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Impact of Citrus Thrips (Thysanoptera: Thripidae) on the Growth and Productivity of Southern Highbush Blueberries in California

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Abstract

Citrus thrips, *Scirtothrips citri* (Moulton), is a foliage-feeding pest of blueberries in the San Joaquin Valley of California. We conducted a 4-yr field study to determine the type and amount of damage caused by this species. Using pesticides, we established gradients of citrus thrips in commercial blueberry fields near Richgrove, CA, in the fall of 2006, 2007, 2009, and 2014. Thrips densities were evaluated weekly for ~1 mo to determine cumulative thrips-days and correlate levels with the average length of new growth. During all four years of the study, there were significant negative correlations between thrips-days and shoot length (for every 100 thrips-days over a period of 4–5 wk there were reductions in the length of new shoot growth of 0.41 to 2.45 cm, 6.4–10.3%). During the spring following each trial, we evaluated the impact of thrips-days on blueberry yield and quality. During the 2006 trial, there was a significant negative correlation between thrips-days and yield as well as the number of berries per plant, but no yield effect was observed in the other three years of the study. No impacts on fruit quality were found any year. A discussion of the complexity of economic injury levels in blueberries is provided, especially considering that the cost of spraying for citrus thrips (estimated at US$150/ha) is almost irrelevant given crop values often in excess of US$100,000/ha.

Key words: economic injury level, yield, monitoring, high-value crop, pesticide resistance management

Citrus thrips, *Scirtothrips citri* (Moulton), is a key insect pest of blueberries in the hot inland valleys of California (Haviland et al. 2009). This association has developed over the past few decades, as commercial blueberry varieties that do well in the San Joaquin Valley have been introduced (Morse 1995, Jimenez et al. 2005). Historically, citrus thrips is known primarily for the damage it causes to citrus (Horton 1918, Flint et al. 1991, Morse 1995). Feeding by citrus thrips on the rind of the stem end of young citrus fruit causes damage that is commonly referred to as a ring scar (Grafton-Cardwell et al. 1997, 2003); damage to young leaves causes them to twist and grow abnormally (Grafton-Cardwell et al. 1997). Damage to blueberry plants is similar to the damage on young citrus leaves and is characterized by the distortion, discoloration, and stunting of new vegetative growth from late June through September (Haviland et al. 2009). In blueberries, new vegetative growth in the early fall becomes the fruiting wood for harvest the following spring.

Thrips damage to blueberries varies geographically throughout North America. In the southeastern United States where southern highbush blueberries (*Vaccinium corymbosum* x *Vaccinium darrowi* Camp) are the dominant species, *Frankliniella bispinosa* (Morgan) and *Frankliniella tritici* (Fitch) are the most important species of thrips (Arévalo et al. 2006). Both of these species cause damage primarily to the buds and new fruit. Flower thrips are also very common on blueberries during bloom in California, but they are almost exclusively the western flower thrips, *Frankliniella occidentalis* (Pergande). This species has not been reported to cause blueberry damage in California (Haviland et al 2009) and is considered a less common species of little importance to blueberries in Florida or Georgia (Arévalo and Liburd 2007).

In the northeastern United States, where northern highbush blueberries (*Vaccinium corymbosum* L.) are grown, the eastern flower thrips, *F. tritici*, is also considered a pest, although the predominant thrips species is *Scirtothrips ruthveni* Shull (Polavarapu 2001). *Scirtothrips ruthveni* is not a flower thrips, and damage to northern highbush blueberries in New Jersey (Rodriquez-Saona et al. 2010) is similar to damage caused by *S. citri* to southern highbush blueberries in California (Haviland et al. 2009). In both cases the *Scirtothrips* spp. feed primarily on young plant tissues, thus causing stunting, discoloration, and deformation of new vegetative growth.

Despite observations that feeding by *Scirtothrips* spp. can affect the quality of vegetative growth, very little is known about whether or not this damage equates to economic losses in either yield or quality of fruit. In this study, we investigated this relationship over four seasons in field plots where insecticides were used to establish a gradient of citrus thrips densities over a period of ∼1 mo in late summer to early fall. This is the period of time when new shoots from that season are still elongating and begin to develop fruiting buds that will become fruit during the following season. We documented the relationship between citrus thrips density and new growth, and then evaluated the impacts of citrus thrips levels on yield and size of the fruit the following spring.

Materials and Methods

The effects of citrus thrips on blueberry growth and productivity were measured in four field trials in commercial blueberry fields near Richgrove, Tulare County, CA, that were initiated in 2006, 2007, 2009, and 2014. The 2006 trial was located in a field consisting of a repeated four-row sequence of one row each of the varieties ′Misty′, ′Georgia′, ′Misty′, and ′O′Neal′. Trials in 2007 and 2009 were conducted in fields with an eight-row repeated configuration of two rows of ′Star′, two rows of ′Jubilee′, two more of ′Star′, and two rows of ′Santa Fe′. Fields with ‘Star’ were chosen due to field trials in 2006 showing thrips preference for this variety (Haviland et al. 2009). The 2014 trial was conducted in a solid planting of the variety ‘Rocio’. This self-pollinating variety was chosen due to questions arising during the first three years of the study about potential differences in varietal susceptibility to injury by thrips. Bushes in each field were planted at 0.91-m intervals on raised beds that were 3.35 m apart for a total of 3,262 bushes per ha.

Trials were organized in a randomized complete block design with four blocks of six, seven, three, and three different treatments in 2006, 2007, 2009, and 2014, respectively. Plot sizes were 4 rows (14.4 m) wide by 26.2, 17.7, and 23.4 m long for a total of 352, 237, and 315 m^2 per plot and 0.84, 0.66, and 0.38 ha for each trial from 2006 to 2009, respectively. Plot size in 2014 was 8 rows (26.86 m) wide by 183 m long for a total of 4,915 m^2 per plot and 5.9 ha for the trial. For studies in 2006, all data were collected from the row of ′Misty′ toward the center of the plot. Spray plots in 2007 and 2009 were laid out to contain two central rows of ′Star′ flanked by individual rows of ′Jubilee′ and ′Santa Fe′. Blueberry data were collected from the central two rows of ′Star′. In 2014, data were collected from the central six rows of ‘Rocio’.

Insecticide Treatments and Thrips Densities

During each year of the study, thrips populations were allowed to develop naturally through the end of harvest in mid-June. In late June to early July of each season, fields were sprayed with spinosad (Success 2SC [0.24 kg AI/liter soluble concentrate], Dow AgroSciences, Indianapolis, IN) at a rate of 105 g AI/ha to reduce thrips density. Populations were then allowed to rebuild through the month of July. Experiments began on 31 July 2006, 8 August 2007, 19 August 2009, and 25 August 2014 by treating plots with insecticides to establish different densities of thrips. Each insecticide was applied only once using a pto-driven (power take off) custom-made sprayer owned by the grower-cooperator. The sprayer was equipped with a series of spray nozzles and fans that were placed on booms that wrapped around each of the two rows of blueberries flanking the sprayer. This allowed insecticides to be applied from both sides and the top of the row with penetration into the canopy facilitated by the fans. The equipment was calibrated to spray at a water volume of 935 liters/ha at a ground speed of 2.4 km/h.

Treatments used to establish a gradient of thrips densities varied each year of the study, with each material applied only once to a separate set of replicate plots. Treatments were chosen each year based on efforts to simultaneously complete this study while generating pesticide efficacy data of interest to the California blueberry industry. In 2006 the treatments were chlorantraniliprole (Altacor 35WDG [35% water dispersible granules], DuPont, E.I. de Nemours, Inc., Wilmington, DE) at 98 g AI/ha; diazinon (Diazinon 50WP [50% wettable powder], Makhteshim Agan, Inc., Collierville, TN) at 1,121 g AI/ha; fenpropathrin (Danitol 2.4EC [287.6 g AI/liter emulsifiable concentrate], Valent USA Corp., Walnut Creek, CA) at 336.2 g AI/ha; formetanate hydrochloride (Carzol 92SP [92% soluble powder], Gowan Company, Yuma, AZ) at 1,031 g AI/ha; methomyl (Lannate 90SP, DuPont, E.I. de Nemour, Inc.) at 1,009 g AI/ha; and spinetoram (Radiant SC [120 g AI/liter], Dow AgroSciences) at 52.6 g AI/ha. In 2007 treatments were fenpyroximate (Fujimite 5EC [47.9 g AI/liter], Nichino America, Wilmington, DE) at 112 g AI/ha; novaluron (Novaluron 0.83EC [99.5 g AI/liter], Chemtura Corp., Middlebury, CT) at 65.4 g AI/ha; spirotetramat (Movento 240SC [240 g AI/liter], Bayer CropScience, Research Triangle Park, NC) at 140.4 g AI/ha; diazinon at 1,121 g AI/ha; formetanate hydrochloride at 1,031 g AI/ha; methomyl at 1,009 g AI/ha; and an untreated check. In 2009 the treatments were formetanate hydrochloride at 1,031 g AI/ha; spirotetramat at 140.4 g AI/ha; and an untreated check. In 2014 the treatments were tolfenpyrad (Bexar 15SC [157.0 g AI/liter], Nichino America, Wilmington, DE) at 313.4 g AI/ha; pyrifluquinazon (Pyrifluquinazon 20SC [216 g AI/liter], Nichino America) at 102.0 g AI/ha; and kaolin clay (Surround WP [95% AI], Tessenderlo Kerley, Inc. (NovaSource), Phoenix, AZ) at 26.6 kg AI/ha. All insecticides used during each year of the four years of study except for Surround were applied with the addition of the nonionic surfactant Dyne-Amic (Helena Chemical Company, Collierville, TN) at a rate 0.31 ml per liter of water. Treatments included insecticides that currently are, and are not, registered for use on blueberries in California.

Thrips Evaluations

Thrips densities in each trial were evaluated using beat samples. This was done by beating the terminal 20 cm of an unbranched shoot onto a black, 0.3-m square piece of acrylic, and then counting the number of thrips of all life stages (Haviland et al. 2009). Ten beat samples were taken from random shoots in the center row of each plot on each evaluation date. Each trial was evaluated prior to treatment on the day of application and then five (2007) or six (the other three years) times during the 4–6 wk after treatment (Tables 1–4). Each year at the end of the evaluation period of ∼1 mo, each trial was oversprayed with a tank mix of insecticides known to be effective on thrips to eliminate further impacts from thrips populations during the end of the period of new shoot elongation.

Leaf Growth and Harvest Evaluations

Shoot growth was assessed on 5 September 2006, 4 September 2007, 23 September 2009, and 30 September 2014, on the date of the last thrips sample except in 2006 when the last (32-day) sample was taken 1 September 2006. Prior to the application of insecticides, thrips caused the terminal ends of each shoot to have short internodes and scarred, red bark. Following insecticide applications, the reduced levels of thrips resulted in increased internode lengths and a return of the bark to an unscarred green color. Therefore, new shoot growth was assessed by measuring the length of green growth at the

Table 1. The effects of insecticide treatments on thrips densities, 2006

		Mean ± SE thrips per beat						Cumulative thrips-days
Treatment	Precounts	4 DAT	8 DAT	14 DAT	21 DAT	25 DAT	32 DAT	
Formetanate	30.0 ± 1.7a	1.5 ± 1.2a	1.2 ± 0.2a	1.1 ± 0.4a	1.8 ± 0.4a	2.6 ± 0.5a	2.6 ± 0.9a	54.7 ± 2a
Spinetoram	33.0 ± 2.6a	9.3 ± 4.5ab	0.8 ± 0.6a	3.5 ± 1.7a	8.2 ± 1.9b	8.4 ± 1.0b	11.7 ± 1.1b	214 ± 7b
Fenpropathrin	36.8 ± 3.3a	17.5 ± 4.1bc	16.5 ± 3.5b	20.2 ± 1.9b	17.2 ± 3.3c	21.6 ± 4.5c	12.0 ± 3.0b	573 ± 18c
Methomyl	35.4 ± 1.1a	10.4 ± 3.7b	14.2 ± 2.4b	22.9 ± 4.1b	20.4 ± 2.4c	24.8 ± 2.6cd	17.3 ± 2.2c	590 ± 18c
Diazinon	34.8 ± 1.7a	32.6 ± 3.5cd	38.9 ± 9.9c	35.3 ± 2.0c	29.3 ± 3.6d	36.3 ± 4.8e	16.6 ± 3.1bc	1,038 ± 33d
Chlorantraniliprole	29.7 ± 4.5a	49.6 ± 10.3d	41.4 ± 4.8c	41.0 ± 7.2c	31.9 ± 6.7d	33.2 ± 4.8de	15.4 ± 3.7bc	1,183 ± 37d
F	1.34	14.99	64.57	39.88	31.84	34.18	18.26	91.77
P	0.3003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means within a column followed by the same letter are not significantly different ($P = 0.05$; Fisher's protected LSD). Data are reported as original means with *F*, *P*, and means separation values determined after square root $(x + 0.5)$ transformation of the data. For all columns df = 5, 15.

Table 2. The effects of insecticide treatments on thrips densities, 2007

		Mean ± SE thrips per beat					Cumulative thrips-days
Treatment	Precounts	6 DAT	9 DAT	13 DAT	19 DAT	27 DAT	
Formetanate	24.9 ± 7.3a	1.7 ± 0.5a	3.8 ± 1.4a	6.8 ± 2.5a	8.3 ± 2.1a	14.3 ± 4.6a	182 ± 45a
Novaluron	20.5 ± 6.6a	11.6 ± 2.6b	10.2 ± 1.7b	8.1 ± 4.2ab	15.5 ± 3.6ab	16.8 ± 1.8a	354 ± 10b
Spirotetramat	30.3 ± 12.1a	13.7 ± 2.3bc	18.7 ± 1.6c	11.4 ± 3.7abc	14.8 ± 3.3ab	12.4 ± 1.4a	395 ± 57bc
Fenpyroximate	20.0 ± 8.8a	17.8 ± 8.2bcd	20.3 ± 3.6c	11.9 ± 2.0abc	19.6 ± 2.2bc	30.1 ± 2.5b	549 ± 76cd
Diazinon	28.5 ± 3.7a	20.7 ± 8.7bcd	19.9 ± 2.0c	15.0 ± 4.8b	22.8 ± 2.6bcd	31.0 ± 4.7b	611 ± 63d
Methomyl	21.4 ± 6.2a	26.7 ± 6.7cd	23.2 ± 2.8c	12.9 ± 4.0abc	27.2 ± 6.2cd	34.6 ± 6.6b	710 ± 136de
Untreated	20.5 ± 9.1a	30.1 ± 4.5d	34.2 ± 2.8d	18.8 ± 5.2c	34.4 ± 4.2d	32.6 ± 5.4b	848 ± 25e
F	1.43	6.16	36.15	2.18	5.89	5.75	17.07
P	0.2574	0.0012	<0.0001	0.0931	0.0015	0.0017	<0.0001

Means within a column followed by the same letter are not significantly different ($P = 0.05$; Fisher's protected LSD). Data are reported as original means with *F*, *P*, and means separation values determined after square root $(x + 0.5)$ transformation of the data. For all columns df = 6, 18.

Table 3. The effects of insecticide treatments on thrips densities, 2009

		Mean ± SE thrips per beat						Cumulative thrips-days
Treatment	Precounts	5 DAT	9 DAT	16 DAT	23 DAT	30 DAT	35 DAT	
Formetanate	19.0 ± 1.4a	1.7 ± 0.2a	4.9 ± 1.1a	6.4 ± 0.5a	11.5 ± 1.9a	21.5 ± 2.8a	20.4 ± 1.0	343 ± 13a
Spirotetramat	21.9 ± 1.9a	13.1 ± 1.2b	25.4 ± 2.0b	16.7 ± 0.7b	22.4 ± 2.2b	26.8 ± 2.4b	27.2 ± 2.3	733 ± 41b
Untreated	21.5 ± 1.2a	33.5 ± 4.0c	30.8 ± 4.9b	28.4 ± 1.4c	31.9 ± 1.2c	36.9 ± 2.5b	26.8 ± 1.9	1,114 ± 60c
F	3.86	69.96	25.48	213.10	30.16	11.64	3.56	150.11
P	0.0838	<0.0001	<0.0001	<0.0001	0.0007	0.0086	0.0957	<0.0001

Means within a column followed by the same letter are not significantly different ($P = 0.05$; Fisher's protected LSD). Data are reported as original means with *F*, *P*, and means separation values determined after square root $(x + 0.5)$ transformation of the data. For all columns df = 2, 6.

Table 4. The effects of insecticide treatments on thrips densities, 2014

		Mean ± SE thrips per beat						Cumulative thrips-days
Treatment	Precounts	3 DAT	10 DAT	16 DAT	23 DAT	29 DAT	36 DAT	
Pyrifluquinazon	23.7 ± 2.0a	1.6 ± 0.6a	1.2 ± 0.1a	2.2 ± 0.5a	8.9 ± 0.8a	20.5 ± 1.1a	3.9 ± 0.5a	237 ± 17a
Tolfenpyrad	23.8 ± 2.0a	2.9 ± 0.7a	3.9 ± 0.9b	5.9 ± 1.5b	15.4 ± 1.1b	21.5 ± 0.6a	4.3 ± 0.5a	337 ± 17b
Kaolin clay	23.0 ± 1.5a	25.7 ± 1.8b	19.4 ± 0.5c	21.0 ± 1.4c	22.4 ± 0.7c	18.0 ± 0.3b	4.8 ± 0.3a	709 ± 20c
F	0.03	215.57	142.02	103.65	246.43	6.80	1.10	682.24
P	0.9713	<0.0001	<0.0001	<0.0001	<0.0001	0.0287	0.3915	<0.0001

Means within a column followed by the same letter are not significantly different ($P = 0.05$; Fisher's protected LSD). Data are reported as original means with *F*, *P*, and means separation values determined after square root $(x + 0.5)$ transformation of the data. For all columns df = 2, 6.

terminal end of each of the 20 shoots per plot during each year of the study.

The effects of thrips densities on yield and fruit quality were evaluated during the spring following each trial. For the 2006–2009 trials a total of 10 plants from the center of each plot were hand-harvested weekly for a period of 6 wk during May and June. Fruit was weighed and subsamples of ∼500 g of fruit were used to determine the number, size, and average weight of fruit on all evaluation dates. Fruit size was evaluated by the number and weight of berries from the subsamples that could pass through a 11.2 or 12.5 mm sieve for berries of the varieties 'Misty' and 'Star', respectively. Different mesh sizes were chosen each year due to natural differences in fruit size between varieties. In 2014 each row of the trial was assigned a bar code number and each row was picked weekly by commercial picking crews. Each bin of fruit was tagged with a bar code and weighed at the packinghouse and a calculation was made of the total yield from the center 0.36 ha (middle six rows) of each plot.

Statistical Analysis

Average thrips densities on each sampling date were calculated for each plot by determining the average number of thrips per beat sample. Cumulative thrips pressure to the blueberry bushes over the duration of each trial was determined for each plot using thrips-days (Ruppel 1983). On the first evaluation date, we multiplied the average thrips density per plot by the number of days since insecticide treatments (this ranged from 3 to 6 days after treatment). For subsequent evaluations, we calculated the average thrips density from the previous and current evaluation dates and multiplied that by the number of days between evaluations. These values were added to determine cumulative thrips-days for each plot. Thrips density for each sampling date and cumulative thrips-days were analyzed by one-way ANOVA using transformed data (square root $(x + 0.5)$) to satisfy model assumptions regarding homogeneity of variances (SAS Institute 1999). Means were separated using Fisher's protected LSD at $P = 0.05$.

For each plot we determined the average length of new shoot growth and cumulative yield per plant across all harvest dates. For studies from 2006 to 2009, we also calculated the number of berries per plant, weight per berry, and percentage of berries over 11.2 mm (2006 study) or 12.5 mm in size (studies in 2007, 2009). Yield data for each plot were also summed for the first two, middle two, and final two weeks of harvest and converted into a percentage of the total yield for each plot to determine whether or not thrips affected harvest date. All parameters of potential crop loss were analyzed by ANOVA with means separated by Fisher's protected LSD at $P = 0.05$ (SAS Institute 1999).

Relationships between thrips-days and plant response were determined through regression analysis. Separate linear regression analyses were performed for cumulative thrips-days (independent factor) against new shoot growth, yield per plant, and number of berries per plant (2006 to 2009 only) for each year of the study using data from individual plots. Regressions were not performed for the parameters berry weight, berry size, or harvest date due to nonsignificant ($P > 0.10$) results after analysis by ANOVA.

Economic injury levels were calculated for the number of citrus thrips per day over a period of ∼1 mo. Calculations were made using the formula $EIL = CN/YPL$ where $C =$ the cost per unit of control (US$/ha), $N =$ pest density (mean citrus thrips levels per day using weekly beat sample data over a period of ∼1 mo), $Y =$ yield (in kg/ha), $P =$ price per unit of yield (US$/kg), and $L =$ the percentage reduction in crop value for each increase of one thrips per day using beat sample data over a period of ∼1 mo.

Results and Discussion

Insecticide Treatments and Thrips Densities

Insecticide treatments had a significant impact on thrips densities during all the years of the study. In 2006 there were highly significant ($P < 0.0001$) differences in thrips densities among the seven treatments for all evaluation dates from 4 to 32 DAT (days after treatment; Table 1). The lowest thrips densities were in plots treated with formetanate while the highest densities were in plots treated with diazinon and chlorantraniliprole. In 2007 there were significant differences ($P < 0.0017$) in thrips densities among the six treatments for all evaluation dates from 6 to 27 DAT with the exception of 13 DAT (Table 2). The lowest thrips densities were in plots treated with formetanate and novaluron while the highest were in plots that were either untreated or treated with methomyl. In 2009 there were significant differences ($P < 0.0086$) in thrips density among the three treatments for all evaluation dates from 5 to 30 DAT (Table 3). Thrips densities in plots treated with formetanate were lower than in the untreated and spirotetramat plots on all evaluation dates through 30 DAT while the highest thrips densities were in the untreated plots on all evaluation dates through 30 DAT. In 2014, there were significant differences among the three treatments ($P < 0.0001$) from 3 to 29 DAT (Table 4). Plots treated with pyrifluquinazon or tolfenpyrad had lower thrips densities than those treated with kaolin clay.

Variations in the effectiveness of insecticides allowed for the establishment of a gradient of thrips densities each year that was used to determine the impacts of *S. citri* on blueberry plant response. During each of the four years of the study, the initial densities of thrips (from precounts) were relatively consistent at 33.3 ± 1.1, 23.7 ± 2.78, 20.8 ± 0.9, and 23.5 ± 1.0 thrips per beat sample, respectively (Tables 1–4). After application, the most effective insecticide treatments resulted in cumulative thrips-days of 55 ± 2, 182 ± 45, 343 ± 13, and 237 ± 17 for the four years of the study; maximum thrips-days among treatments were 1,183 ± 37, 848 ± 25, 1,114 ± 60, and 709 ± 20, respectively. This was the equivalent of 22-, 5-, 3-, and 3-fold differences in thrips densities between the most effective and least effective treatment over the 4-yr study, respectively.

Thrips Impact on Shoot Growth

During all four years of the study there were significant differences in the length of new shoot growth across treatments [2006, $F = 52.26$; df = 5, 15; $P < 0.0001$; 2007, $F = 6.97$; df = 6, 18; $P = 0.0006$; 2009, $F = 19.88$; df = 2, 6; $P = 0.0023$; 2014, $F = 461.03$; df = 2, 6; $P < 0.0001$]. In 2006 (Table 5), shoot growth was greatest in plots treated with formetanate and spinetoram and least in plots treated with diazinon and chlorantraniliprole. In 2007 (Table 6) the longest shoot growth was in plots treated with formetanate while the least growth was in plots treated with methomyl or that were untreated. In 2009 (Table 7), growth was longer in plots treated with dormetanate than in plots treated with spirotetramat or that were untreated. In 2014 (Table 8) there were statistical differences in shoot length for each treatment, with the longest growth in plots treated with pyriproxifen, followed by tolfenpyrad, followed by kaolin clay.

Table 5. Effects of insecticide treatments on shoot growth, yield, fruit size, and harvest date, 2006–2007

Treatment	Cumulative thrips-days	Shoot growth (cm)	Yield (kg/plant)	Berries per plant	Average wt/berry (g)	% of berries >11.3 mm diam.	Percent harvested wk 1, 2	Percent harvested wk 3, 4	Percent harvested wk 5, 6
Formetanate	54.7 ± 2a	22.4 ± 0.8a	7.9 ± 0.4a	6,206 ± 373	1.27 ± 0.04	59.6 ± 2.4	13.4 ± 0.9	47.5 ± 4.7	39.1 ± 4.5
Spinetoram	214 ± 7b	22.4 ± 0.6a	7.5 ± 0.3ab	7,020 ± 394	1.07 ± 0.05	50.7 ± 3.9	13.3 ± 1.5	45.8 ± 2.2	40.8 ± 2.8
Fenpropathrin	573 ± 18c	17.4 ± 0.7b	7.1 ± 0.7ab	6,273 ± 339	1.13 ± 0.09	50.9 ± 7.6	15.4 ± 0.6	46.1 ± 1.3	38.5 ± 1.7
Methomyl	590 ± 18c	13.5 ± 0.9c	7.2 ± 0.4ab	5,890 ± 252	1.22 ± 0.06	56.6 ± 7.2	10.7 ± 1.0	46.0 ± 2.9	43.3 ± 3.9
Diazinon	1,038 ± 33d	10.5 ± 0.8d	5.9 ± 0.6c	5,380 ± 310	1.09 ± 0.05	50.5 ± 4.4	15.8 ± 1.8	50.4 ± 1.9	33.8 ± 1.7
Chlorantraniliprole	1,183 ± 37d	11.1 ± 0.6d	6.6 ± 0.2bc	5,770 ± 230	1.15 ± 0.03	58.2 ± 2.3	17.7 ± 2.5	46.8 ± 4.0	35.6 ± 4.9
F	91.77	52.26	3.04	2.93	2.22	0.89	2.45	0.43	1.05
P	<0.0001	<0.0001	0.0432	0.0484	0.1058	0.5121	0.0817	0.8241	0.4276

Means (± SE) within a column followed by the same letter are not significantly different ($P = 0.05$; Fisher's protected LSD). For all columns df = 5, 15.

Table 6. Effects of insecticide treatments on shoot growth, yield, fruit size, and harvest date, 2007–2008

Treatment	Cumulative thrips-days	Shoot growth (cm)	Yield (kg/plant)	Berries per plant	Average weight/berry (g)	% of berries >12.5 mm diam.	Percent harvested wk 1, 2	Percent harvested wk 3, 4	Percent harvested wk 5, 6
Formetanate	182 ± 45a	5.5 ± 0.8a	5.0 ± 0.5a	2,715 ± 299a	1.84 ± 0.02a	91.9 ± 0.9a	21.7 ± 2.3a	62.2 ± 1.7a	16.1 ± 2.9a
Novaluron	354 ± 10b	4.3 ± 0.5ab	5.1 ± 0.2a	2,838 ± 165a	1.81 ± 0.04a	91.5 ± 1.7a	23.7 ± 2.4a	62.3 ± 1.5a	14.0 ± 4.6a
Spirotetramat	395 ± 57bc	3.8 ± 0.6bc	5.0 ± 0.4a	2,911 ± 304a	1.74 ± 0.05a	91.2 ± 1.5a	28.3 ± 2.8a	62.6 ± 4.4a	9.1 ± 2.9a
Fenpyroximate	549 ± 76cd	2.9 ± 0.3bcd	5.2 ± 0.2a	3,036 ± 222a	1.72 ± 0.06a	89.6 ± 2.5a	22.7 ± 2.3a	68.1 ± 1.5a	9.1 ± 0.3a
Diazinon	611 ± 63d	2.3 ± 0.6cd	5.2 ± 0.1a	3,007 ± 179a	1.73 ± 0.06a	90.8 ± 1.3a	26.0 ± 2.6a	61.4 ± 3.1a	12.6 ± 3.2a
Methomyl	710 ± 136de	1.8 ± 0.3d	4.6 ± 0.2a	2,608 ± 163a	1.75 ± 0.04a	91.8 ± 0.8a	24.5 ± 2.5a	64.3 ± 2.6a	11.2 ± 2.7a
Untreated	848 ± 25e	2.1 ± 0.4d	5.0 ± 0.4a	2,996 ± 268a	1.68 ± 0.04a	90.2 ± 1.3a	21.9 ± 2.2a	68.0 ± 2.4a	10.1 ± 2.6a
F	17.07	6.97	0.47	0.52	1.46	0.33	0.61	1.42	0.78
P	<0.0001	0.0006	0.8232	0.7844	0.2457	0.9150	0.7184	0.2610	0.5936

Means (± SE) within a column followed by the same letter are not significantly different ($P = 0.05$; Fisher's protected LSD). For all columns df = 6, 18.

Table 7. Effects of insecticide treatments on shoot growth, yield, fruit size, and harvest date, 2009–2010

Treatment	Cumulative thrips-days	Shoot growth (cm)	Yield (kg/plant)	Berries per plant	Average wt/berry (g)	% of berries >12.5 mm diam.	Percent harvested wk 1, 2	Percent harvested wk 3, 4	Percent harvested wk 5, 6
Formetanate	343 ± 13a	9.1 ± 1.1a	4.7 ± 0.1a	2,535 ± 105a	1.77 ± 0.05a	83.3 ± 1.8a	41.5 ± 4.9a	39.6 ± 7.1a	18.9 ± 3.4a
Spirotetramat	733 ± 41b	4.6 ± 0.4b	4.4 ± 0.2a	2,692 ± 127a	1.73 ± 0.01a	79.6 ± 1.4a	33.2 ± 6.1a	48.8 ± 7.6a	18.0 ± 2.0a
Untreated	1,114 ± 60c	2.2 ± 0.6b	4.6 ± 0.3a	2,666 ± 152a	1.72 ± 0.03a	79.2 ± 2.1a	32.6 ± 1.5a	52.9 ± 2.3a	14.5 ± 0.9a
F	150.11	19.88	0.49	0.39	0.37	1.14	2.30	1.73	0.74
P	<0.0001	0.0023	0.6328	0.6949	0.7048	0.3797	0.1810	0.2546	0.5173

Means (± SE) within a column followed by the same letter are not significantly different ($P = 0.05$; Fisher's protected LSD). For all columns df = 2, 6.

Table 8. Effects of insecticide treatments on shoot growth and yield, 2014–2015

Treatment	Cumulative thrips-days	Shoot growth (cm)	Yield (kg/plant)
Pyrifluquinazon	237 ± 17a	17.4 ± 0.4a	3.3 ± 1.1a
Tolfenpyrad	337 ± 17b	16.7 ± 0.3a	3.1 ± 0.8a
Kaolin clay	709 ± 20c	6.2 ± 0.2b	4.7 ± 0.7a
F	682.24	461.03	1.35
P	<0.0001	<0.0001	0.3271

Means (± SE) within a column followed by the same letter are not significantly different ($P = 0.05$; Fisher's protected LSD). For all columns df = 2, 6.

The results from ANOVA determined that insecticide treatments had a significant impact on the length of new shoot growth, which we hypothesized was due to differences in the densities of *S. citri*. To test this theory for each year of the study, we regressed average thrips per day against new shoot length for each treatment (Fig. 1) and cumulative thrips-days against the length of new shoot growth using data from all plots regardless of treatment (Table 9). During all four years of the study there were significant, negative, linear

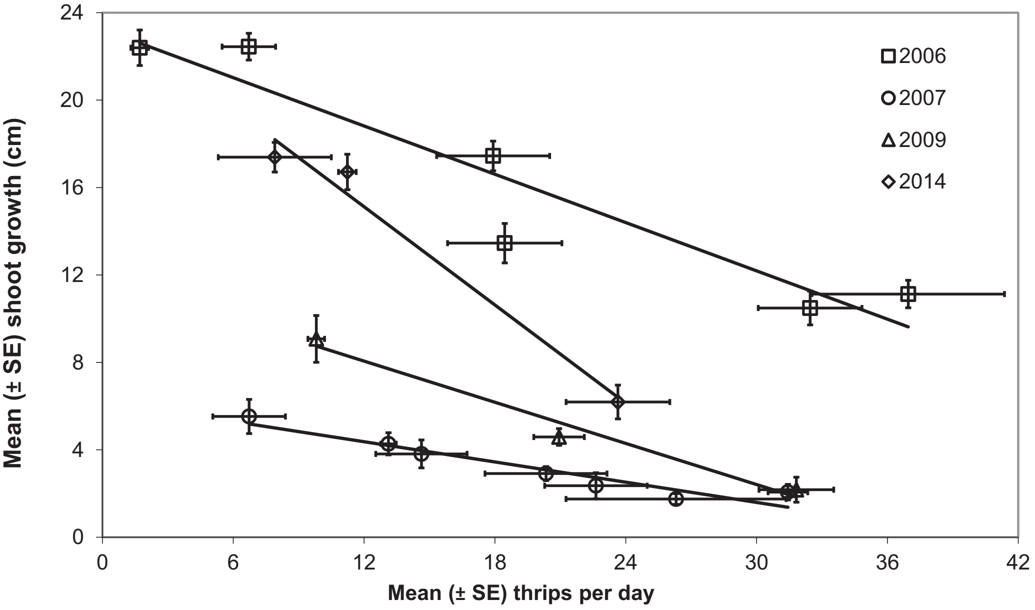

Fig. 1. Linear regression [2006 shoot growth = −0.3683x + 23.24 (R^2 = 0.89); 2007 shoot growth = −0.1543x + 6.22 (R^2 = 0.91); 2009 shoot growth= −0.3137x + 11.82 (R^2 = 0.97); 2014 shoot growth = −0.749x + 24.11 (R^2 = 0.97)] between length of shoot growth and cumulative thrips-days for 6, 7, 3, and 3 levels of infestation in 2006, 2007, 2009, and 2014, respectively.

Table 9. Results of linear regression analysis of five parameters of potential crop impact in blueberries against cumulative thrips-days for trials in 2006, 2007, 2009, and 2014 using data from individual plots regardless of treatment

Year (df)	Parameter of crop impact	Linear regression analysis				
		(Harvest parameter against thrips-days)				
		F	*P*	Slope	Y-int	R^2
2006	Length of new shoot growth (cm)	68.13	<0.0001	−0.0103	22.5	0.76
(1, 22)	Yield per plant (kg)	11.35	0.0028	−0.0014	7.88	0.34
	No. of berries per plant	10.53	0.0037	−1.0028	6,701	0.32
	Berry weight (g)	0.76	0.3927	−0.0001	1.19	0.03
	Berry diameter (% >11.2 mm)	0.09	0.7700	−0.0014	55.3	0.00
2007	Length of new shoot growth (cm)	18.81	0.0002	−0.0041	5.40	0.42
(1, 26)	Yield per plant (kg)	0.17	0.6838	−0.0002	5.13	0.01
	No. of berries per plant	0.02	0.8901	0.0489	2,848	0.00
	Berry weight (g)	2.02	0.1670	−0.0001	1.81	0.07
	Berry diameter (% >12.5 mm)	0.00	0.9492	−0.0001	90.92	0.00
2009	Length of new shoot growth (cm)	43.53	<0.0001	−0.0087	11.7	0.81
(1, 10)	Yield per plant (kg)	0.00	0.9809	−0.0000	4.58	0.00
	No. of berries per plant	0.07	0.7939	0.0614	2,586	0.01
	Berry weight (g)	1.24	0.2909	−0.0001	1.79	0.11
	Berry diameter (% >12.5 mm)	1.21	0.2037	−0.0045	83.9	0.15
2014	Length of new shoot growth (cm)	197.31	<0.0001	−0.0245	23.9	0.95
(1,10)	Yield per plant (kg)	1.42	0.2604	0.0029	2.47	0.12

relationships between the length of new shoot growth and thrips-days [2006: $F = 68.13$, df = 1, 22, $P < 0.0001$, $R^2 = 0.76$; 2007: $F = 18.81$, df = 1, 26, $P = 0.0002$, $R^2 = 0.42$; 2009: $F = 43.53$, df = 1, 10, $P < 0.0001$, $R^2 = 0.81$; 2014: $F = 197.31$, df = 1, 10, $P < 0.0001$] that could be expressed by the equations $y = -0.0103x + 22.5$ (2006), $y = -0.0041x + 5.40$ (2007), $y = -0.0087x + 11.7$ (2009), and $y = -0.0245 + 23.9$ (2014), where y equals the length of new shoot growth in cm and x equals the cumulative thrips-days. This was the equivalent of a 1.03 cm (6.4%), 0.41 cm (7.6%), 0.87 cm (7.5%), and 2.45 cm (10.3%) reduction in the length of new shoot growth for every 100 thrips-days over a period of ∼1 mo for the four years of the trial, respectively.

Thrips Impact on Yield and Fruit Quality

During the 2006, 2007, and 2009 studies, we hand-harvested ∼2.6 million berries, weighing a total of 3.6 metric tons; yield evaluations from the larger plots in 2014 were based on a total of 53.4 metric tons of fruit. During the 2006 study there were significant differences among treatments for yield ($F = 3.04$; df = 5, 15; $P = 0.0432$) and berries per plant ($F = 2.93$; df = 5, 15; $P = 0.0484$), but not for average berry weight, berry size, or percentage of harvest during the first two, middle two, or last two weeks of harvest ($P > 0.08$; Table 5). During the 2007 (Table 6), 2009 (Table 7), and 2014 (Table 8) studies there were no significant differences in any measured parameter at harvest ($P > 0.18$).

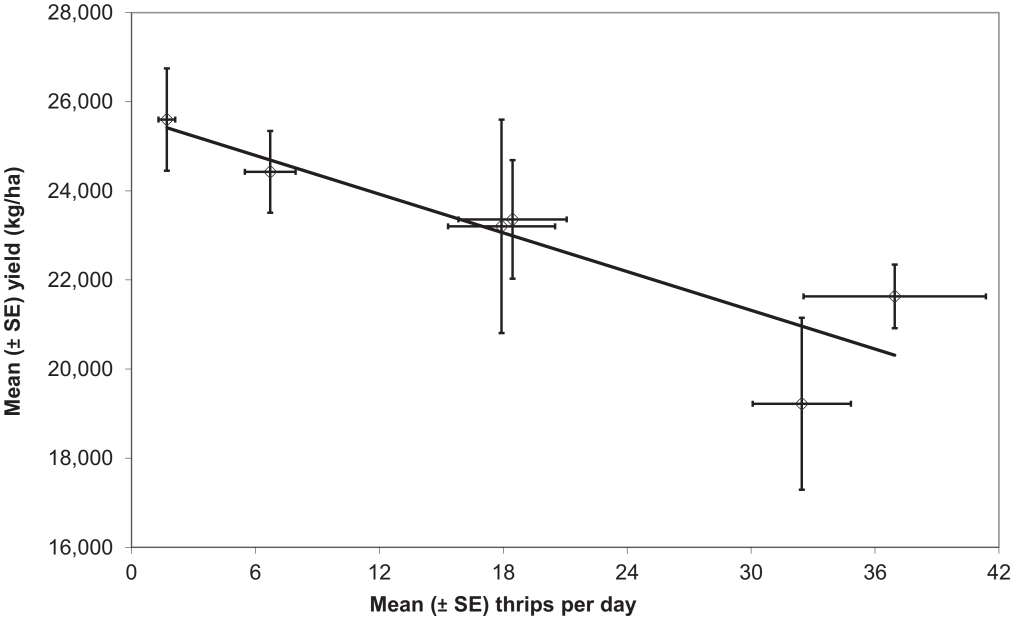

Fig. 2. Linear regression [yield = −144.86x + 25,664 (R^2 = 0.80)] between mean blueberry yields (kg/ha) and average daily thrips densities (cumulative thrips-days divided by the number of days) for plots treated with six different insecticides in 2006.

The results of the 2006 ANOVA documented that insecticide treatments can have a significant impact on blueberry productivity, which we hypothesized was due to differences in density of *S. citri*. To test this theory, for each year of the four years of the study we used data from individual plots to regress thrips-days against yield per plant. For 2006, 2007, and 2009 data we also regressed thrips-days against number of berries per plant, berry weight, and percentage berries greater than 11.2 mm (for Misty) or 12.5 mm (for Star) in diameter (Table 9). In the 2006 study there was a significant negative linear relationship between thrips-days and yield per plant ($F = 11.35$; df = 1, 22; $P = 0.0028$; $R^2 = 0.34$) and a significant negative linear relationship for the number of berries per plant ($F = 10.53$; df = 1, 22; $P = 0.0037$; $R^2 = 0.32$). In 2006, thrips-days were not correlated with a reduction in berry weight or diameter ($P > 0.39$). In the 2007, 2009, and 2014 studies there were no correlations between any parameter of crop loss and thrips-days ($P > 0.16$).

These results suggest that despite repeatable, consistent reductions in plant growth caused by citrus thrips across varieties in each year of the study, in only one out of four years of the study (2006 in the variety Misty) did these reductions result in measurable yield losses the following spring. Additionally, no losses in fruit quality or changes in harvest timing were determined for any year of the study.

Economics of Citrus Thrips Management

Economic considerations for the need to treat for citrus thrips were made by using study data to determine economic injury levels. For the 2006 trial, we evaluated data according to the formula EIL = CN/YPL (Pedigo et al. 1986). The cost of control (C) was assumed to be US$150/ha based on the costs to a grower of making one application of spinetoram (Delegate WG), which is common practice for growers in this region to achieve thrips control for ∼1 mo. Pest density (N) was defined as an average of one thrips per beat sample per day for ∼1 mo. Yield (Y) was defined as the y-intercept (if zero thrips were present) of the regression between average yield per plant (Table 5) and average thrips per day (Table 1) for each of the six insecticide treatments (Fig. 2). Prior to analysis, per plant yield data were multiplied by 3,260 plants/ha to convert data to yield per ha. Price (P) was defined conservatively as the minimum price California growers receive for blueberries of US$6.6/kg; growers stop harvesting when prices are <US$6.6/kg because costs of hand-harvest and fruit processing exceed the value of the crop. The percentage reduction in crop value (L) was determined through regression analysis of yield per hectare against average daily thrips density for the six treatments (Fig. 2). This regression formula was used to calculate the difference between yields for 1 thrips per day compared to 0 thrips per day, with the ratio between the two used as the percentage reduction in crop value. The result was a proportion crop loss (L) of 0.0056 for every 1 thrips per beat sample per day over a period of ∼1 mo.

$$\text{Therefore, EIL} = \frac{(\text{US\$150}) * (1)}{(7.87\text{kg}) * (\text{US\$6.6}) * (0.0056)}$$
$$= 0.16 \text{ thrips per beat per day for } \sim 1 \text{ mo.}$$

These results suggest that growers that collect 0.16 thrips per beat sample are economically justified in treating citrus thrips. This number, however, is in stark contrast to economic injury levels for trials in 2006, 2009, and 2014 where no crop loss was determined with >23 thrips per beat for a period of ∼1 mo.

The inconsistency among treatment thresholds across the years of this study make it difficult for grower to know when treatments for thrips are economically justified. From a grower perspective, citrus thrips is considered to be the most important insect pest of blueberries in the San Joaquin Valley of California, followed by spotted wing drosophila (*Drosophila suzukii* Matsumura) and a few species of grubs, katydids, and a borer (Haviland 2014). This perception is due, in part, to the fact that there are relatively few blueberry pests in California compared to other states like Michigan, New Jersey, and Florida (Williamson et al. 2013, Schilder et al. 2015), and due to the striking visual symptoms of thrips damage.

During all four years of this study we confirmed that citrus thrips can cause a decrease in the length of new shoots that support fruiting buds for the following year's harvest (Fig. 1) and this is something that growers can see easily when comparing growth in fields where they treat aggressively versus those in which they do not. Observations showed that plots having the least new growth also had increases in stem scarring and leaves that were discolored and or misshapen. The symptomology of damage to blueberry stems and leaves can be explained by the feeding behavior of *Scirtothrips* spp. and their concentrated feeding on new plant growth. For example, in young citrus trees in California, *S. citri* feed on new leaves, leaving them misshapen and scarred (Grafton-Cardwell et al. 1997, 2003); in mature citrus, *S. citri* feeds on new fruit and causes surface scarring that becomes increasingly pronounced as the fruit expands. *Scirtothrips aurantii* Faure causes similar damage on citrus in South Africa (Bedford 1943). On avocados in California and Mexico, *S. perseae* Nakahara feed on young avocado fruit and cause scarring as the fruit expands (Hoddle et al. 2003, Dreistadt 2008). *Scirtothrips dorsalis* is a severe pest of chilli and other vegetables in Asia (Kumar et al. 2013, Dickey et al. 2015). In blueberry, Haviland et al. (2009) reported that *S. citri* feeds on the new growth tips, thus causing leaves to be misshapen and discolored while leaving the stem scarred; similar observations were made by Polavarapu (2001) that *S. ruthveni* causes curling and malformation of leaves on blueberries in New Jersey.

Reductions in new shoot growth, however, by themselves do not constitute an economic loss to growers. Results of ANOVA and regression analysis showed that *S. citri* does not have any impact on blueberry quality, but that it can cause a reduction in blueberry yields (2006 results). However, data also showed that yield losses do not always occur (2007, 2009, and 2014 studies). This is despite the fact that initial thrips densities (23–33 thrips per beat sample), maximum cumulative thrips-days (709–1,183), and ranges of average thrips per day were similar across the four years of the study (see Tables 1–4, Fig. 1). This discrepancy among years shows that the relationship between thrips density and blueberry yield is more complicated than what could be explained through our trials, and that a single EIL for blueberries is not readily attainable.

One potential confounding factor with blueberries is variety. During the first year of the study in 2006 the trial was conducted in the variety 'Misty' that is known for having high yields of fruit at the tips of long, stout shoots. In this variety for every 500 thrips-days there was a 22.9% reduction in shoot length associated with an 8.9% reduction in yield (calculated from correlations in Table 9). However, in subsequent years, the other three studies were conducted in the varieties 'Star' and 'Rocio' that have half the length of new shoots compared to 'Misty' (see Fig. 1), lower yields (see y-intercepts for yield correlations in Table 9), and are more prone to setting fruit on smaller, branching shoots. In these varieties for every 500 thrips-days there were 37.1–51.2% reductions in the length of new growth, but no impact on productivity. As a result, varietal differences may exist such that thrips injury to the apical meristem of primary shoots of varieties that grow like 'Misty' may reduce yields whereas thrips injury to the apical meristem of shoots on varieties that grow like 'Star' and 'Rocio' may have little effect or offsetting effects. For example, citrus thrips may cause a reduction in the quality of fruiting wood, but may actually cause an increase in the amount of fruiting wood by killing the shoot terminal and encouraging the growth of lateral shoots that bear fruit. This "biological pruning" of the blueberry bushes has the potential to provide some of the same benefits growers hope to achieve by mechanically pruning shoot tips in the summer once harvest is over.

Another difficulty in the development of EILs is the relationship between the costs of blueberry treatments compared to crop value. Yields during the four years of the study for plots with no thrips (y-intercept of yield regressions from Table 9), when converted to kg/ha, were 25,689 (2006), 16,723 (2007), 14,930 (2009), and 8,052 (2014) kg/ha. When these yields are multiplied by a conservative value that growers receive for blueberries of US$6.6/kg, the result is crop values of ~US$170,000, US$110,000, US$100,000, and US$53,000/ha for the four years of the study, respectively. This is in contrast to the costs of an insecticide treatment that we estimated to be US$150/ha. This means that, according to Pedigo's EIL formula (Pedigo et al. 1986), an insecticide treatment is justified economically if it can prevent a one, one-thousandth reduction in crop value. In our scenario during 2006, the EIL that resulted from our calculations was 0.16 thrips per beat, which for all practical purposes should be considered below the minimum detection threshold for this pest and well below the thrips density at which visual symptoms on leaves and shoots can be seen.

The economics of blueberry production and visual symptoms of thrips damage make it natural for blueberry growers to want to use insecticides frequently. However, blueberry growers in California have limited tools available. For example, across the four years of the study the most effective insecticides were products that are not currently registered for use (formetanate and pyrifluquinazon). In total, we evaluated 12 insecticides, of which only eight are currently registered on blueberries in California (diazinon, fenpropathrin, fenpyroximate, kaolin clay, methomyl, novaluron, spirotetramat, and spinetoram). However, three of these products had poor efficacy (diazinon, methomyl, and kaolin clay; Tables 1–2, 4–6, and 8) and three only had moderate efficacy (fenpyroximate, spirotetramat, and fenpropathrin; Tables 1–3 and 5–7). The two effective products (defined as having shoot growth statistically equivalent to the best treatment) included spinetoram (Tables 1 and 5) and novaluron (Tables 2 and 6). However, within the past two years, blueberry growers that have relied almost exclusively on spinosyn-based insecticides have reported that they no longer work. This was confirmed in a field study by Haviland and Rill (2016) showing no benefit from foliar applications of spinetoram or spinosad and in laboratory bioassays showing moderate levels of resistance compared with citrus thrips collected from citrus (Morse and Haviland, unpublished data). With repeated use of any insecticide, additional cases of resistance in blueberries are likely to occur, as has already occurred for this pest in California citrus (Morse and Brawner 1986, Immaraju et al. 1989, Khan and Morse 1998, Morse and Grafton-Cardwell 2012), such that control often cannot be attained when it is needed.

This study highlights the complexity of developing an integrated pest management program for citrus thrips in blueberries. Growers are faced with a situation where highly visual thrips damage can cause significant damage to the crop, though in a majority of the cases this does not occur. Nevertheless, the almost irrelevant cost of treating blueberries compared to crop value leads growers to want to treat often, yet only a few insecticides are available and effective, resistance to those insecticides is becoming an increased reality, and effective cultural and biological controls do not exist. There are also other factors not evaluated in this study, such as temporal differences in when thrips pressure occurs, the effects of thrips pressure for periods longer than one month, the effects of repeated episodes of thrips pressure, and interactions between thrips damage and variety. The lack of data related to these factors, and variability in data that do exist, mean that considerably more research will be needed by researchers that attempt to develop improved economic injury levels for citrus thrips in blueberries in the future.

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References Cited

Arévalo, H. A., A. B. Fraulo, and O. E. Liburd. 2006. Key to the most common species of thrips found in early-season blueberry fields in Florida and southern Georgia. IFAS Ext. Publ. ENY836, Univ. Fla. Gainesville, FL, p. 5.

Arévalo, H. A., and O. E. Liburd. 2007. Flower thrips oviposition and dispersion behavior in early season blueberries. J. Insect Sci. 7: 28.

Bedford, E.C.G. 1943. The biology and economic importance of the South African citrus thrips, *Scirtothrips aurantii* Faure. Publ. Univ. Pretoria, Series II; Nat. Sci. No. 7.

Dickey, A. M., V. Kumar, M. S. Hoddle, J. E. Funderburk, J. K. Morgan, A. Jara-Cavieres, R. G. Shatters Jr., L. S. Osborne, and C. L. McKenzie. 2015. The *Scirtothrips dorsalis* species complex: Endemism and invasion in a global pest. PLoS ONE 10: e0123747.

Dreistadt, S. H. 2008. Integrated pest management for avocados. Univ. Calif. Div. Ag. Nat. Res. Publ. 3503, Oakland, CA, p. 222.

Flint, M. L., B. Kobbe, J. K. Clark, S. H. Dreistadt, J. E. Pehrson, D. L. Flaherty, N. V. O'connell, P. A. Phillips, and J. G. Morse. 1991. Integrated pest management for citrus, 2nd ed. Univ. Calif. Div. Ag. Nat. Res. Publ. 3303, Oakland, CA, p. 144.

Grafton-Cardwell, E. E., J. G. Morse, and A. Gjerde. 1997. Effects of insecticide treatments to reduce infestation of citrus thrips (Thysanoptera: Thripidae) on growth of nonbearing citrus. J. Econ. Entomol. 91: 235–242.

Grafton-Cardwell, E. E., N. V. O'connell, C. E. Kallsen, and J. G. Morse. 2003. Photographic guide to citrus fruit scarring. Univ. Calif. Div. Agric. Nat. Res. Publ. 8090. Oakland, CA, p. 8.

Haviland, D. R., and S. M. Rill. 2016. Citrus thrips control in southern highbush blueberries in California, 2014. Arthro. Manage. Tests 40: C11. DOI: http://dx.doi.org/10.1093/amt/tsv021.

Haviland, D. R. 2014. UC IPM Pest Management Guidelines: Blueberry. Div. Agric. Nat. Res. Publ. 3542, Univ. California, Oakland, CA, p. 15.

Haviland, D. R., S. M. Rill, and J. G. Morse. 2009. Southern highbush blueberries are a new host for *Scirtothirps citri* (Thysanoptera: Thripidae) in California. Fla. Entomol. 92: 147–149.

Hoddle, M. S., K. M. Jetter, and J. G. Morse. 2003. The economic impact of *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae) on California avocado production. Crop Prot. 22: 485–493.

Horton, J. R. 1918. The citrus thrips. Usda Technical Bulletin 616. p. 42..

Immaraju, J. A., J. G. Morse, and D. J. Kersten. 1989. Citrus thrips (Thysanoptera: Thripidae) pesticide resistance in the Coachella and San Joaquin Valleys of California. J. Econ. Entomol. 82: 374–380.

Jimenez, M., R. Carpenter, R. H. Molinar, K. Wright, and K. R. Day. 2005. Blueberry research launches exciting new California specialty crop. Calif. Agric. 59: 65–69.

Khan, I., and J. G. Morse. 1998. Citrus thrips (Thysanoptera: Thripidae) resistance monitoring in California. J. Econ. Entomol. 91: 361–366.

Kumar, V., G. Kakkar, C. L. McKenzie, D. R. Seal, and L. S. Osborne. 2013. An overview of chilli thrips, *Scirtothrips dorsalis* (Thysanoptera: Thripidae) biology, distribution and management, pp. 53–57. *In* S. Soloneski and M. Larramendy (eds.), Weed and pest control: Conventional and new challenges. InTech doi: 10.5772/55045.

Morse, J. G. 1995. Prospects for IPM of citrus thrips in California, pp. 371–379. *In* B. L. Parker, M. Skinner, and T. Lewis (eds.), Thrips Biology and Management. Proceedings, 1993 International Conference on Thysanoptera, Towards Understanding Thrips Management. Sept. 28–30, 1993. Plenum, New York, NY.

Morse, J. G., and O. L. Brawner. 1986. Toxicity of pesticides to *Scirtothrips citri* (Thysanoptera: Thripidae) and implications to resistance management. J. Econ. Entomol. 79: 565–570.

Morse, J. G., and E. E. Grafton-Cardwell. 2012. Management of citrus thrips to reduce the evolution of resistance. Citrograph 3. 22: 26–30.

Pedigo, L. P., S. H. Hutchins, and L. G. Higley. 1986. Economic injury levels in theory and practice. Annu. Rev. Entomol. 31: 341–368.

Polavarapu, S. 2001. Blueberry thrips: An emerging problem in New Jersey highbush blueberries. Blueberry Bull., Rutgers Coop. Ext. XVII: 2.

Rodriquez-Saona, C. R., S. Polavarapu, J. D. Barry, D. Polk, R. Jörnsten, P. V. Oudemans, and O. E. Liburd. 2010. Color preference, seasonality, spatial distribution and species composition of thrips (Thysanoptera: Thripidae) in northern highbush blueberries. Crop Prot. 29: 1331–1340.

Ruppel, R. F. 1983. Cumulative insect-days as an index of crop protection. J. Econ. Entomol. 76: 375–377.

SAS Institute 1999. User's manual, version 8.0. SAS Institute, Cary, NC.

Schilder, A., R. Isaacs, E. Hanson, and B. Cline. 2015. A pocket guide to IPM scouting in highbush blueberries. Michigan State Univ. Ext. Publ. E2928, East Lansing, MI.

Williamson, J. G., P. F. Harmon, O. E. Liburd, and P. Dittmar. 2013. 2013 Florida blueberry integrated pest management guide. IFAS Ext. Publication, University of Florida, Gainesville, FL. 30. pp.