appropriate price per pound. Seventh, the grower returns for Nonpareil (50% of each orchard), Monterey (25%) and Fritz (25%) were added to determine a total grower per-acre crop value. Eighth, the economic value of mating disruption was assessed by comparing total crop value with and without MD, and comparing this number to the costs of implementing MD. For this study, the cost of implementing mating disruption was assumed to be $120 per acre.

Objective 7: Maintain a University-based research and demonstration orchard for almond pest management research

Funding provided by the Almond Board of California allows us to maintain a 7-acre orchard in Shafter in Kern County on land that used to be part of the UC Shafter Research and Extension Center. The orchard is planted on a 20’ by 22’ spacing with alternating rows of Nonpareil and Monterey. Irrigation is set up using microsprinklers with the capability to turn water on and off on each individual row. The orchard has a total of 700 trees that were harvested for the first time in 2011. The orchard is made available to all researchers we can accommodate, both public and private, that have interest in doing research that will be of benefit to the almond industry. To date, the majority of the research conducted in this orchard is related to the management of insects, weeds and diseases due to our ability to allow pest pressure that is higher than what is tolerated in commercial orchards, and due to our ability to apply non-registered pesticides without the risks related to crop destruct in commercial orchards. Costs for this orchard are distributed evenly between the Almond Board of California and donations from other companies within the almond industry that benefit from the research.

Results and Discussion:

Objective 1: Develop practical implications from sixspotted thrips literature

During 2016 we conducted a literature search that yielded four journal articles of particular interest. This includes a 1939 paper introducing sixspotted thrips as a predator of spider mites in California, a 1976 Hilgardia paper on the bionomics of sixspotted thrips, a 1976 paper containing life tables and feeding habits of sixspotted thrips, and a 1995 review paper that used laboratory data to make an argument for why sixspotted thrips has high potential as a predator in the field.

Laboratory data from these four publications suggest that sixspotted thrips have the potential philosophically to be an excellent predator for Pacific spider mite in almonds in California. Laboratory data show that this species thrives in hot conditions, has a very fast life cycle, has high fecundity, can survive in the absence of prey through cannibalism, is well adapted to navigating within mite webbing, and specialized in feeding on spider mites.

During 2017 we used this information to guide our research and couple laboratory-based information with orchard-generated data to provide guidelines that can be used to make decisions regarding spider mite management. That information is reported within objectives 2-4 of this report.

Objective 2: Evaluate sticky cards for monitoring sixspotted thrips and predatory beetles

Part a (Trap type). There were significant differences in the numbers of sixspotted thrips and spider mite destroyer beetles captured on commercially-available sticky traps that were all cut to the same size. The most effective traps for sixspotted thrips were the large yellow strip, small yellow strip, small yellow and green traps that each caught greater than 290 and 31 thrips per card per week in Wasco and Lost Hills, respectively (**Table 3**). These same four traps, with the addition of the yellow whitefly trap, also caught the greatest number of spider mite destroyer beetles.

In determining which of these top traps to recommend to growers and pest control advisors, we also considered ease of use and cost. Of these four traps, the large yellow strip and small yellow strip were the most convenient to use, especially due to the type of adhesive that catches insects but is not gooey and does not come off onto your fingers. These same traps were also the least expensive. Therefore, we now recommend yellow strip traps from Great Lakes IPM for use by growers in their efforts to monitor sixspotted thrips and mite destroyer beetles.

Table 3. Capture rates of four spider mite natural enemies for nine commercially-available sticky card traps that were all cut to a standardized size of 5” by 3”.

	Wasco				Lost Hills			
Trap	Six-spotted thrips	Lace-wing	Pirate Bug	Spider mite destroyer	Six-spotted thrips	Lace-wing	Pirate Bug	Spider mite destroyer
Small Blue Strip	8.8c	0.0	0.0	0.3c	16.8de	0.0	0.0	1.5c
Blue Thrips	80.8c	0.3	0.3	14.0c	2.8e	0.0	0.0	0.0c
Green	293.5ab	0.3	0.3	23.0b	72.0a	0.0	0.0	6.5a
Large Yellow	46.0c	0.0	0.0	4.8c	4.8e	0.0	0.0	0.3c
Small Yellow	322.3ab	0.0	0.0	52.8a	51.3abc	0.3	0.0	5.5ab
White	23.8c	0.3	0.0	1.5c	4.5e	0.0	0.0	0.3
Large Yellow Strip	419.0a	0.0	0.3	28.5ab	67.3ab	0.0	0.0	1.8bc
Small Yellow Strip	474.3a	0.0	0.0	25.5ab	31.3bcd	0.0	0.0	1.5c
Yellow Whitefly	198.0b	0.0	0.0	38.5ab	26.8cd	0.3	0.0	2.0c
F	15.84	0.69	0.69	11.78	3.34	0.84	-	4.11
P	<0.0001	0.6946	0.6946	<0.0001	<0.0001	0.5774	-	0.0033

Means in a column followed by the same letter are not significantly different (*P* > 0.05, Fisher’s protected LSD) after square root (x + 0.5) transformation of the data. Untransformed means are shown.

Part b (Trap size). Natural enemy capture on five different sizes of yellow strip trap are shown in (**Table 4)**. In all cases sixspotted thrips and spider mite destroyer captures were directly proportional to the size of the trap **(Figure 1**). This suggests that particularly large or small traps do not have any specific added benefit with regards to trap attractiveness. This was confirmed by dividing trap captures by trap size, which resulted in captures per square inch values that were consistent across all trap sizes. This means that when considering which trap size to use, the single key factor that needs to be considered is how many thrips you need to catch to assist in making decisions. Traps need to be large enough to capture enough natural enemies to provide meaningful data, but not so large that it takes excessive amounts of time to evaluate the trap. This topic will be revisited later.

Table 4. Capture rates of four spider mite natural enemies for yellow strip traps cut to five different sizes.

	No. natural enemies per card per week							
	Wasco				Lost Hills			
Card size (in)	Six-spotted thrips	Lace-wing	Pirate bug	Spider mite destroyer	Six-spotted thrips	Lace-wing	Pirate bug	Spider mite destroyer
12 x 6	1989.5a	0.0	0.0	183.3a	139.0a	0.0	0.0	8.3a
6 x 6	1216.5b	0.0	0.0	71.3b	67.8b	0.3	0.0	3.5b
6 x 3	419.0cd	0.0	0.3	28.5c	67.3b	0.0	0.0	1.8bc
3 x 3	148.3de	0.0	0.0	14.0cd	19.8d	0.0	0.0	1.8bc
3 x 1.5	58.0e	0.0	0.0	4.8d	10.0d	0.0	0.0	0.3c
5 x 3[1]	474.3c	0.0	0.0	25.5c	31.3bc	0.0	0.0	1.5bc
F	15.13	-	1.00	57.60	6.46	1.00	-	6.84
P	<0.0001	-	0.4509	<0.0001	0.0010	0.4509	-	0.0016

[1] Small yellow strip trap (purchase size of 5” x 3”) All other treatments were made using large yellow strip traps (12” x 6”) that were cut down to the appropriate size.

Means in a column followed by the same letter are not significantly different (*P* > 0.05, Fisher’s protected LSD) after square root (x + 0.5) transformation of the data. Untransformed means are shown.

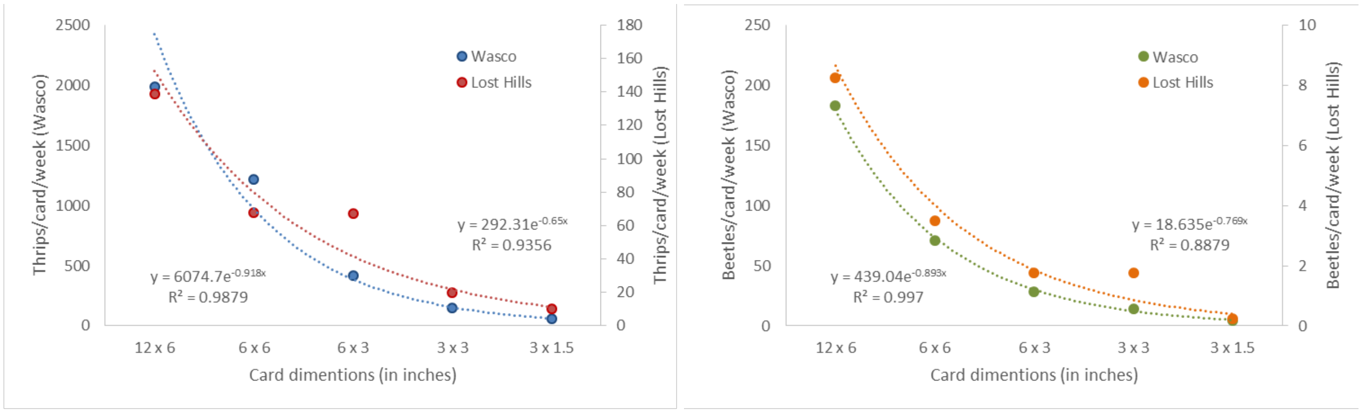


Figure 1. Capture rates of sixspotted thrips and mite destroyer beetles for five different sizes of yellow strip traps.

Objective 3: Evaluate seasonal sixspotted thrips abundance and activity patterns in almonds

Sixspotted thrips had two main periods of activity at all three locations. The first period was from mid-April until late May, peaking during the first two weeks of May (**Figure 2**). We hypothesize that these thrips overwintered as adults and become active at this time in the spring. The period from April to May also coincides with when spider mite prey becomes available. Spider mites overwinter as adult females, start emerging in mid- to late March, and begin to reproduce by April. In all three orchards spider mites were found in low numbers at this time, but then disappeared, presumably due to predation by the thrips. By late May there was no more spider mite prey available and the thrips either flew away or ate each other (in the absence of spider mite prey, sixspotted thrips is cannibalistic). Thrips captures during the months of June and July were negligible.

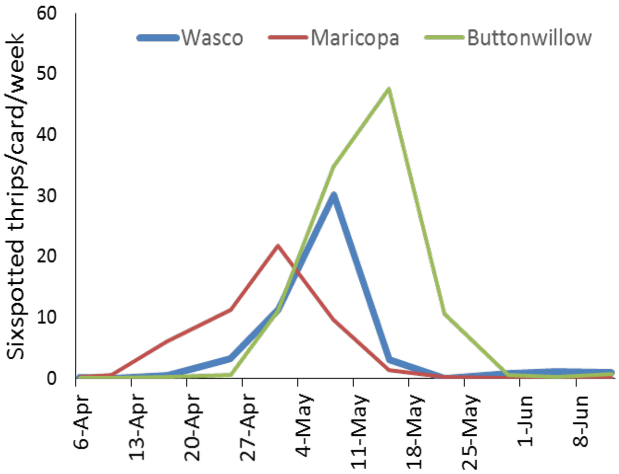


Figure 2. Sixspotted thrips captures in three Kern County orchards during spring 2017

The second period of activity occurred in late July and August in response to an upswing in spider mite populations (**Figure 3**). At all three orchards spider mite populations began to build in the last two weeks of July. During this period sixspotted thrips populations remained very low. However, as spider mite populations increased, thrips populations likewise increased, eventually causing spider mite populations to crash by late August. The lag time between exponential spider mite increases and an exponential response by thrips predators was approximately two to three weeks. In all three orchards spider mite densities exceeded current treatment thresholds before thrips caused mite populations to crash. However, in all three orchards thrips caused the mite population to crash before mites reached levels that are generally considered to be economically significant.

Evaluations of population doubling time were calculated during periods of maximum increase for spider mites (mostly late July when food was abundant but before thrips arrived) and maximum increase for sixspotted thrips (mostly in the first half of August when spider mites were plentiful, but before their populations crashed). Sixspotted thrips population doubling times were 2.4, 2.7 and 3.6 days compared to 3.8, 9.3 and 3.0 days for Pacific spider mite. When doubling times calculated in 2016 ((4.2 and 4.2 for thrips; 15.9 and 6.0 for spider mites)

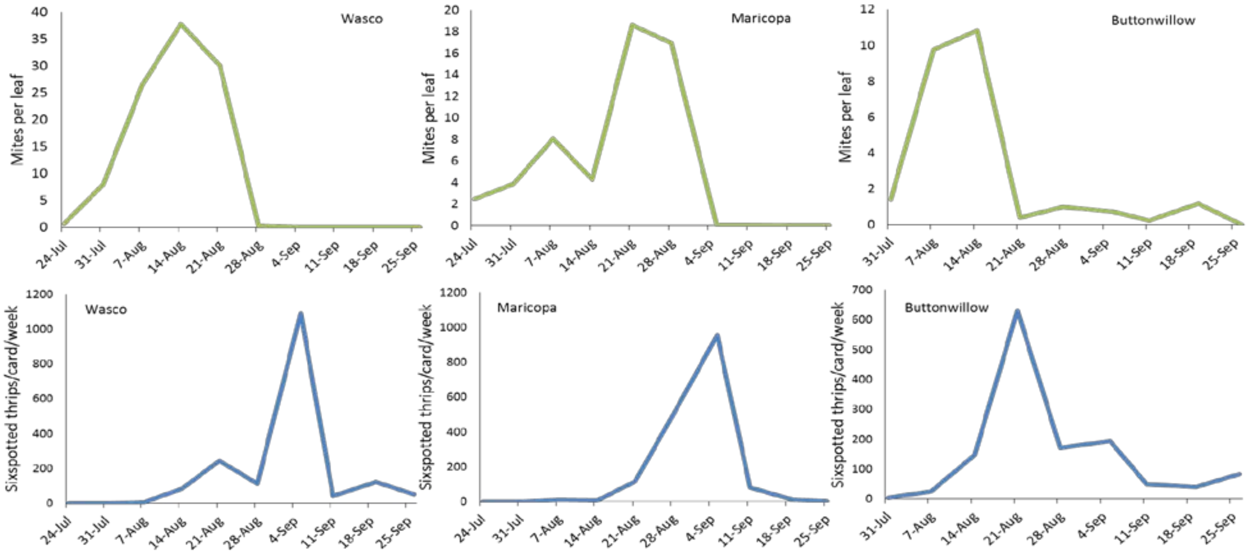


Figure 3. Pacific spider mite and sixspotted thrips captures in three Kern County orchards from July to September 2017

are averaged with times calculated in 2017, the two-year averages were 3.4 days for thrips and 7.6 days for Pacific spider mite. The short doubling time for thrips suggests that rapid increases in thrips populations in all three orchards, from less than 5 to more than 600 per week over a 4-week period (**Figure 4**) can primarily be attributed to within-orchard reproduction and not immigration from outside of the orchard. The fact that thrips can double their populations in half the time required for their prey also helps explain sixspotted thrips' ability to overtake spider mites and cause their populations to decline rapidly within a few weeks.

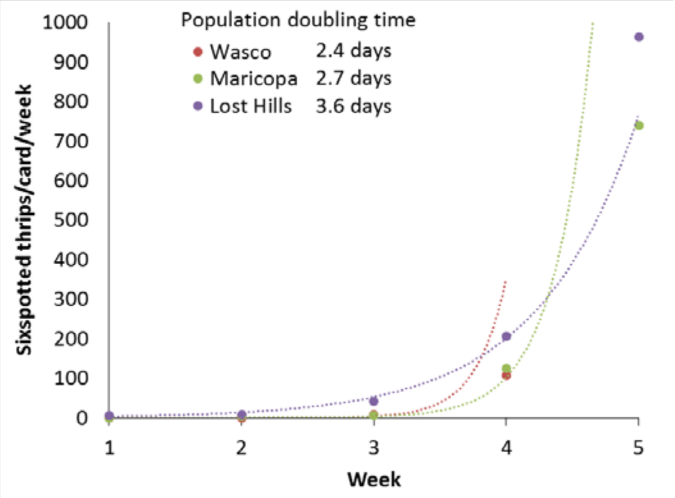


Figure 4. Population doubling times for sixspotted thrips in three almond orchards, 2017

Objective 4: Evaluate the impacts of sixspotted thrips on spider mite populations

There was a direct correlation between thrips to mite ratio and change in mite density one week later (**Figure 5a**) and two weeks later (**Figure 5b**). Mite density increased exponentially as thrips to mite ratios approached zero whereby mite density decreased exponentially as thrips to mite ratios approached infinity ($Y=1.9227x^{-0.278}$, R^2 = 0.23 for 7 days later; $Y=10.036x^{-0.758}$, R^2 = 0.43 for 14 days later). (**Figures 6a, 6b)** show linearized versions of the same data by converting both the x and y-axes to a log scale. In these charts, values greater than 1 on the y-axis mean that mite population increased, values of 1 indicated that they stayed the same, and values less than 1 (fractions) indicate reductions in mite density. By solving the regression formulas for X where Y=1 (the point at which mite density stays the same), the results is that on average, mite density stays the same 7 days later when there are 10.5 thrips/card/week per 1 mite/leaf and stays the same 14 days later when there are 21.0 thrips/card/week per every 1 mite/leaf.

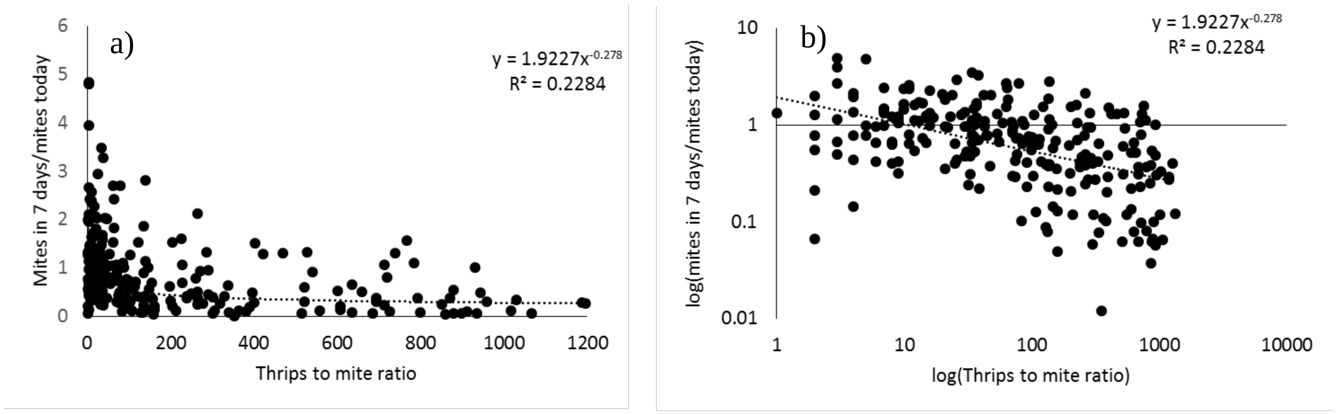


Figure 5. Relationship between predator to prey ratios and change in mite population 7 days later using original numbers on normal (left) and log-transformed (right) axes.

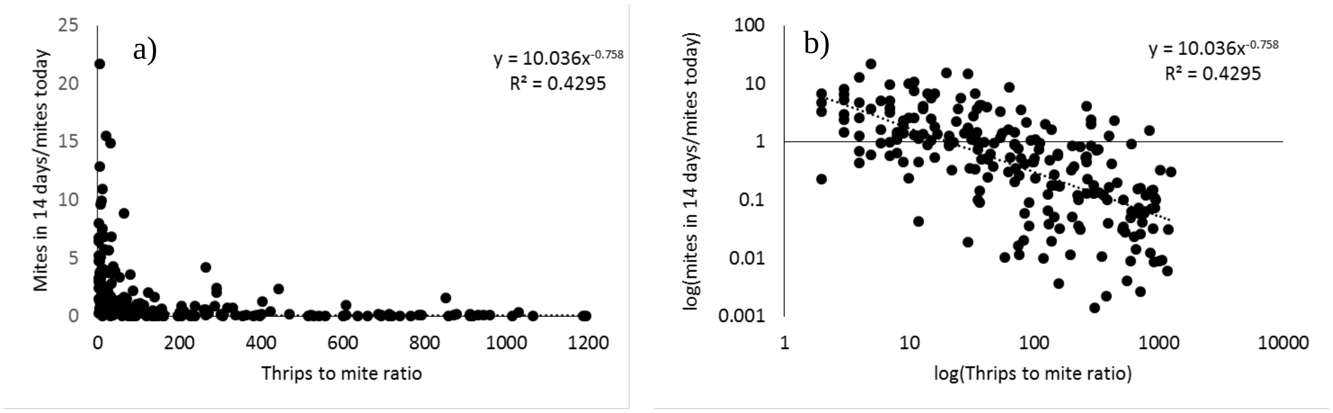


Figure 6. Relationship between predator to prey ratios and change in mite population 14 days later using original numbers on normal (left) and log-transformed (right) axes.

While thrips to mite ratios are perhaps the most accurate predictor of how mite density will change in the future, the reality is that calculating these ratios is likely to be too time-consuming and overly complicated for everyday use by pest control advisors. For that reason, we completed a second evaluation of our data by placing the absolute number of thrips collected on cards (not thrips to mite ratio) on the x-axis and compared this to the change in mite population. Before doing this we made an assumption that a pest control advisor would make management decisions based on the average of two yellow strip traps (perhaps one at each of two NOW monitoring locations). Therefore, we paired up all our data points with adjacent traps such that each data point now represented the average of two traps.

There was a direct correlation between the numbers of thrips/card/week and changes in mite density after 7 (**Figure 7a**) and 14 days (**Figure 7b**). These relationships were described by the formulas $Y=11.526x^{-1.106}$ ($R^2=0.47$) and $Y=15.57x^{-1.106}$ ($R^2=0.49$), respectively. Solving these equations for the average thrips/card/week for which mite populations remain the same results in thrips densities of 23.3 thrips/trap/week (7 days) and 12.0 thrips/trap/week (14 days). When using a tentative threshold of 25 thrips/card/week there was a 72.7% likelihood that mite density would be lower within 7 days (64 out of 88 data points). Further evaluation of the 24 exceptions showed that, in 87% of the cases (21 out of 24 data points), mite density was lower at 14 days than at 7 days.

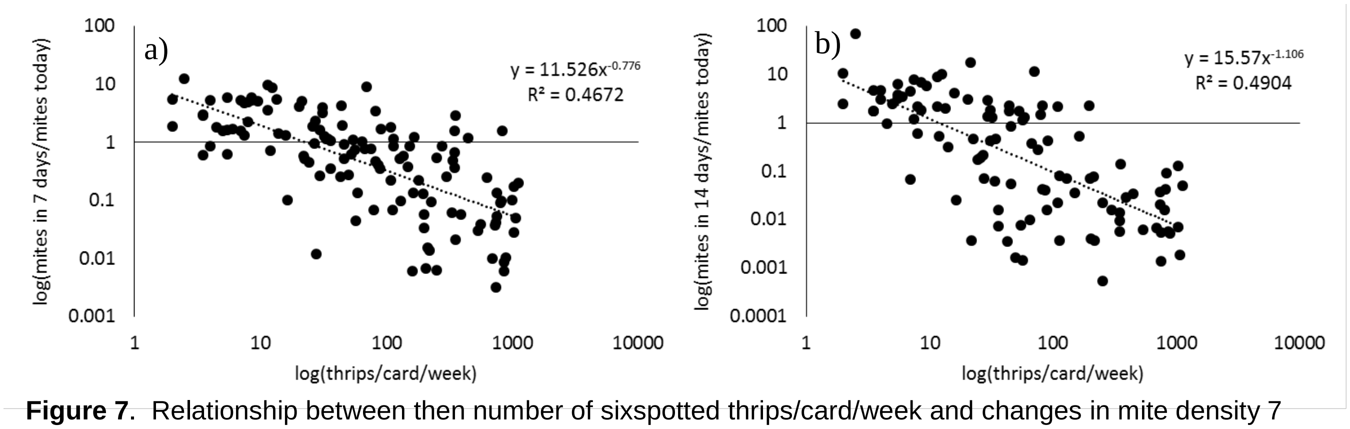


Figure 7. Relationship between then number of sixspotted thrips/card/week and changes in mite density 7 (left) and 14 (right) days later. Data are presented as original numbers on log-transformed axes.

When these statistics are combined, using a threshold of 25 thrips/card/week (6” x 12” yellow strip trap) or 6 thrips/card/week (3” x 5” yellow strip trap) results in a 96.6% probability (85 out of 88 data points) that mite populations will go down within 7 days, or be on a downward trend by 14 days without the use of a miticide. For these reasons we believe that initial thresholds of 25 thrips/card/week (large trap) or 6 thrips/card/week (small trap) are good thresholds for determining whether or not there are enough thrips present to avoid the use of a miticide.

Objective 5: Evaluate the effects of miticides on Pacific spider mite

There were no significant differences in mite density prior to treatment, 3 DAT or 8 DAT (**Table 5**). By 14 DAT all treatments significantly reduced mite densities compared to the Untreated Check. The lowest mite densities 14 DAT were in plots treated with bifenazate (Banter, Vigilant) and Nealta, though these treatments were statistically equivalent to all other treatments except for Onager Optek. By 21 DAT populations of sixspotted thrips entered the orchard and reduced mite populations in all plots to 0.2 or less per leaf. Data on cumulative mite-days across all evaluation dates showed significant reductions in mite density in plots treated with bifenazate (Banter, Vigilant), the METI inhibitors (Nealta, Fujimite and Magister) and the growth regulator Envidor. Mite densities in plots treated with Biomite, Kanemite, and 1180AA were statistically equivalent to the best treatments as well as the untreated check.

Table 5. The effects of miticide treatments on the density of Pacific spider mite in almond, Shafter 2017.

Treatment[1]	Rate form. product/ac[1]	Mean spider mites per leaf					
		Pre	3DAT	8DAT	14DAT	21DAT	Mite-days[2]
Banter	16 fl oz	3.3a	0.6a	0.2a	0.2ab	0.0a	5.1ab
Banter	24 fl oz	3.0a	0.4a	0.3a	0.1a	0.0a	3.9a
Biomite	0.59gal/A	3.6a	1.2a	0.8a	0.2ab	0.0a	10.3abcde
Envidor	18 fl oz	8.0a	1.0a	0.7a	0.4ab	0.0a	10.2abcd
Fujimite SC	32 fl oz	1.2a	0.4a	0.2a	0.5ab	0.1a	6.2abc
Kanemite 15SC	31 fl oz	8.0a	1.6a	0.5a	0.2ab	0.1a	11.4abcde
I180AA	20.5 fl oz	3.8a	1.8a	1.3a	0.4ab	0.1a	16.4bcde
Magister	32 oz	3.9a	0.4a	0.4a	0.5ab	0.0a	7.0abcd
Nealta	13.7 oz	2.3a	0.1a	0.3a	0.2a	0.0a	3.4a
Onager Optek	24 oz	6.5a	3.0a	1.4a	1.0b	0.1a	26.0de
Vigilant 4SC	24 fl oz	4.1a	0.3a	0.1a	0.2a	0.0a	2.8a
415 Oil	1%	8.1a	2.0a	1.7a	0.4ab	0.2a	19.6cde
Untreated Check	-	3.6a	2.1a	0.9a	1.9c	0.0a	26.2e
	F	1.01	1.44	1.79	2.89	0.98	2.48
	P	0.4596	0.1924	0.0876	0.0068	0.4842	0.0177

Means in a column followed by the same letter are not significantly different (P>0.05, Fisher's Protected LSD) after square root (x + 0.5) transformation of the data. Untransformed means are shown.

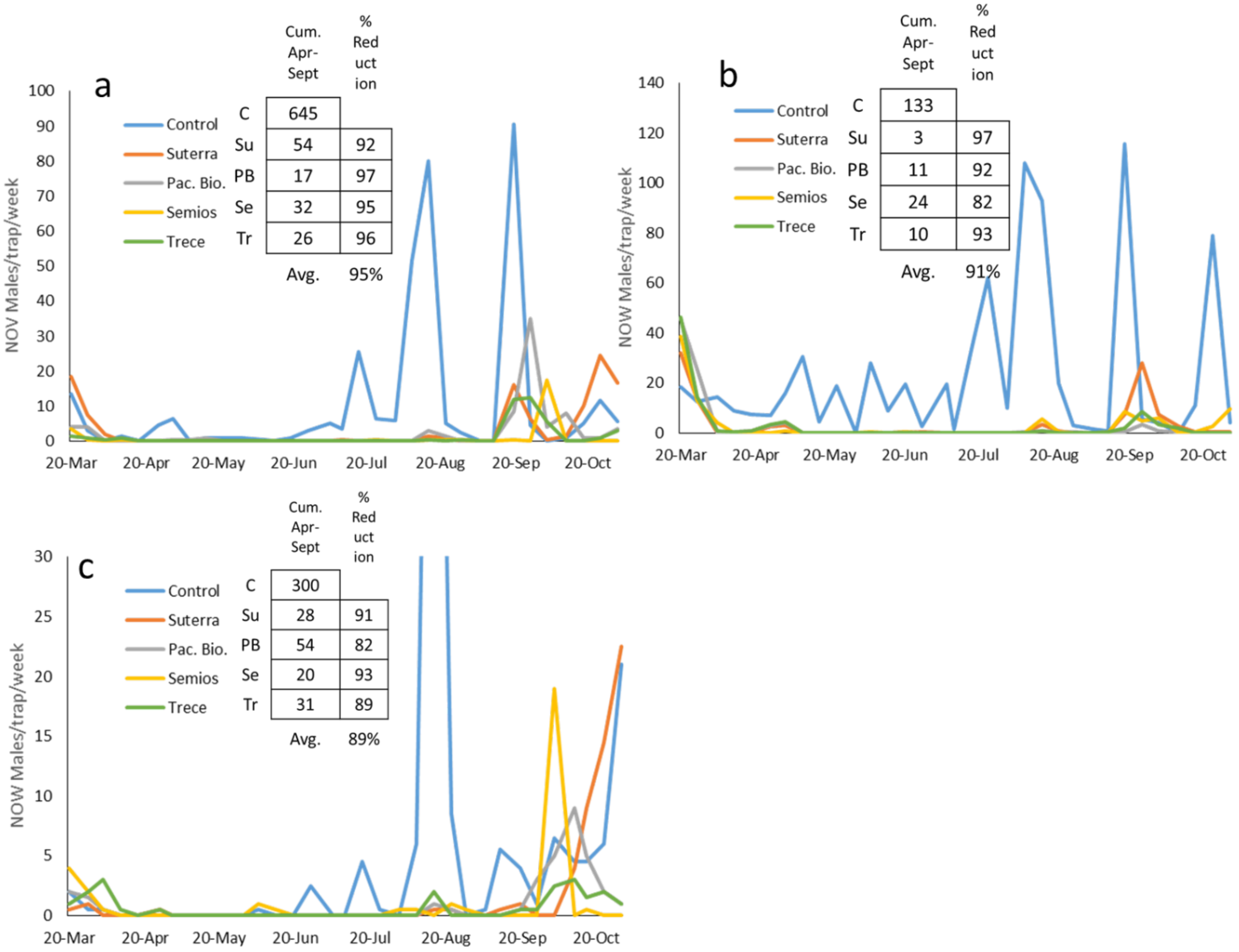
[1] All treatments had 1% 415 oil as a surfactant except 415 Oil.

[2] Mite-days is a cumulative measurement that is determined by adding the average mites per leaf for each of the 21 days of the trial.

Objective 6: Evaluate the efficacy of four mating disruption products for navel orangeworm control

The effects of mating disruption products on pheromone trap captures are shown in (**Figure 8**). From April through September (MD deployment through harvest), MD products reduced male captures in Buttonwillow, Maricopa and Wasco by an average of 95, 91, and 89%, respectively. Across orchards MD products made by Suterra, Pacific Biocontrol, Semios and Trécé reduced male captures by 93, 90, 90 and 93%, respectively. During the same time period the average egg trap captures in MD plots across all trials was 22% lower than in no-MD plots. However, we do not give much credibility to this number due to high levels of inconsistency in results across orchards and across treatments. Simply stated, egg traps proved to be a poor metric for evaluating the effects of mating disruption.

The effects of mating disruption on damage at harvest are shown in (**Figure 9**). Across all orchards the average percentage of NOW-infested kernels was 2.28% for the no-MD check compared to 1.13 to 1.33% for the four MD products. There were no significant differences across the four MD products. When all four MD products were averaged, MD reduced NOW



a

	Cum. Apr-Sept	% Reduction
C	645	
Su	54	92
PB	17	97
Se	32	95
Tr	26	96
	Avg.	95%

b

	Cum. Apr-Sept	% Reduction
C	133	
Su	3	97
PB	11	92
Se	24	82
Tr	10	93
	Avg.	91%

c

	Cum. Apr-Sept	% Reduction
C	300	
Su	28	91
PB	54	82
Se	20	93
Tr	31	89
	Avg.	89%

Figure 8. The effects of MD products on male captures in pheromone traps in a) Buttonwillow, b) Maricopa and c) Wasco

damage by 35% in Nonpareil, 51% in Monterey and 55% in Fritz with an overall reduction of 46%.

Average grower returns for fields implementing MD ranged from $7,381 to $7,400 compared to $7,275 for the no-MD check. This was the equivalent of increased crop values of $125/ac for Suterra, $110/ac for Semios, $110/ac for Pacific Biocontrol, and $106/ac for Trécé. When all four MD products were averaged, grower returns where MD was implemented increased by $158/ac in Buttonwillow, $154/ac in Maricopa, and $25/ac in Wasco.

Our primary conclusions from this study are 1) mating disruption was effective at reducing NOW damage by approximately 50%, and 2) that the economic benefits of adding MD to an existing NOW management program offset the cost of MD implementation. Additionally, there are other benefits of mating disruption. For example, even if the costs to implement and return on investment are the same, the result of implementation is half the damage. This decreases aflatoxin risk and improves huller efficiency. MD is also a valuable part of resistance management programs to help mitigate further pyrethroid resistance and protect the two main insecticides (Intrepid and Altacor) that comprise the majority of NOW treatments. MD also has no pre-harvest intervals, no re-entry intervals, no residues on fruit, and is heralded as a green and environmentally-friendly method to manage pests sustainably. Our data suggest that almond growers in California, with orchards as small as 40 acres, can benefit from using MD. It is also assumed that these benefits would increase when the number of contiguous acres of MD is further increased.

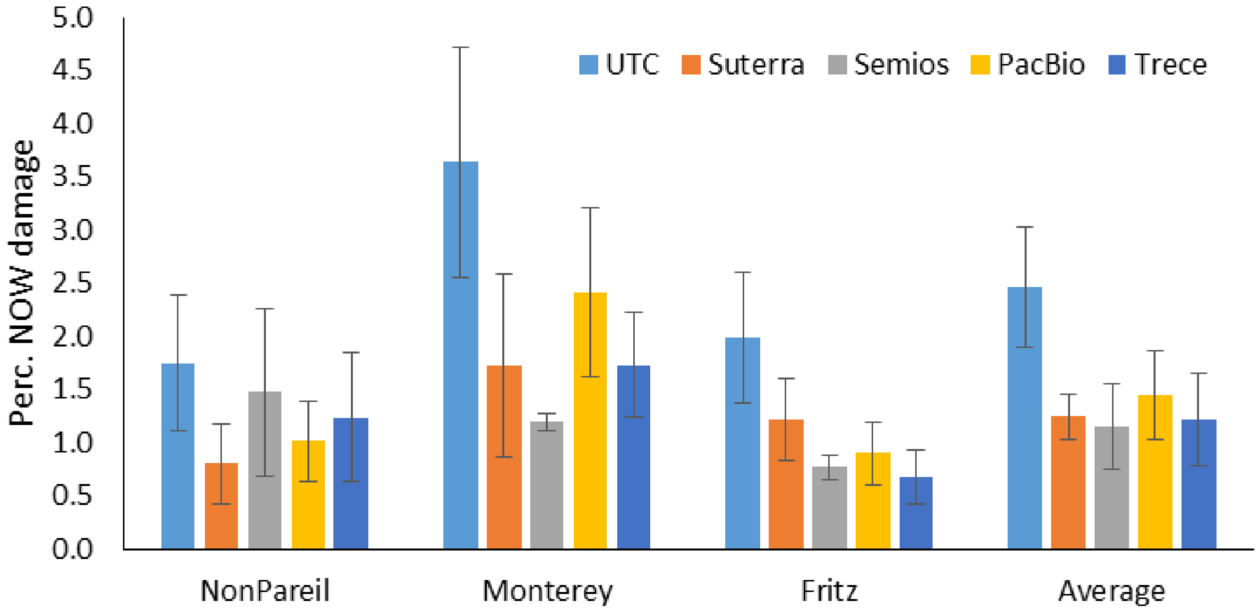


Figure 9. Population doubling times for sixspotted thrips in three almond orchards, 2017

Objective 7: Maintain a University-based research and demonstration orchard for almond pest management research

During 2017 there were a total of five research projects supported by or completed in the research orchard in Shafter that is maintained in part by funding from the Almond Board of California. This included trials on miticides for control of spider mites, trapping studies for sixspotted thrips and other spider mite predators, a study on predator-prey relationships for spider mites, a study on canker diseases and strategies to manage them, and support for a navel orangeworm study. Principal investigators of the trials included academics at UC Davis, UC Farm Advisors, a researcher associated with an almond producer, and a researcher associated with a company that produces products for crop protection. In total since 2010, this orchard, and a parallel orchard funded by the Almond Board of California at the Westside Research and Extension center through 2013, have hosted or provided support for 64 different research trials.