Combined Report for:

Avocado Thrips Subproject 1: Laboratory Studies on Biology, Field Phenology, and Foreign Exploration

Subproject Leader: Mark S. Hoddle
Department of Entomology, UC Riverside

Cooperating Personnel: Lindsay Robinson, Miwa Takano-Lee, and Judy Virzi

Avocado Thrips Subproject 3: Pesticide Screening, Sabadilla Resistance, Goetheana and Lacewing Studies

Subproject Leader: Joseph G. Morse
Department of Entomology, UC Riverside

Cooperating Personnel: Alan Urena, Cressida Silvers,
Kris Tollerup, and Pamela Watkins

Avocado thrips, *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae) was discovered in California in July of 1996, and spread rapidly from two initial sites of discovery near Port Hueneme in Ventura County and at the Irvine Ranch in Orange County. Avocado thrips larvae and adults can build to such high densities over the fall through spring period on young leaves on top-worked trees that leaves damaged from feeding can drop. The main source of economic loss attributable to avocado thrips, however, is scarring of immature fruit in spring by feeding thrips.

Economic losses attributable to avocado thrips have been calculated using pack-out records. Economic data for 22 anonymous growers were combined with costs of thrips control incurred by either using biological control agents, Veratran-D (sabadilla), or Agri-Mek (abamectin). An economic model was developed by an agricultural economist at UC Davis to estimate the effects to growers and consumers of rising production costs, retail prices, and decreases in quality. The model indicated an annual short-run loss to avocado growers of between $7.6 and $13.4 million in 1998 from the combined effects of losses in quality and increased production costs associated with avocado thrips management. Economic losses to avocado thrips continue to accrue annually, but the magnitude of decreased revenue will vary yearly depending on the severity of thrips infestations, costs of control (biological or chemical), percentage of crop damaged, severity of damage, and market value for harvested fruit.

Our research sponsored by the California Avocado Commission has taken a three-pronged approach to investigating potential control strategies to minimize economic losses to avocado thrips. Our thrips management program is based on: (1) an improved understanding of this pest's biology, behavior, ecology, and natural enemies. We intend to use this information for the development of biological and cultural control programs for avocado thrips. (2) Screening and selection of IPM compatible insecticides and monitoring avocado thrips populations for resistance to these insecticides, and (3) investigating cost effective strategies for applying insecticides by air or ground as selected from screening trials.

Avocado Thrips Behavior and Ecology

Monitoring with Sticky Cards (Research by Hoddle & Robinson).

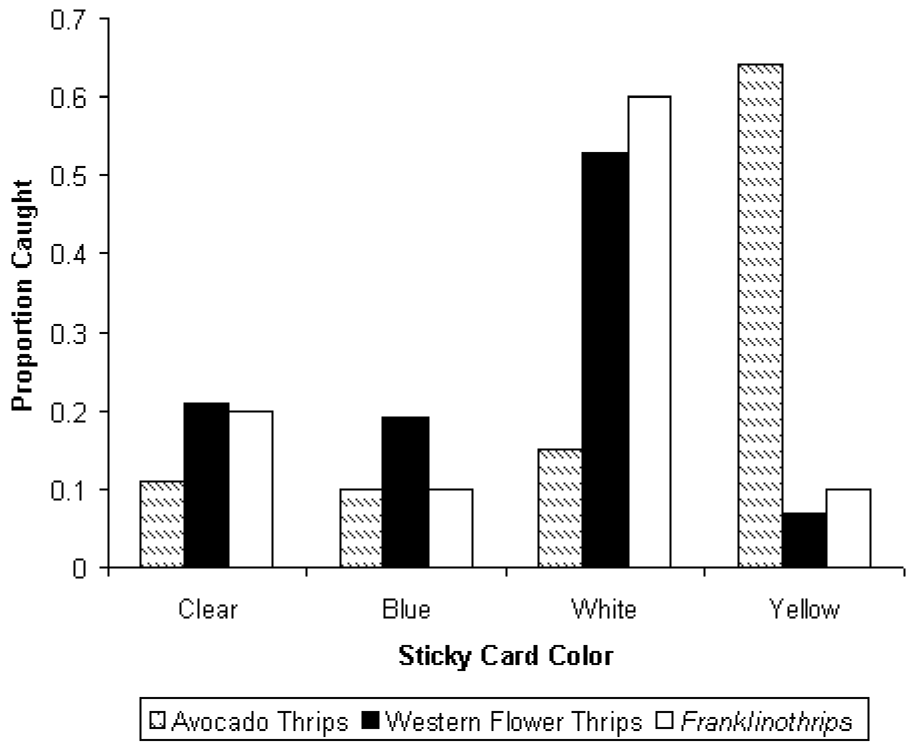
Sticky cards or traps provide a simple method for detecting pest insects and their natural enemies with relatively little sampling effort. A number of factors can affect sticky card efficiency-one important consideration is color, others are shape, size, and the type of adhesive on the trap or card. Many insects show color preferences which influence orientation and landing behaviors. Thrips have been shown to be most attracted to sticky cards that are either white, yellow, or blue in color (Childers and Brecht, 1996). Sampling with sticky cards for various species has been used to assist with pest control decisions, and for monitoring pest and natural enemy population trends throughout the year.

Before sticky cards could be used to monitor avocado thrips, color attraction studies in avocado orchards needed to be conducted to determine the color preferences of avocado thrips, its key natural enemy *Franklinothrips* n. sp., and western flower thrips (*Frankliniella occidentalis*) a common pollen feeding thrips in southern California avocado orchards.

Color attraction studies were conducted in Fallbrook in a top-worked Hass avocado orchard heavily infested with avocado thrips. Stakes 2 m tall with a 2 m cross arm were placed between rows of top-worked trees and on each arm four sticky cards were placed: (1) yellow, (2) blue, (3) white, and (4) clear (this experimental control coated with tangle foot acted as a passive interception trap to determine numbers of thrips caught by random landing). Card color combinations on arms in all possible combinations were tested to determine if the color of an adjacent card influenced trap catch. We replicated the experiment simultaneously in each cardinal direction of the orchard to allow for wind effects on trap catch. The trial was replicated four times over the period April to June, 1999. Numbers of avocado thrips, *Franklinothrips* n. sp. and western flower thrips were recorded in the laboratory.

Significant differences in color preferences were detected for avocado thrips ($\chi^2 = 4704$, df = 3, $P < 0.0005$), western flower thrips ($\chi^2 = 9141$ df = 3, $P < 0.005$) and Franklinothrips n. sp. ($\chi^2 = 569$, df = 3 $P < 0.005$). Avocado thrips was most attracted to yellow cards, western flower thrips and Franklinothrips n. sp. preferred white cards (Fig. 1).

Figure 1. Sticky card color preferences of avocado thrips, western flower thrips, and Franklinothrips n. sp.



This study was done primarily to develop a monitoring tool for use in future research studies. Using yellow sticky cards to monitor avocado thrips most growers may find it difficult to accurately distinguish this thrips from western flower thrips with a hand lens and use of a microscope may be necessary in many instances. In addition, this method of monitoring is labor intensive and normal grower or pest control advisor monitoring is probably best accomplished by monitoring leaves and fruit for the presence of avocado thrips and its natural enemies.

Pupation Biology (Research by Hoddle and Oishi).

Predatory and phytophagous thrips have been captured emerging from the ground beneath citrus trees (Childers *et al.* 1994), and pupation beneath host plants is common for pestiferous phytophagous thrips (Grout *et al.* 1986, Harrison 1963, Okada 1981, Reed & Rich 1975, Schweizer & Morse 1996, 1997, Tsuchida 1997). Adult avocado thrips have been retrieved from leaf duff samples collected from beneath avocado trees in Ventura county indicating that this pest also pupates on the ground (Hoddle *et al.* 1998). The proportion of avocado thrips larvae that pupate on avocado trees or abandon trees to pupate beneath host plants was unknown until recently. We undertook laboratory studies to determine the proportion of avocado thrips larvae that either pupate on host plants or abandon branches to pupate beneath trees.

The pupation biology of avocado thrips was studied in the laboratory by placing known numbers of second instar thrips larvae on young ¾ expanded avocado leaves that were flushing on 2 m tall plants in pots. The base of each branch was coated with tangle foot to prevent larvae leaving experimental branches. Under each branch a clear sheet of plastic coated with tangle foot was placed to trap thrips larvae falling or jumping from experimental branches. After 3-4 days, branches were destructively sampled for thrips pupae and numbers of larvae trapped on plastic sheets were recorded. For each replicate 25-30 avocado thrips larvae were placed on a branch with suitable leaves for feeding and we replicated this study 12 times.

On average we managed to recover 77% of deployed avocado thrips larvae. Of those thrips recovered, 22% pupated in cracks on branches and 78% were recovered on plastic sheets beneath branches.

These laboratory data suggest that the majority of avocado thrips drop or jump to the ground to pupate. We are currently investigating the potential of green yard waste mulches that are used for biological control of avocado root rot for reducing avocado thrips pupation rates. We hypothesized that mulches may harbor invertebrates or pathogens antagonistic to avocado thrips that are not present in avocado leaf duff. Our current field experiments are designed to record numbers of avocado thrips falling from leaf flush onto mulched or unmulched soils, and the numbers of adult thrips that successfully emerge from mulched and unmulched soils. Concurrent with these observations we are recording monthly changes in diversity of the arthropod and entomopathogenic fauna of mulches and leaf duff to determine if any significant differences between the two orchard floor substrates are correlated with suppressive activity towards avocado thrips.

Natural Enemies of Avocado Thrips

***Franklinothrips* n. sp. (Thysanoptera: Aeolothripidae) (Research by Hoddle, Robinson, Jones, and Oishi).**

This predator is the dominant natural enemy associated with avocado thrips in southern California. Laboratory colonies of *Franklinothrips* are maintained on lima bean plants and adults and larvae are feed irradiated *Ephestia kuehniella* (Mediterranean flour moth) eggs. We have been studying the developmental and reproductive biology of this predator to ascertain what conditions are necessary to optimally mass rear this predator. An efficient mass-rearing program could result in the commercialization of this predator as an avocado thrips natural enemy. We have determined that the optimal rearing temperature for *Franklinothrips* n. sp. is 25°C (Hoddle *et al.* 2000a). The best diet for mass rearing is a combination of irradiated *E. kuehniella* eggs combined with *Tetranychus* pacificus eggs (pacific spider mite). Both of these food types are available commercially (*E. kuehniella* eggs are sold for mass rearing *Trichogramma* and *T. pacificus* eggs are sold for mass rearing phytoseiid mites) (Hoddle *et al.* 2000b). The most efficient way to harvest and ship this predator is to provide late second instar *Franklinothrips* larvae with small parafilm cones to pupate in. Shipping *Franklinothrips* as cocoons in parafilm cones can reduce transit mortality by 52% in comparison to aspirating adults from rearing cages and shipping them in glass vials (Hoddle *et al.* 2000c).

***Goetheana incerta* Annecke (Hymenoptera: Eulophidae). (Research by Schweizer, Morse, and Urena).**

This parasitoid was first discovered in 1995 to attack South African citrus thrips (Grout and Stephen 1995), *Scirtothrips aurantii* Faure, and we are interested in ascertaining whether this species will attack California citrus thrips, *S. citri* (Moulton), and avocado thrips. On 20 July 2000, our third shipment of *Goetheana incerta*, arrived at UCR's Quarantine Facility. We have been spending 2-16 hours per day working with this species over the last two weeks. The first shipment, sent in April of 1997, was lost because of our lack of knowledge regarding the parasitoid's basic biology. The second shipment, arrived in April of 1998 and was also lost, because most of the parasitoids emerged in transit and only of six were alive or emerged over the following four weeks.

This thrips parasitoid is very difficult to work with. Adults are very small and fragile. Adults emerge from second instar thrips which are of similar size as avocado thrips, and we have so far been able to keep adults alive for only 2-4 days. Behavioral differences sometimes allows us to separate males and females, otherwise sexual differentiation is very difficult, even when adults are slide mounted and examined under a microscope. The ovipositor of the female is tiny and visible under high magnification only when she is in the process of stinging thrips. Unmated females lay only male eggs (males are obviously of limited value in building up a colony except for their critical input during mating) and as of 5 Aug. 2000, we have observed only a single mating in quarantine.

Much remains to be discovered regarding the basic biology of *G. incerta*. In addition, it is unclear how suitable either avocado thrips or citrus thrips are as alternative hosts to *S. aurantii*. Our hypothesis to date, is that citrus thrips may be recognized as a host (*Goetheana* has been observed host-feeding and parasitizing this species) but avocado thrips may not be recognized by the female as a suitable host. This may occur because of different host cues (e.g., odors) that may be related to host plant chemistry.

Although progress has been frustratingly slow to date, it is possible that *G. incerta* may not help us with future avocado thrips control. However, we feel this work is important to continue in order to develop the technology needed to collect and maintain thrips parasitoids for shipment to the U.S. This could be particularly important during future foreign exploration trips looking for parasitoids of avocado thrips in Latin America. For example, an interesting preliminary observation is that healthy citrus thrips will readily feed on and consume ("cannabilize") parasitized thrips 3-4 days after parasitization by *G. incerta*. Once parasitized thrips become less active and unable to defend themselves they are eaten by other members of the same species. This was a completely unexpected observation and may partially explain why we saw parasitization in shipment one but relatively few parasitized thrips survived to pupation. It was only when we caught a thrips in the act of eating an obviously parasitized thrips that we determined that "disappearing" thrips were not escaping but being eaten.

In retrospect, this explains the observation that parasitized citrus thrips go into early pupation behavior as second instars and never transform to the propupal stage. Thus, in our Quarantine work and during foreign exploration, it may be necessary to individually isolate parasitized thrips to protect them from being cannabilized. This is something we might not have anticipated and which might have frustrated foreign exploration for avocado thrips parasitoids (assuming Latin American parasitoids behave similar to *G. incerta*). Another problem facing this project is that relatively few researchers around the world have conducted detailed behavioral studies with thrips parasitoids. Consequently, we have very little available research to assist us when designing a protocol for rearing and maintenance of our *G. incerta* colony. If we are able to maintain the *G. incerta* colony, our next steps will be to determine more precisely the host suitability of citrus thrips, avocado thrips, and several beneficial thrips species (e.g., *Franklinothrips* n. sp. larvae) prior to requesting permission to release the parasitoid from Quarantine.

Green Lacewings (*Chrysoperla rufilabris* [Neuroptera: Chrysopidae]). (Research by Silvers, Hoddle, and Morse).

The following research was completed by Ms. Cressida Silvers as part of a Master's thesis project on the biological control of avocado thrips by lacewings and *Franklinothrips* n. sp. (Silvers 2000). Silvers' research was funded through a scholarship from UCR's Graduate Division and a grant awarded to Hoddle by UC's Division of Agriculture and Natural Resources.

Shipping Trial. Several commercial insectaries produce and sell various green lacewing species. Based on previous research with citrus thrips (Khan and Morse 1999a, b), we decided to conduct a quality assessment of *Chrysoperla rufilabris* (Burmeister). Lacewings were shipped from three different suppliers (Beneficial Insectary, Oak Run; Buena Biosystems, Ventura; and Rincon Vitova, Ventura). Lacewings shipped by all three insectaries were of similar quality following transit.

Some interesting differences were noted. First, two insectaries normally shipped much more than the requested number of lacewings, while the third sent just a little more than requested. Second, the survivorship of lacewings was a little higher when shipped from the third insectary. Our conclusion from the lacewing shipping trial was that there was no advantage in ordering from one particular insectary.

Feeding and Pesticide Compatibility Assays. Laboratory studies were run to determine if *C. rufilabris* and *Franklinothrips* n. sp. would feed on and reduce avocado thrips numbers on avocado terminals. Both predator species significantly reduced avocado thrips numbers in comparison to control plants without predators. Second, Silvers determined if relatively fresh residues of pesticides applied for avocado thrips control would have adverse affects on *C. rufilabris* and *Franklinothrips* n. sp. Avocado leaves were treated with abamectin, malathion, sabadilla, or spinosad at commercial rates (adding oil to abamectin and spinosad; sugar to sabadilla). Residues were allowed to dry in the laboratory for 2-3 hours, and predators were confined on treated leaves and checked daily for mortality. Sabadilla was fairly innocuous to both species of predators. Neither abamectin nor spinosad affected *C. rufilabris* much, and malathion was moderately toxic to lacewings (only 20% of the lacewings were dead after 5 days). This confirms previous research by other workers indicating that lacewings are fairly tolerant of pesticides.

In contrast, abamectin, malathion, and spinosad aged in the laboratory were toxic to *Franklinothrips* n. sp. and most predaceous thrips were dead within 1-3 days. It is possible that if these pesticide residues were aged outdoors toxicity may have declined to fairly innocuous levels within 12-24 hours after treatment due to sunlight degradation. Abamectin and spinosad continue to be effective against avocado thrips because some of the pesticide moves into the leaves. This translaminar movement is assisted by oil, hence its inclusion or addition of a surfactant appears to help persistence. These two materials are "locally systemic" and they don't move far in the plant but do move far enough into the leaf or fruit to be protected from sunlight breakdown.

There is also the likelihood of "food-chain" impacts that may result from using abamectin or spinosad. Even if *Franklinothrips* doesn't pick up surface residues more than a day after treatment, this predator may acquire and be killed by these pesticides after eating avocado thrips that have ingested these toxins. Given the large number of thrips this predator feeds on daily, this might be a problem in treated orchards. There is considerable room for additional research on this subject.

Silvers also conducted a field study in Fallbrook California, to evaluate the efficacy of natural enemies alone, pesticides alone, and combing natural enemies and pesticides for avocado thrips control. The treatments were as follows:

1. A low level of lacewings applied 23 days apart (planned at a rate of 200 first instar larvae/ tree during each release). The actual release rate was an average of 325 larvae applied per tree. This was due to more than one lacewing surviving in each release cell. Lacewings received as eggs in hexal cells were reared on food through the first instar; the insectary often placed more than one egg per cell and many survived. Lacewing larvae were evenly distributed at 10 release points on each experimental tree.
2. Two releases of lacewings applied at a high rate (planned at 2,000 larvae/ tree but actual rate was an average of 5,045 larvae applied per tree).
3. Two releases of adult *Franklinothrips* n. sp. (planned at 500 larvae/ tree but actual rate was an average of 218 larvae applied per tree; shipment of adults from the Netherlands resulted in substantial mortality before release).
4. One Agri-Mek 0.15 EC + NR415 Oil spray at 10 fl oz + 1%/ acre.
5. Two sprays of Success 2SC at 6 fl oz acre timed 23 days apart.
6. Two sprays of Success 2SC + Oil at 6 fl oz + 1%/ acre.
7. Two sprays of Veratran D 0.2% + Sugar at 15 lbs + 10 lbs/ acre.
8. A Veratran + Sugar spray followed by a low rate release of lacewings.
9. Low release rate of lacewings followed by Veratran + Sugar.
10. Control (water spray).

Trees used in the study were relatively small, 10 foot tall Hass avocado trees which had been top worked from Reed rootstock two years earlier. Predators were placed on trees and pesticides were applied with a backpack sprayer (see description of this sprayer below) in early June 1999 at a dilution rate of 50 gallons of water per acre. Each treatment was replicated on eight single tree replicates and thrips levels were assessed prior to treatment and approximately weekly thereafter by counting the number of immature avocado thrips per leaf on 10 leaves per tree. Thrips levels averaged about 12 immatures per leaf before treatment, rose slightly to 18 thrips per leaf in the control 1 week after treatment, and then declined gradually over the following 6 weeks of the trial, decreasing to an average level of 2 immatures per leaf on the control trees by the middle of July.

This study was designed to evaluate natural enemies head to head with pesticides against relatively high thrips populations. Natural enemies were expected to perform comparably to pesticides in this "augmentative" setting and this may have been an unrealistic expectation. An "inoculative" approach, where natural enemies are released early in the season and allowed to increase in density in response to increasing pest numbers may be a better approach for using biological control agents against avocado thrips. With this yet untested strategy, early releases of lacewings and *Franklinothrips* n. sp. on lower initial thrips levels would be made to see if avocado thrips densities are kept below economically injurious levels thereby reducing pesticide treatments and contributing to pesticide resistance management.

Results of this field study can be summarized as follows. All four pesticide treatments (abamectin + oil, sabadilla + sugar, spinosad, or spinosad + oil) were effective in reducing avocado thrips levels and maintaining them at fairly low levels for the six weeks of this study. However, avocado thrips levels were on a downward trajectory on control trees during this time. Low levels of lacewings and the *Franklinothrips* release were ineffective in reducing avocado thrips levels. The high rate release of lacewings reduced thrips levels but not nearly to the degree that pesticides did. Because of the very high release rate of lacewings in treatment two on small trees, we concluded that lacewings may be of limited value in reducing high levels of thrips in comparison with pesticides. As mentioned above, what remains to be evaluated is how lacewings might be used in early releases on low level avocado thrips populations to possibly maintain this pest at lower levels and reduce the need for one or more pesticide treatments.

Our conclusions are less clear with *Franklinothrips* because of the observed poor quality of these adult thrips shipped from the Netherlands (although about 50% of them were alive at release they may have been greatly weakened following transit stress (see research described above by Hoddle to solve this shipping problem). More research is needed to evaluate early lacewing releases and releases of *Franklinothrips* n. sp. This research is planned for winter / spring of 2000-01 assuming *Franklinothrips* n. sp. can be reared by a commercial source effectively (Koppert in the Netherlands has abandoned their colony since our research was done).

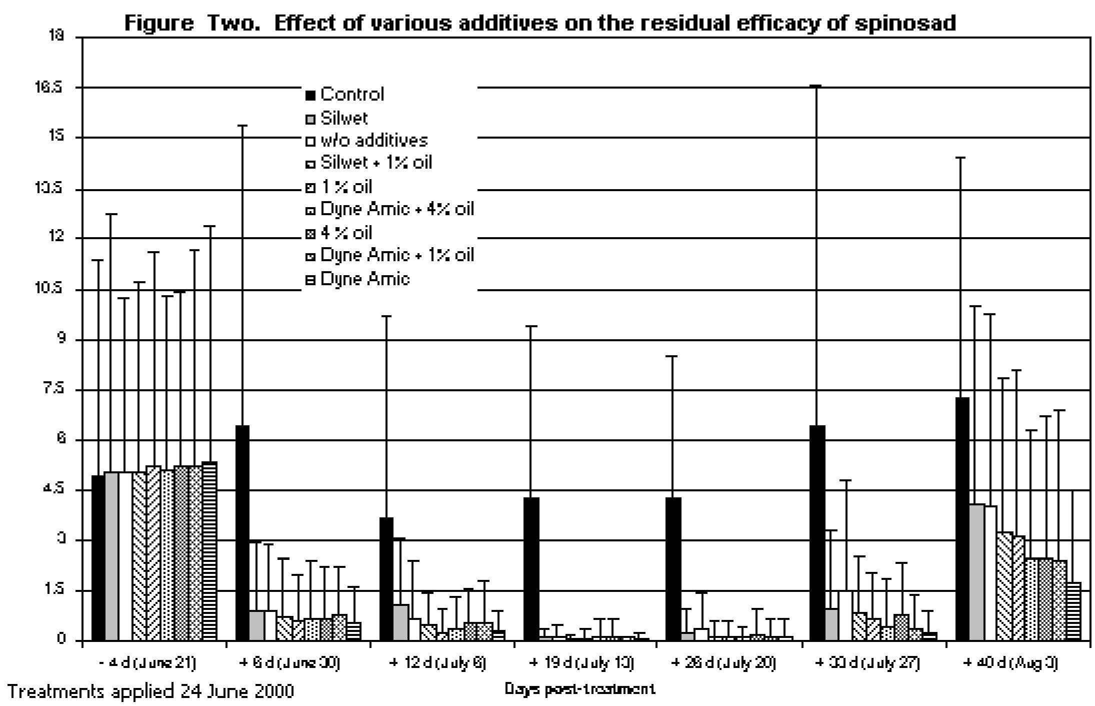
Pesticide screening trials with Avocado Thrips (Research by Tollerup, Morse, and Urena; Companion field studies run in Ventura Co. by Yee and Phillips).

Pesticide screening research with avocado thrips borrows heavily from citrus thrips pesticide screening funded by the Citrus Research Board and is of benefit to both avocado and citrus growers. One aspect of this research is to evaluate the benefit of adding various additives to either abamectin (Agri-Mek) or spinosad (Success) to help in leaf penetration and thus possibly extend the persistence of these materials (surface residues are broken down rapidly by sunlight so the amount successfully penetrating the leaf is important) in killing avocado thrips. This research has been done mostly by M.S. student Kris Tollerup.

Initial trials evaluated adding various rates of Narrow Range 415 Spray Oil to either abamectin or spinosad (0.25, 1, 2, and 4% oil were compared to no oil). Addition of oil helped extend the persistence of both materials but the amount of oil did not appear to be critical (the low rate of 0.25% was about as good as higher rates). Next, the addition of six surfactants (most applied at 50% of maximum label rate) to spinosad were compared to adding 1% oil or no additive. From this work, despite somewhat variable results, Silwet and Dyne Amic used as additives were chosen for further evaluation.

In a field study in Ventura put on with the assistance of Dr. Wee Yee, nine treatments were applied with a backpack sprayer by ground using approximately 0.75 liters (16.4 gallons.acre) of spray per tree (model SR-400 Pacific Stihl low volume backpack mistsprayer, L&M Fertilizer, Temecula, CA; see the article by Yee *et al.* in this issue about the use of this backpack sprayer for ground applications). Treatments evaluated the value of various additives added to spinosad (Success 2 SC at 10 oz/ acre). Ten single tree replicates were chosen for each treatment and 10-40 leaves were examined approximately weekly to determine the number of immature avocado thrips per leaf.

Figure 2 summarizes the data (oil = 1% or 4% NR415 oil; Silwet was added at a rate recommended by an industry contact = 2 oz/ acre; and Dyne Amic was added at 1/2 the maximum label rate = 40 oz/ acre). Despite great variability in the data (the thin lines about the mean data bars are standard errors of the mean for the 10 data trees per treatment), by examining data at 40 days after treatment it appears that all of the spinosad treatments maintained thrips levels below levels seen in the untreated control. Despite a lack of statistical separation, there is a slight trend indicating Dyne Amic should be evaluated in future trials as one of the better additives to use with spinosad. Until field trials are run, these data should be extrapolated with caution, as additives to other materials such as abamectin could have different results.

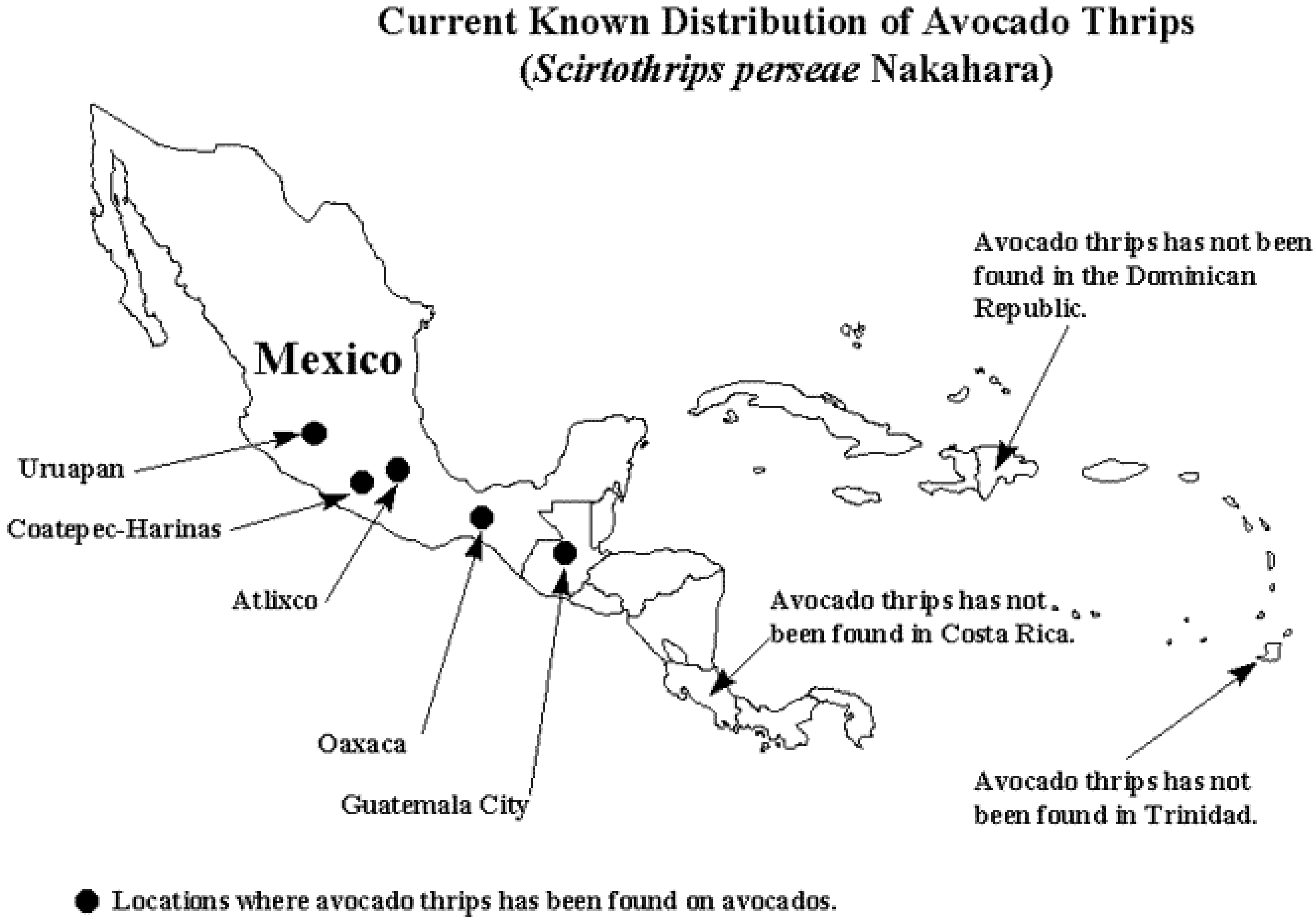


A number of other pesticide studies are underway. One of these involves monitoring avocado thrips susceptibility to abamectin, sabadilla, and spinosad as these materials are used in the field for control. We have not heard (or found in our tests to date) of any evidence of resistance to these materials but because of the ease with which other thrips species, such as citrus thrips, develop resistance to various chemicals, this is something we will be watching for. We now have a good test method and will soon have susceptibility data for all three pesticides which can serve as "baseline" data should resistance appear to be a concern in the future.

Foreign Exploration for Natural Enemies in Latin America

Foreign exploration for avocado thrips and its natural enemies by Hoddle and Phillips is ongoing. Surveys have been completed in Mexico, Guatemala, Costa Rica, the Dominican Republic, and Trinidad. The current known distribution for avocado thrips is from Mexico City south to Oaxaca, through to Guatemala City (see map). In Costa Rica avocado thrips has been replaced on avocados by another species of *Scirtothrips* which is most probably a species new to science (S. Nakahara pers. comm.). No species of Scirtothrips have been recovered from avocados grown in the Dominican Republic or Trinidad.

The most common natural enemies associated with avocado thrips on avocados in Latin America have been species of predaceous thrips, and parasitoids in the genus *Ceranisus* [Hymenoptera: Eulophidae]). In addition to documenting the natural enemy fauna associated with avocado thrips in Latin America and the Caribbean, we have also been able to compile an inventory of thrips species attacking avocados that are not yet present in California. These catalogued thrips could pose a threat to California avocados should they enter and establish in this state.



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