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The Introduction of Avocado Thrips into California: History and Current Status

Avocado thrips (*Scirtothrips perseae* Nakahara [Thysanoptera: Thripidae]) (Fig. 1A) was first discovered in California in June of 1996 when fruit scarring (Fig. 1B) and the presence of a thrips that appeared similar to citrus thrips (*Scirtothrips citri* Moulton) were noticed on avocados. Pest control advisor (PCA) Charlie Gribble (Biospectrum Inc., Ventura, CA) took samples from an avocado grove near Port Hueneme (Saticoy, Ventura County) to Phil Phillips (Area IPM Advisor, UC Cooperative Extension, Ventura Co.) at about the same time that PCA Joe Barcinas (Entomological Services Inc., Corona, CA) took samples from a grove at the Irvine Ranch (Irvine, Orange County) to Joseph Morse at UC Riverside. Citrus thrips (*Scirtothrips citri* [Moulton]), which is very similar in appearance to the thrips attacking avocados, has rarely been observed on avocados. Thus, the presence of this thrips on avocados causing both leaf and fruit scarring was surprising. Phillips sent thrips samples to the California Department of Food and Agriculture (CDFA) Plant Pest Diagnostics Center (Sacramento, CA) and they were determined to be an unknown species of thrips similar to but different from citrus thrips. In 1997, Steve Nakahara (USDA Systematic Entoto employ them as trap trees by treating them with insecticides, may be considered. In each of the four above categories of infestation, different compounds should be used.

Concluding remarks

The shot hole borers found in Israel and California are identical and carry the same fungal symbiont *Fusarium* sp. (nov.). Comparisons of the mtDNA and rRNA of the typical *Euwallacea fornicatus* tea shot hole borer native to Sri Lanka and that of the Israeli and California shot hole borer of avocado show that they are different but appear to be closely related species. So far there is no effective solution for management of the problem. The conspicuous penetration points make the monitoring and 'surgical' treatments of the initial beetle infestation feasible. For the moment, preventive management, including surveys, sanitation and intensive chemical treatments should be considered in order to stop or reduce the spread of the pest.

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thrips infested 80% of California avocado acreage (Hoddle et al. 1999) and this reached 95% by 2002 (Hoddle et al. 2002b). An economic analysis by Hoddle et al. (2003a) estimated that thrips feeding in untreated infested groves reduced industry revenues by 12% in 1998 and that short run (i.e., over the time period that the industry adapted to managing this new pest) costs were an estimated $8.65 million per year.

Given the speed with which avocado thrips spread (in part likely due to movement of contaminated picking bins containing leaves) and the type of scarring it caused on fruit, the UC Hansen Trust (July, 1997) and the California Avocado Commission (CAC) (Nov., 1997) quickly funded a team of researchers (Hoddle, Morse, Phillips, and Faber) to study various aspects of avocado thrips biology, where the insect originated, whether biological control could be implemented, what pesticides were effective in chemical control, how to best monitor thrips levels, and how treatment decisions should be made. In addition, PCAs were a critical link to learning how to deal with this new pest, as were many growers who allowed research trials to be conducted in their avocado groves. Steve Peirce (CAC Field Coordinator) was instrumental to the avocado thrips project in coordinating research done at UC Riverside by Hoddle and Morse with that done by UC Cooperative Extension in Ventura County by Phillips, Faber, John Rogers, and SRAs Lynn Wunderlich, Wee Yee, and Eve Oevering, who were hired (sequentially) to work on the project; in helping to arrange field study sites; and in disseminating information about avocado thrips research to growers and PCAs. A second pivotal decision the CAC made was to invite Laurence Mound, a world-renowned authority on thrips identification, biology, and ecology to visit southern California in June 1997, tour field sites infested with avocado thrips, and give us his views on the situation. We clearly remember sitting down with Mound on June 23, his looking at slide mounted thrips specimens Hoddle had prepared, and telling us only five minutes later that this thrips likely originated from Mexico and/or Central America based on specimens he had viewed in past years. This helped set the stage for foreign exploration to determine the likely area of origin of avocado thrips and the potential for classical biological control (i.e., returning to the area of origin to search for natural enemies that co-evolved over millennia with the introduced pest species). Mound was especially critical of tree management in California, and made it clear in meetings where he was presenting his assessment of the avocado thrips mology Laboratory, Beltsville, MD) gave this insect a name, calling it avocado thrips, *Scirtothrips perseae* (Nakahara 1997).

Figure 1: (A) Adult avocado thrips and (B) fruit showing evidence of scarring from avocado thrips feeding damage (Photo Credit: Regents, University of California).

It is interesting that prior to avocado thrips showing up in California in 1996, we don't believe there is any published report of its presence or the damage it causes elsewhere in the world. This lack of information is surprising, as avocado thrips feeding damage is readily observable on young fruit at certain times of the year in areas where this pest is native. This feeding damage by avocado thrips may have been confused with something else, perhaps wind scarring, bacterial/fungal diseases affecting the skin of these fruit, or even feeding damage from other species of thrips known to be present in avocado orchards (e.g., *Frankliniella* spp.). Interestingly, after *S. perseae* was described, reports from Mexico were published that this thrips was present and causing damage to Hass fruit (González Hernández et al. 2000). This entrance into the literature is curious given Mexico is the world's largest producer and exporter of Hass avocados and this pest was apparently unknown until after its discovery in California. Consequently, we think it is very likely there are additional pest species attacking avocados in Mexico that await discovery, but whose identity and presence in Mexico are poorly documented, if at all, which could be unintentionally moved into new areas.

By July of 1997, avocado thrips had spread north to San Luis Obispo County and south to San Diego County (Hoddle et al. 2002b). Heavily infested groves in Ventura County showed 50-80% crop damage in 1997 (Hoddle & Morse 1997, 1998). By May 1998, avocado situation, that the vast majority of avocado trees in commercial orchards were simply too tall. He viewed this size problem as greatly hampering pest monitoring, pesticide applications, and fruit harvesting, especially on steep hillsides in San Diego County.

Area of Origin and Prospects for Classical Biological Control

As noted above, when initially discovered in California, *S. perseae* was an undescribed species that was new to science, and its country of origin was unknown. The California avocado industry has a long history of relying on biological control as a cornerstone for pest management (Fleschner 1954, Fleschner et al. 1955, McMurtry 1992, Hoddle et al. 2003b) before the arrival of avocado thrips. Consequently, concern over crop damage caused by *S. perseae* prompted funding of a "classical" biological control program by the California Avocado Commission. Because *S. perseae* was an unknown entity when discovered in California, the first step in this biological control initiative was to locate and delineate the home range of *S. perseae* and to simultaneously prospect for natural enemies associated with this pest. Knowing where *S. perseae* originated was also critical for determining potential invasion pathways into California.

Five principal reasons justified initial exploration for *S. perseae* in Mexico and Central America: 1) *Scirtothrips perseae* is morphologically more similar to other thrips in this genus from Mexico and Central America than North America and other areas of the world (Nakahara 1997); 2) In 1971, two undescribed specimens of *Scirtothrips* were found on leaves of avocado plants intercepted from Oaxaca, Mexico by APHIS-PPQ at the Port of San Diego, California. One damaged specimen examined was thought to vary slightly from *S. perseae*, but subsequent reexamination by S. Nakahara indicated that it was within the acceptable range of morphological variation for this species. Later, a second thrips specimen from the same interception was located, and both specimens are now considered to be the first known record of *S. perseae*; 3) Host plant surveys in California avocado orchards have found immature stages of *S. perseae* feeding only on avocados and this was the only *Scirtothrips* species causing economic damage to avocados; 4) In California, *S. perseae* outbreaks occur during cool spring weather when avocados are developing young leaves and fruit. Immature leaves and fruit are used for feeding and oviposition by *S. perseae* and population outbreaks are closely tion of thrips natural enemies for use in a "classical" biological control program in California against *S. perseae* were not pursued as it seemed unlikely that successful suppression of *S. perseae* could be achieved with any of these generalist species. Furthermore, several species were already present in California and known to attack *S. perseae* (e.g., *Franklinothrips*) (Hoddle et al 2002a).

In addition to delineating the geographic distribution of *S. perseae* and collecting natural enemies, foreign exploration allowed the compilation of a list of other phytophagous thrips species associated with avocados that are unknown in California and which could be serious avocado pests should they become established. One species, *Neohydatothrips burungae*, was as common as *S. perseae* on avocados in Mexico and was not known to be present in California when these surveys were originally done. Given the common occurrence of *S. perseae* on avocados in Mexico and its pestiferous nature in California, *N. burungae* was considered an invasive threat to California grown avocados (Hoddle et al. 2002b). Interestingly, this prediction was realized in 2004, when sampling efforts in San Diego County for another invasive avocado pest, the avocado lace bug (*Pseudacysta perseae* [Hemiptera: Tingidae]), resulted in the first collection of *N. burungae* in California (Hoddle 2004). Fortunately, this pest has not become problematic on avocados in California and in fact, appears to be present only on backyard trees near the coast in San Diego Co.

Two other pest thrips species were found during foreign exploration efforts for *S. perseae* that are considered highly dangerous to California's avocados; these are *Pseudophilothrips perseae* (formerly known as *Liothrips perseae*) in Guatemala and *P. avocadis* (formerly *L. avocadis*) in Costa Rica. These phlaeothripids are particularly damaging when they form breeding aggregations (dense adult populations) on small to medium sized Hass fruit. The large red larvae (Fig 2A) and black adults (Fig 2B) feed on the fruit surface and cause significant pit-like scarring. Beige-colored eggs are deposited in depressions on the fruit surface, and all life stages (even eggs) are easily visible with the naked eye or a low powered hand lens. The naturally rough surface of Hass fruit is probably highly desirable for these thrips as the "nooks and crannies" provide excellent feeding and hiding places for adults and larvae, as well as protection for eggs (in comparison, avocado thrips uses its ovipositor to insert eggs into plant tissue so they are not exposed). Another sobering thought synchronized with plant phenology induced by cool weather (Hoddle 2002a). Furthermore, laboratory generated demographic growth statistics are highest for *S. perseae* reared on avocado leaves at low temperatures (≤ 20°C), suggesting that this pest likely evolved closely with avocado to exploit nutritive and oviposition resources induced by low temperatures (Hoddle 2002b); 5) Three geographic races of avocados are recognized; *Persea americana* var. *drymifolia* (Mexican race), *P. americana* var. *guatemalensis* (Guatemalan race), and *P. americana* var. *americana* (West Indian race). The Mexican and Guatemalan races evolved in high altitude regions of central Mexico and Guatemala, respectively. West Indian varieties are thought to have developed in humid lowland Pacific Ocean areas from Guatemala through Costa Rica. Humans transported avocados from these areas of origin, probably as seeds, into other areas of the Americas, and elsewhere.

Laboratory and field studies in California indicated that *S. perseae* appears closely adapted to avocado phenology. Host plant surveys showed a highly restricted host range (i.e., as far as we know, avocado thrips can complete their entire life cycle only on avocado) suggesting this pest may have evolved with *P. americana* somewhere in the natural range of this plant.

Foreign exploration for *S. perseae* and other species of thrips was conducted in Mexico by Hoddle et al. (various regions sampled over 1997 – 2000), Guatemala (1998), Costa Rica (1999), the Dominican Republic (2000), Trinidad (2000), and Brazil (2000). A total of 2,136 phytophagous (plant-feeding) thrips specimens were collected and identified, representing over 47 identified species from at least 19 genera. Foreign exploration efforts indicated that *S. perseae* occurred on avocados grown at high altitudes (>1500 m) from Uruapan in Mexico south to areas around Guatemala City in Guatemala. In Costa Rica, *S. perseae* is replaced by *S. astrictus* as the dominant plant feeding thrips on avocados grown at high altitudes (>1300 m). No species of *Scirtothrips* were found on avocados in the Dominican Republic, Trinidad, or Brazil. Of collected material, ~4% were potential thrips biological control agents. Natural enemies were dominated by six genera of predatory thrips (*Aeolothrips*, *Aleurodothrips*, *Franklinothrips*, *Leptothrips*, *Scolothrips*, and *Karnyothrips*). One genus each of a parasitoid (*Ceranisus*) and predatory mite (*Balaustium*) were found. All of these natural enemies, including the parasitoid, are generalists. Consequently, prospects for the importafor the casual U.S. tourist. One possibility is that an avocado enthusiast who visited the breeding station in Coatepec-Harinas was impressed with some new avocado cultivar and illegally moved plant material from this region to California that was infested with *S. perseae* (Hoddle 2004). Additionally, the genetic studies revealed another interesting piece of information; the invading population went through a severe breeding bottleneck indicating that the number of thrips on host plant material entering California was small (Rugman-Jones et al. 2007).

Understanding Avocado Thrips Basic Biology and its Application to Field Situations

Avocado thrips has a life cycle typical of all thrips in the Suborder Terebrantia; females use their ovipositor to lay eggs individually inside suitable plant material, and for avocado thrips, young leaves and small fruit are highly preferred oviposition substrates. Following egg hatch, there are two larval instars, the first and second, that are mobile and whose feeding activities cause economic damage to fruit (such feeding can also result in significant scarring to the undersides of leaves). Following the larval stage, there are two non-feeding and non-motile stages, the propupa and pupa. It is during these two "pupal" stages that larvae undergo metamorphosis into the winged adult form (Fig. 3). When ready to pupate, second instar larvae enter a walking phase and they will often look for pupation sites in cracks and crevices in twigs or bark, and sometimes pupation may occur inside the webbed nests of persea mite, another invasive avocado pest. Avocado thrips is a sexually reproducing species, and fertilized eggs produce female thrips, whereas unfertilized eggs result in males. Full details on

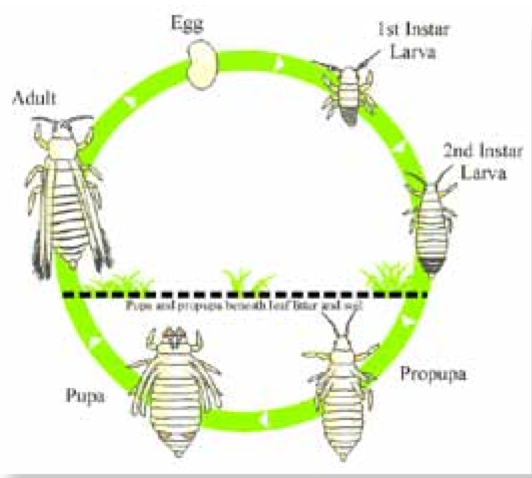

Figure 3: Life cycle of the avocado thrips. At temperatures over 68-77°F (20-25°C), approximately 27% of the life cycle (i.e., the larval stages) exhibit an exposed life style (i.e., on leaves and fruit feeding) making them vulnerable to pesticide applications (Hoddle 2002b).

is the large number of thrips that were collected and identified to species, for which we have absolutely no biological or ecological information (especially *Frankliniella* species). It is possible that some of these species may be serious pests in their home countries, but because they have not been studied, we are ignorant of their invasion potential and the threat they may or may not pose to California avocado growers

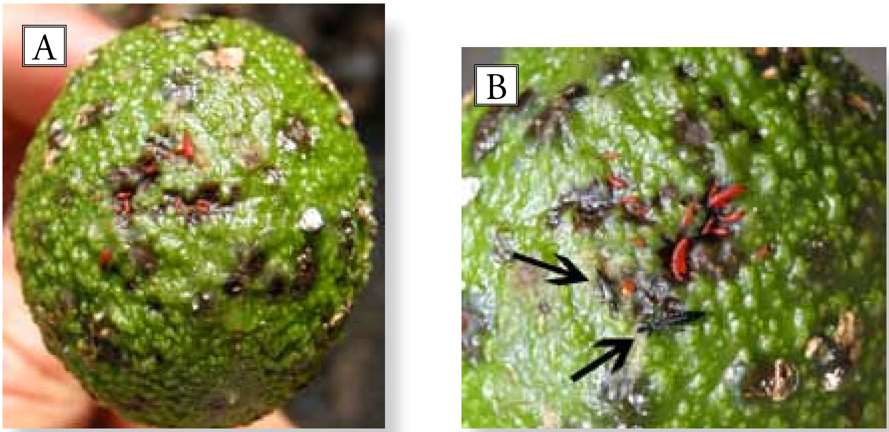

Figure 2: (A) A heavily damaged immature Hass fruit in Guatemala showing deep scarring from feeding by larval (red colored insects) and (B) adult female and male Pseudophilothrips perseae (black thrips, the larger individual [black arrow] is the female).

Because foreign exploration efforts identified the home range of *S. perseae* as being central Mexico through to central Guatemala, other questions demanded answers: (1) where in this vast area did California's invading population originate, and (2) how did this founding population come to California? To answer these questions, molecular studies were undertaken. The goal was to use "genetic fingerprinting" to compare the genetic constitution of the California population to collections of *S. perseae* made from various areas in Mexico and Guatemala with the aim of identifying a region that may have been the probable area from which California's population originated (Rugman-Jones et al. 2007).

The DNA analyses revealed that *S. perseae* in California was most closely related to populations in central Mexico, and Coatepec-Harinas, Mexico, was the most likely source of the California population (Rugman-Jones et al 2007). This finding was significant because Coatepec-Harinas is a major avocado breeding center in Mexico and given its significant distance from California (it is ~150 miles southwest of Mexico City and ~1,800 miles from Riverside), it is not a popular destination the developmental and reproductive biology of avocado thrips across five different temperatures are available (Hoddle 2002a).

Combined field and laboratory studies have indicated that approximately 77% of *S. perseae* larvae drop from avocado trees to pupate in the upper 2" of leaf duff beneath the tree canopy before emerging as winged adults that fly back up into the canopy to commence feeding and reproduction. One strategy for increasing thrips pupation mortality rates beneath trees that was investigated was the use of composted organic yard waste used for avocado root rot (*Phytophthora cinnamomi*) control (Hoddle et al. 1999, 2002a). Data from replicated field trials indicated that coarse, composted mulch placed around trees and over existing leaf mulch to a depth of ~ 12 inches, and spread to the edge of the canopy, reduced peak emergence rates of adult *S. perseae* by approximately 50% in comparison to emergence rates from naturally occurring leaf duff under avocado trees that lacked mulch. Additionally, the cumulative emergence of adult thrips from mulched plots was significantly lower than under non-mulched trees. The exact mechanism causing reduced adult thrips emergence from mulch is unknown but may be due to antagonistic micro-arthropods associated with the mulch (especially generalist predators like small mites, Collembola, beetles, and spiders that colonize the mulch and opportunistically prey on thrips larvae and pupae when they find them) (Yee et al. 2001e, Hoddle et al. 2002a), release of secondary plant compounds from decaying yard waste, or a more favorable habitat for entomopathogens (i.e., pathogens causing disease in insects) such as fungi (e.g., *Beauveria* spp.) or nematodes (e.g., *Steinermema* spp.) that were recovered from the mulch. In addition to the potential for avocado thrips suppression, mulches offer other benefits including improved water retention, soil quality, weed suppression, and reduced erosion and aeration needed for root respiration (Hoddle et al. 1999, Hoddle et al. 2002a).

Numerous field surveys have clearly indicated that young fruit are vulnerable to avocado thrips feeding damage. As young foliage from the spring growth hardens in late May and early June during or after fruit set, adult female avocado thrips move from foliage to oviposit into young fruit. It is the feeding by emerged larvae that results in damage to the skin of developing fruit. Laboratory observation of field-collected fruit indicated that females lay eggs in fruit ranging from 0.16 - 3.0" in length. The majority of larvae (> 95%) emerged from fruit 0.6 - 2.5" in

2001e) to respond in a timely manner to prevent the pest from causing economic damage. Augmentative biological control has been used most successfully in protected agriculture, especially greenhouses; success rates on outdoor crops is modest as (an exception is augmentative releases of *Aphytis melinus* for California red scale control on citrus in the San Joaquin Valley of California).

Research efforts on augmentative biological control of avocado thrips focused on two natural enemy species: (1) commercially available green lacewings (*Chrysoperla carnea* [Neuroptera: Chrysopidae]), and (2) a native natural enemy, the predatory thrips *Franklinothrips orizabensis* (Thysanoptera: Aeolothripidae), which was observed to respond to *S. perseae* outbreaks in avocado orchards. Before augmentative releases of *F. orizabensis* could be evaluated, significant obstacles in our understanding of the developmental and reproductive biology, diet requirements, predation behavior, and pupation biology of this natural enemy had to be overcome if it was to be mass reared (Hoddle 2003b, c, Hoddle et al. 2001a, b). Jake Blehm of Buena-Biosystems in Ventura undertook the mass rearing program for this natural enemy once UC Riverside researchers had figured out the rearing and harvesting system. The mass rearing turned out to be quite simple; irradiated *Ephestia* eggs (food) sprinkled on top of potted bean plants (oviposition substrate for the predator) resulted in the reliable production of large numbers of *F. orizabensis* and predators were harvested as pupae inside small plastic tubes. The plastic tubes were placed on the floor of the rearing cages and larvae would enter and spin their pupal cocoons inside these tubes. Empty tubes were separated from tubes with pupae using a venturi-airstream separation principle – an airstream delivered by an aquarium pump caused tubes with pupae to fly further than empty tubes when they entered the airstream and were collected in containers at distances greater than where empty tubes landed. Despite promising laboratory results, augmentative releases of *F. orizabensis* replicated across different field sites were unable to significantly reduce *S. perseae* densitities in comparison to control sites not receiving predators (Hoddle et al. 2004).

Green lacewings are commercially available as eggs (either loose or attached to cards which are hung in trees) or larvae, which are packaged in ventilated hex-cell units to prevent cannibalism. Hex-cell units are opened in the field, attached to branches, and larvae are left to disperse naturally. Lacewing larvae are extremely aggressive predators and length. Once fruit exceed 2” in length, avocado thrips are found primarily on young leaves (Hoddle 2002b). These observations strongly suggest that fruit < 2” in length are quite vulnerable to attack by avocado thrips. This relationship between fruit size and attack by avocado thrips was investigated in commercial avocado orchards by Wee Yee in Ventura who was working with Phil Phillips and Ben Faber (Yee et al. 2001d).

Field biology studies conducted over three years at three sites with different temperatures in Ventura and Santa Barbara counties indicated that fruit may be most susceptible to damage over a two-week growing period just after fruit set, when fruit are 0.2 - 0.6” in length (Yee et al. 2001d). These studies also indicated that when approximately 3-5 thrips were consistently found per leaf during fruit set, feeding caused 6-15% economic scarring damage on fruit. Furthermore, young fruit 0.5” long or less infested with an average of 0.5-1.5 larvae per fruit in May and June resulted in 22-51% economic scarring. Over all years and sites, thrips were generally more abundant on young leaves than on fruit from early to mid June when fruit were setting. When leaves aged and hardened from late June through August (depending on region), equal or higher numbers of thrips were generally found on fruit, although overall numbers of thrips declined during this period with increasing summer temperatures (Yee et al. 2003). These results suggest that thrips numbers on leaves prior to or during fruit set may be used to predict scarring damage on fruit, and that the economic injury level may be less than 5 larvae/leaf during this time (Yee et al. 2001d). However as noted below (see the section “Making avocado thrips treatment decisions”), this relationship may not always be clear-cut and other factors may strongly influence treatment decisions

Evaluation of Augmentative Releases of Commercially Reared Biological Control Agents

As management plans were being developed for avocado thrips, the potential for augmentative releases of natural enemies was of great interest to growers and PCAs. Augmentative biological control is a simple concept, i.e., it is the release of mass reared, commercially available natural enemy species to augment or boost naturally-occurring populations of biological control agents. These supplemental releases may be desirable at critical times because the population density of the resident natural enemy fauna on leaves, fruit, and leaf litter are too low (Yee et al.

they have a very broad diet, consuming most soft bodied arthropods (i.e., insects and mites, and each other) that are smaller than the larva in size. To evaluate the efficacy of green lacewings for control of avocado thrips in commercial Hass orchards, two different field trials were run by two different research teams, in different years, and locations. Releases of lacewing larvae were evaluated by Silvers and Morse (UCR) in Fallbrook in 1999, and releases using lacewing eggs were evaluated by Hoddle and Robinson (UCR) in San Diego and Orange Counties in 2003.

Work by Silvers and Morse (Silvers 2000) clearly demonstrated that lacewing larvae provided no appreciable control of avocado thrips when compared to control plots not receiving predators. When this news was shared with the avocado community, several insectaries immediately challenged the results, declaring that the release program didn't accurately follow successful release strategies developed by PCAs. Their view was that most often, lacewing eggs, not larvae, were deployed in orchards because they are cheaper and larger numbers could be dispersed across trees needing treatment, thereby giving much better coverage which ultimately resulted in pest control. Additionally, Silvers' work was criticized by PCAs because release timings, release rates, and tree size (Silvers used top-worked Hass trees which had a lot of flush), differed from conditions under which PCAs reported control with augmentative releases of lacewings.

To address these criticisms, a meeting organized by Steve Peirce was held in the Old Entomology Building at UCR, which was attended by Insectary representatives, PCAs, and UCR researchers. It was decided that lacewing releases for avocado thrips control should be evaluated according to industry practices and two PCAs offered to assist with this. Consequently, with funding from the CAC, field evaluations of lacewing releases made by PCAs, deployed either as eggs on release cards, or as loose eggs (at 75% egg hatch) mixed with corn grits and sprayed onto trees with a motorized sprayer were evaluated by UCR researchers. Lacewing eggs were deployed by PCAs using these methods 7 to 8 times over a four-month period. Eggs on paper cards were deployed at a rate of 16,592 eggs per acre, while sprays of ~75% hatched lacewing eggs were around 208,216 eggs per acre. Avocado thrips in blocks treated with lacewing eggs were monitored every two weeks and densities were compared over the same time intervals to paired control blocks not receiving lacewing treatments. The results at the end of the trial were convincing start to harden off or when new set fruit come in contact with heavily infested young leaves (Yee et al. 2003). This has the effect of concentrating female oviposition and feeding by the immature stages on young fruit and amplifies the risk of economic fruit damage if young leaves are not available when susceptible young fruit are present. Consequently, we are most concerned about fruit scarring by immature and adult avocado thrips, but the second instar avocado thrips, because they are larger and feed more than first instars, will cause more damage than first instars. Female avocado thrips are thought to move a lot as they look for suitable young leaves or fruit to lay eggs in and thus, are less likely to concentrate their feeding damage at particular locations on fruit.

Several factors can affect potential fruit scarring (i.e., in the absence of sprays) in a particular year. (1) For example, the phenology of leafing patterns (timing of flushes in relation to thrips levels) is one important factor. If a heavy leaf flush and suitable weather are present prior to fruit set, then thrips levels are likely to build up on the leaf flush and immature thrips will begin feeding on the fruit as the leaves harden. If a large thrips population builds up prior to fruit set and the set is light, then a relatively large population of thrips will concentrate their feeding on fewer fruit. This can lead to brown patches of heavy scarring on the fruit and because thrips cannot feed effectively on the scarred portion of the fruit, they move to feed on other portions of the fruit leading to more and more scarring over time. In the extreme case, we have seen 100% of the surface of every fruit scarred by avocado thrips on a tree. (2) A related factor is temperature. Fruit scarring can be especially problematic if weather conditions remain ideal for thrips development as the fruit mature (i.e. below 90°F with relatively high humidity) and if natural enemy levels are low and don't help slow the growth of the thrips population. In most years, avocados grown in hotter areas distant from the coast (e.g., Riverside County and Valley Center in the "south" or in the Fillmore and Ojai areas in the "north") are less likely to suffer high levels of avocado thrips damage than areas nearer the coast where hot weather present at some time after fruit set normally leads to relatively lower thrips levels and potential for scarring. However, one can sometimes run into the unusual year when conditions prior to and just after fruit set are moderate in these interior regions and higher than normal thrips scarring in these interior groves occurs. The spring of 2004 was one such year in the Temecula region. In this region, PCAs have noticed and identical across sites and release strategies. There were no significant differences in avocado thrips populations (larvae or adults) when augmentative releases of lacewing eggs were made in commercial Hass avocado orchards using PCA release rates, methods, and timings, when compared to blocks that were not treated with lacewing eggs (Hoddle & Robinson 2004). Despite the results of this research, several PCAs believe that green lacewings contribute in a substantial way to avocado thrips biological control.

From these studies it was concluded that augmentative releases of lacewings as either larvae (Silvers 2000) or eggs (deployed in two different ways; Hoddle & Robinson 2004) failed to provide a significant reduction in densities of avocado thrips larvae or adults when population densities were compared through time to control blocks not receiving augmentative predator releases. Consequently, augmentative releases of lacewings cannot be recommended for biological control of avocado thrips in California.

Making Avocado Thrips Treatment Decisions

As noted above, avocado thrips prefers to feed on young leaves and fruit. To some degree, varying with life stage, avocado thrips has difficulty feeding on older, tougher leaves or large fruit. Adult avocado thrips can survive by feeding on older leaf tissue if that is all that is available; but, immature thrips, especially first instars, suffer progressively higher mortality when confined to increasingly older leaves, likely in part because they have difficulty feeding on such leaves and obtaining sufficient nutrition. When laying eggs, adult female thrips search for younger leaves or fruit wherein to lay their eggs. Immature thrips can move some distance if placed on suboptimal plant tissue, but the female ensures high survivorship of her offspring if she lays eggs in the type of leaf or fruit tissue that will optimize survival after her eggs hatch. Thus, adult female avocado thrips have evolved to do just this, and are very good at finding the right stage leaves and fruit to lay their eggs in.

The pattern of leaf flushes and fruit set on avocados varies from year to year and is influenced by weather conditions, tree health, irrigation, fertilizer applications, and to a good extent on when the previous year's crop is harvested, either sequentially or all at once (Strand et al. 2008). Avocado thrips populations typically build up on leaf flushes that occur prior to or during fruit set and will move to young fruit if leaves populations later build to higher levels than expected and suggest a treatment is warranted? If thrips buildup is slow prior to fruit set and natural enemy levels are high, then relatively little fruit scarring may result. Weekly surveys of avocado thrips populations in three avocado orchards in two distinct climate zones in southern California over 1998 - 2000 indicated that mean weekly temperatures over a 24-32 week period that averaged ≈59°F (range 47.7-77.0°F) were significantly correlated with population increases of this pest. Conversely, population declines were strongly correlated with the onset of moderately warm weather where mean weekly temperatures over a 17-21 week period averaged >68°F (range 55.0-80.7°F) (Hoddle 2003a). Avocado thrips populations appear to be quickly decimated by heat waves especially if both hot and dry conditions last for 2-3 days or longer. If heat waves (often associated with Santa Ana winds) occur early in the season prior to fruit set, thrips levels may not rebound to levels such that treatment is needed. Alternatively, hot spells may occur after fruit set, which can affect fruit retention in addition to reducing avocado thrips levels. Warm weather can also increase the rate of fruit growth, thereby reducing the window of fruit susceptibility to damage by avocado thrips. With low to moderate thrips levels, if one has unusually high levels of fruit set, then the amount of scarring on specific fruit is diluted by the number of fruit. Thrips scarred fruit tend to grow more slowly than unscarred fruit and with heavy scarring, eventual fruit size is reduced.

Human perception of damage and risk can also affect a specific grower's tolerance for avocado thrips scarring. Human nature predicts that if one had heavy thrips scarring the year before and/or the application did not go on at the optimal time, perhaps due to being caught in the spray queue, one is going to be more conservative managing avocado thrips the subsequent year or may hire a PCA to monitor more closely so as to better time treatments. Growers may use a lower threshold in deciding whether to spray or how long one is willing to wait after a major fruit set without spraying. The size of one's crop in relation to anticipated prices and/or the size of the anticipated industry-wide crop may affect the amount of thrips scarring one is willing to suffer. With a large anticipated crop and/or anticipated high prices, a grower may be less conservative in terms of spending the money needed to pay for a helicopter-applied avocado thrips treatment. A large industry-wide that in most years, one can expect thrips levels to be depressed by hot weather before significant fruit scarring occurs. However, in 2004, moderate early summer temperatures led to significant levels of fruit scarring in most groves in the Temecula region.

A general observation is that in years when avocado thrips levels are high, they are often high in many groves in a region and/or across different avocado growing areas in California. For example, when avocado thrips levels are high in the south (San Diego, Riverside, and Orange counties), they are often also high in the north (Ventura, Santa Barbara, and San Luis Obispo counties). But this observation is not uniformly applicable within a region. Even in "high thrips years", one is likely to have groves where avocado thrips treatments are not needed. The reverse is often true; i.e., even when avocado thrips pressure is generally light across the industry, one is likely to have some groves where thrips levels are high enough to justify treatment. In 2006, avocado thrips levels were relatively severe across most of the southern California avocado industry. Several factors conspired to make thrips levels severe that year: (1) 2005 was a relatively light year and thus, some in the industry were not monitoring avocado thrips closely in 2006; (2) thrips levels built explosively prior to a major fruit set so that many PCAs and growers were caught by surprise; and (3) spray queues for aerial pesticide applications, especially in the southern region, were long and by the time many growers were able to have their grove sprayed by helicopter, significant levels of fruit scarring had already occurred. The end result was a severe avocado thrips year for most of the industry. Guy Witney (former Director of Industry Affairs for the CAC) estimated that "… 2006 estimates of direct losses from thrips damage to fruit and control costs combined exceeding $50 million" (Witney 2009).

In contrast, a variety of conditions can interact to lead to relatively "light thrips years" with respect to the potential for fruit scarring. Thus, some years a thrips treatment is not justified, as the cost of treatment (both the chemical and application costs) exceeds the reduction in revenues resulting from the thrips scarring that would result without a treatment. The difficulty here is, does one understand this pattern to a sufficient degree, to predict in advance what is going to happen? Second, is the grower and/or PCA risk averse and if a decision is made to withhold treatment, will one be able to get into the spray queue in order to make a timely treatment if thrips et al. 1986, Wiesenborn & Morse 1986, 1987, Morse 1995). Under funding from the Citrus Research Board, Morse had run screening trials to evaluate the efficacy of various products against citrus thrips since 1982 and he quickly adapted methods and experience with citrus thrips to the avocado thrips screening program. Similarly, Phil Phillips and PCAs who worked on both citrus and avocados had field experience with citrus thrips and adapted what they knew to working on avocado thrips as it became problematic in Ventura County. Veratran D had been used on citrus against citrus thrips since 1948 (Morse & Brawner 1986) and Phillips arranged for a 24c Special Local Needs Exemption that was obtained in February 1997, allowing its use against avocado thrips during the spring of 1997, with full registration obtained in time for use in the 1998 season.

Several field trials were run to evaluate other pesticides used against citrus thrips on citrus for control of avocado thrips and one material that looked quite strong in these trials was abamectin. Steve Peirce worked with Morse to develop a request to EPA for a Section 18 Emergency Exemption allowing use of abamectin using either ground or air application. The first abamectin Section 18 was approved in September 1998, allowing applications as of 1 February 1999. Each fall, we updated and revised the Section 18 request resulting in 6 springs in a row, 1999-2004, over which abamectin use was allowed until it was finally registered in time for the 2005 season on 2 March 2005. Renewal of the Section 18 request became more difficult over 2002-2004 because such Exemptions are normally awarded for only three years. This culminated with extreme difficulty in renewal during late 2003 (the initial submission was rejected) as documented by Witney (2004) and an economic analysis was required (as described by Jetter & Morse 2004) before the Section 18 was granted in time for the 2004 season.

Success (spinosad) had been the major pesticide used for control of citrus thrips on citrus in the San Joaquin Valley starting in 1998 when it was first registered for that crop. On citrus, small fruit normally need to be protected from citrus thrips scarring for approximately 6-8 weeks after fruit set (longer on mandarins) and more so than with avocados, fruit set normally occurs over a short period of time (typically over 2-3 weeks). Under these circumstances, Success is quite effective against citrus thrips and was the main product used on citrus for this purpose from 1998-2006 (Delegate registered in 2007). In contrast, fruit set on avocacrop may suggest that packinghouses will have a lower threshold for the amount of avocado thrips scarring that will lead to fruit being downgraded from first to second grade and culls.

In addition to all the above, it is difficult to anticipate how many fruit will set over time during a particular spring, and which fruit will actually remain on the tree. Weather (especially cold or hot spells and/or wind conditions) and a number of other factors such as pollination, fertilization, and tree health affect to what degree various major fruit sets result in fruit that will survive to harvest. If one applies an avocado thrips treatment too early, thrips levels may resurge 8-12 weeks later affecting a later fruit set. If one holds off treatment from a current fruit set, a number of those fruit may be scarred and remain on the tree, leading to more fruit scarring in total at harvest than is desirable. In summarizing all of the above factors that contribute to making decisions on whether or not to treat a particular grove for avocado thrips management, how to treat it, and when to time that treatment, one is faced with a complex set of decisions. We have tried to outline some of the general principles above. This is complicated enough that we cannot provide a simple formula saying when or whether an avocado thrips treatment should be applied. In some cases, growers know enough about their crop and grove, avocado thrips and natural enemy biology and phenology, and the various available treatment options so that they can make well-informed decisions. More often, we believe it would be sensible to employ an independent PCA who has substantial experience understanding the complex interactions between tree health, avocado fruit set, pest population dynamics, levels of important natural enemy species and thrips that are present, and what the various control options are (Hoddle & Morse 2003).

Chemical Control of Avocado Thrips

At the same time as research was being conducted on avocado thrips basic biology, its area of origin, and prospects for biological control (always the first choice if effective natural enemies can be identified), research on chemical control was in progress. Although avocado thrips was new to science, we were extremely fortunate that its basic biology, the type of damage it causes, and its sensitivity to various insecticides turned out to be similar to citrus thrips (same genus as avocado thrips, but a different species), an insect that had previously been studied on citrus for many years (Morse et al. 1986, Morse & Brawner 1986, Rhodes application and for suppressing low to moderate thrips populations during warm weather when the thrips will actively feed on this stomach poison before it degrades (i.e. it has little contact activity and is not translaminar or systemic). It also is a material that can be used after an avocado thrips "failure" with an alternative product, i.e. several materials are most effective when used prior to substantial levels of immature avocado thrips being present whereas Veratran D is a moderately effective "corrective" material. Although Entrust's efficacy is not high, it is one of the few options available for avocado thrips control in organic groves.

The remaining four products listed for avocado thrips control, abamectin, spinetoram (Delegate), fenpropathrin (Danitol), and spirotetramat (Movento) are quite effective and persistent in their impacts on avocado thrips based on field trials run over the last several years (Morse, unpublished data). We suggest that growers and PCAs start as soon as possible using the three alternatives to abamectin so that they can learn their strengths and weaknesses, and to help lessen the risk of resistance developing to abamectin. Based on experience with citrus thrips on citrus (Immaraju et al. 1990, Khan & Morse 1998), we strongly suggest that Danitol be used no more often than once every three years to reduce the potential for avocado thrips and/or persea mite resistance (it is effective against both pests). We still have a good deal to learn about how to best use Movento on avocados. This product is unusual in that it is highly systemic in the tree. It is even slower in its impact against avocado thrips than is abamectin but this impact is also quite persistent. Movento acts as a lipid (fat) biosynthesis inhibitor, especially targeting immature stages, and may have limited impact on adult avocado thrips (more work on this subject is needed).

Pesticide Resistance Management

Although the subject of this article is avocado thrips, in Table 1 we also list various products that might be used for persea mite control. This is because abamectin is also very effective against persea mite and in the past, it has sometimes been used twice a year – in the spring for avocado thrips control and then again in the summer or fall against persea mite. If using something other than abamectin for avocado thrips control but then using abamectin for persea mite control, one is still subjecting avocado thrips to abamectin selection pressure. Humeres & Morse (2005) documented that 7 treatments of abamectin used over 4 dos typically occurs over a longer period of time and a single application of Success usually does not provide sufficiently persistent control of avocado thrips to provide adequate control. Table 1 lists the chemicals that are currently registered for use against avocado thrips and persea mite (Fig. 4A and 4B) or are nearing registration (Zeal was very recently registered; FujiMite will likely not be registered until late 2012). Note that we list only materials that we believe have a significant role in avocado pesticide resistance management (see that topic below). Because Success is in the same class of chemistry as Delegate and the latter is much more effective against avocado thrips, especially using air application, we do not list Success in this table. Entrust (the same active ingredient as Success) is listed because it is one of the few options (other than organic narrow range oil) that is available for use in organic groves.

Fig. 4: (A). Persea mites in a nest on the underside of an avocado leaf, and (B) persea mite damaged leaves showing characteristic circular necrotic spots that result from feeding colonies (Photo Credit: Regents, University of California)..

Abamectin, spinosad (Entrust, Success), and spinetoram (Delegate) are translaminar materials meaning that they move at most several cell layers deep into leaves and fruit; however they are not systemic, i.e. they do not move far or throughout the plant. Use of a small amount of oil (1-4%) or recommended rates of a surfactant should be used to assist in translaminar movement as surface residues are degraded rapidly by sunlight (quickly but not as fast with Delegate). The persistent impact of all three of these pesticides is due to thrips feeding on leaves and fruit and thus, being exposed to translaminar residues of these products that are inside the plant part being fed upon.

Each of the products listed for avocado thrips control in Table 1 has its strengths and weaknesses (see also Phillips et al. 2007). In comparison to other avocado thrips products, Veratran D and Entrust are not highly effective and their impact on thrips populations is not very persistent (Hare & Morse 1997). Veratran D is best suited for ground

Table 1. Pesticides registered or nearing registration on avocados useful in control of avocado thrips and/or persea mite that can be used in a proactive resistance management approach. Products under each pest are listed in the order they were registered on California avocados. This table is only for reference; make sure to **check a current label** to ensure that any planned application is consistent with a current label (e.g., language on different abamectin labels may vary; labels evolve over time). Note that **FujiMite** is **not yet labeled** for use on CA avocados. This table is based on the situation as of 6-17-12. Consult http://www.ipm.ucdavis.edu/ for Avocado Pest Management Guidelines kept current on the Statewide IPM Program website.

Trade name (formulation)	Common name	Class of chemistry	Mode of action[a]	REI (hrs)[b]	PHI (days)	Air application language	Japanese MRL vs. U.S. tolerance	Notes
Avocado thrips materials								
Veratran D (0.2% ai sabadilla alkaloids)	sabadilla	Botanicals	--	24	When dry[b]	10-15 lbs/a in 10-40 gpa	Not in FAS online MRL database	Screen must be mesh size 20 or larger to prevent plugging. It is critical one acidify water in the spray tank to a pH of 4.5 before adding this product so as to improve residual persistence (use citrus acid adjuvant or approved acidifying agents). Use care in adding nutritionals or other additives.[c]
Epi-Mek & generics (several)	abamectin	Avermectins, milbemycins	6	12	14	10-20 fl oz/a of 0.15 EC in min 40 gpa	0.02 (same U.S.)	Translaminar, add oil (1% or more) to aid leaf penetration and persistence. To avoid resistance, suggest no more than one treatment per year of any abamectin product. Activity against avocado thrips is relatively slow but persistent.
Entrust (80%)	spinosad	Spinosyns	5	4	1	1.25-3 oz/a in 10 gpa or more	0.3 (same U.S.)	OMRI approved for use in organic production; translaminar, add [organic] oil (1% or more) to aid leaf penetration and persistence.
Delegate WG (80%)	spinetoram	Spinosyns	5	4	1	4-7 oz/a in 10 gpa or more	Default 0.01; expect 0.3 (U.S.) mid 2013[d]	Translaminar, add oil (1% or ore) to aid leaf penetration and persistence. Do not allow the spray solution to fall below a pH of 6.
Danitol (2.4 lbs ai/gal)[e]	fenpropathrin	Pyrethroids	3A	7 days[b]	1	16-21.3 fl oz/a in 50-100 gpa	2.0 (U.S. 1.0)	Contact material (not translaminar or systemic). Know of no evidence oil improves efficacy of fenpropathrin itself.
Movento (2 lbs ai/gal)	spirotetramat	Inhibitors of acetyl CoA carboxylase	23	1	1	8-10 fl oz/a in 10 gpa or more	0.6 (same as U.S.) expected ca.10-12	Highly systemic; add oil (1% or more) to improve leaf penetration; surface residue are NOT active. Activity against avocado thrips is relatively slow but persistent.

Correction: Zeal has translaminar activity and addition of oil or a surfactant [but not a sticker] will improve performance.

Correction: Envidor has no translaminar activity.

Table 1. (Cont.)

Persea mite materials								
Many oils, e.g., BFR 440, Omni 6E, Loveland Leaf Life Gavicide Green 415	Narrow-range 415 or 440 oil	Paraffinic oils (Narrow range oils) – act via smothering / barrier effects	--	See label	See label	Check the label for specifics	Not applicable	Oil is an option for persea mite control (used in some cases by ground against avocado thrips) either by ground (e.g., 100 gpa LV), application via hand-gun (100-500 gpa), or by air (100 gpa). OMRI approved oils are an organic option.
Envidor (2 lbs ai/gal)	spirodiclofen	Inhibitor of acetyl CoA carboxylase	23	12	2	18-20 fl oz/a in min 50 gpa	2.0 (U.S. 1.0)	Translaminar activity but limited evidence suggests addition of oil with ground treatments may reduce efficacy; this seems unlikely with air application given the relatively low gallonage used by air (so field experience will be needed to resolve this).
Zeal (72%)	etoxazole	Mite growth inhibitors	10B	12	1	2-3 oz/a in 20 gpa or more	Default 0.01 (U.S. 0.2)[d]	Maximum of 1 application per year. Contact material (not translaminar or systemic). Know of no evidence oil improves efficacy of etoxazole itself.
Danitol	See the entries for Danitol under avocado thrips above. We suggest limiting Danitol use to once every 3 years to reduce the potential for resistance evolution.							
FujiMite 5EC (0.4 lb ai/gal)[f]	fenpyroximate	Mitochondrial complex I electron transport inhibitors	21	12	14	2-4 pts/a in min 80 gpa	Default 0.02 (U.S. 0.2)[d]	**Not labeled yet for use on avocados.[d]** Contact material (not translaminar or systemic). Know of no evidence oil improves efficacy of fenpyroximate itself.

[a] Mode of action and class of chemistry based on IRAC (Insecticide Resistance Action Committee) classification; see http://www.irac-online.org/. See text for details on resistance management strategies.

[b] Restricted entry interval (REI) is the number of hours from treatment until the treated area can be entered without protective clothing. In some cases, the REI exceeds the PHI. The longer of the two intervals is the minimum time that must elapse before harvest.

[c] Veratran acts only as a stomach poison and must be consumed by avocado thrips to be effective. Thus, it generally works better during moderate to warm weather than during cold weather. Consider withholding nutritionals or other additives unless experience has shown they do not compromise efficacy by reducing thrips feeding. Standard practice by many is to add sugar (perhaps 5-10 lbs per acre) or unsulphonated molasses (1-2 gallons per acre) to the Veratran D tank mix. Check with the local Agricultural Commissioner's office to make sure such additives are allowed (i.e. whether a label for such additives is needed).

[d] Based on the current MRL in Japan and because that is much less than the U.S. tolerance, the label PHI does not at all ensure MRL export compliance (i.e. contact that company's sales representative for suggestions regarding a safe PHI if the fruit is likely to be exported).

[e] In order to manage both avocado thrips and persea mite resistance, we suggest that fenpropathrin be used no more than once every three years in a particular grove.

[f] NOT REGISTERED yet for use on avocados. PHI and other information are based on the label that is expected late in 2012 (November or so).

Note: Fenpyroximate was labeled for use on avocados late in 2013 under the trade name Miteus (same as Fujimite on citrus).

high cost of additional registrations, avocados are considered a "minor crop" (as is any crop grown on less than 300,000 acres) and thus, it normally falls to the national IR-4 program (Interregional Research Project No. 4 – see http://ir4.rutgers.edu/) to pay for the costs of registration. But IR-4 has a limited budget and thus, a case must be made why one registration project versus another should be undertaken. Once research studies had identified effective products, either Witney or Peirce would attend the annual IR-4 fall conference where priorities were set, pushing for work on products of value to the avocado industry. Based on this, IR-4 worked on the following registrations on avocados (year IR-4 field residue work was initiated): Danitol (2003), Zeal (2006), and FujiMite (2008). IR-4 work was planned with Envidor but the manufacturer stepped in to instead do this; it was not needed with Delegate because the label was based on data bridged from Success.

Why do we believe there is substantial risk of avocado thrips developing resistance to abamectin? In part, the strength of this product (its extreme persistence in avocado leaves) is one reason why resistance is a substantial danger (Hoddle & Morse 2003, Morse 2004, Morse & Witney 2005). As nicely stated by Clark et al. (1994) in reviewing use of the avermectins (the class of chemistry abamectin is in) in a variety of situations against a number of arthropod (insect and mite) pests "… the question is not whether resistance to abamectin will occur but is simply when and how it will occur." Consider that abamectin is the main product we have used for avocado thrips control since 1999;hence 2012 will mean 14 years of continuous use by the industry. A number of PCAs we have talked to believe that abamectin no longer controls avocado thrips and/or persea mite at certain sites as much as it used to. We also have suggestive evidence at one of our 2012 avocado thrips field sites that abamectin resistance is present. The bioassay method we have for evaluating avocado thrips resistance to abamectin is a fairly "blunt tool" and we are initiating research on molecular methods which may be more discriminating. A major reason for our concern is the observation that several different species of thrips have an unusual ability to evolve pesticide resistance (Morse & Schweizer 1996, Morse & Hoddle 2006). Morse has personally experienced 4 different "cycles" of resistance appearing in citrus thrips populations on citrus (summarized in Morse & Grafton-Cardwell 2012). These include resistance appearing against dimethoate in 1981 (Morse & Brawner 1986; heavy use started in 1969), years (4 times in the spring against avocado thrips, 3 times in the fall against persea mite) resulted in a statistically significant loss in persea mite susceptibility to this pesticide. Abamectin use was reduced at this site but had it continued, this could have resulted in both avocado thrips and persea mite developing resistance to abamectin. Because avocado thrips females are fairly mobile, resistance appearing in one locale could result in it spreading to other areas. Abamectin has been found to be effective against avocado thrips and persea mite, even when it is applied by helicopter (the most practical method on steep hillsides) and to groves with large trees and dense canopies (Yee et al. 2001a, b, c). The loss of this product to the avocado industry in California because of resistance would have a significant impact.

Avocado thrips treatments affect the degree to which persea mite populations in summer later become problematic and also can contribute to the evolution of pesticide resistance in persea mite populations. Similarly, persea mite treatments in summer and fall will affect the evolution of avocado thrips resistance. Both of these pests are present when the other is treated, even if levels are too low to be of concern. Thus, we must manage these two pests in concert. When an avocado thrips treatment is applied, realize that low levels of persea mite are present and are also being "treated" even though persea mite may not be on one's mind.

Now that we have a number of different classes of chemistry available for both avocado thrips and persea mite control, there is no reason why we should allow resistance to these products to develop. If one looks at the "Mode of action" column in Table 1 (next page), it can be seen that we will soon have 4 classes of chemistry (once FujiMite is registered) to rotate among in controlling persea mite (in addition to oil by itself which is the only effective alternative for organic groves).This encouraging number of treatment options has not occurred by chance. Well before abamectin was registered for use on avocados in California in 2005 (after 6 years of Section 18s, 1999-2004), Steve Peirce, Guy Witney, and Morse discussed the need to find alternative chemistries that could be used in rotation against both avocado thrips and persea mite. Screening trials were run and materials were identified that were both effective and to the degree possible, were of a different class of chemistry from other products. Chemical companies initially develop pesticide registrations based on the degree that various new materials will be used in large crop markets. Based on projected pesticide sales and the sional severe avocado thrips population. The argument that abamectin is much less expensive than alternatives should not be used as an excuse to overuse this product, likely making it ineffective not only in the groves where it is overused, but likely more broadly in the industry, given how mobile adult avocado thrips are.

Summary and Predictions

When avocado thrips first appeared on avocados in California, it was a species that was new to science, almost nothing was known about this insect, and large changes in how the avocado industry would deal with pest management issues were needed to address avocado thrips management as well as persea mite which had been introduced several years earlier (Hoddle et al. 2003b). Growers and PCAs went from having relatively few significant arthropod pest problems prior to 1990, to having two important pests to deal with in persea mite (arrived 1990) and avocado thrips (arrived 1996), with the latter having the potential to cause serious levels of fruit scarring resulting in increased levels of second grade and/or culled fruit. Some years, avocado thrips caused significant economic damage to the industry and there was obviously an adjustment period in the late 1990s and early 2000s as growers and PCAs became more comfortable with how to effectively monitor and manage avocado thrips populations.

In retrospect, several smart decisions resulted in the industry learning how to deal with avocado thrips relatively rapidly. (1) Both the UC Hansen Trust and CAC quickly funded research to investigate basic thrips biology, determine where the insect originated, evaluate the feasibility of either classical or augmentative biological control, determine how to best monitor and make treatment decisions, and if treatments were warranted, how to apply effective treatments given the challenging logistics of a large percentage of avocado acreage being on hillsides where speed-sprayer or ground, hand-gun, spray applications were problematic. (2) World-renowned thrips expert Laurence Mound was invited to California to contribute his expertise in analyzing the situation. (3) The industry had an experienced and very competent Research Coordinator in Steve Peirce who convinced researchers to work together in a focused approach in dealing with avocado thrips and assisted greatly with field logistics and in convincing the IR-4 program to prioritize products needed on avocados for registration. (4) A number of very talented PCAs

Carzol in 1986 (Immaraju et al. 1989a; use started 1980), Baythroid in 1996 (Morse & Grafton-Cardwell 2009; use started 1991), and the beginnings of Delegate resistance in 2011 (Morse & Grafton-Cardwell 2012; use started 2007 but the related Success was the major pesticide used against citrus thrips starting in 1998). The pattern in each case has been disturbingly similar. Because relatively few effective products were available for rotation, the listed pesticide was the main material used 1-2 times per year for citrus thrips control.

We have used citrus thrips as a model for which pesticides would be effective against avocado thrips and how persistent those impacts would be. Generally, the two *Scirtothrips* species react similarly but there are differences, largely because of different leaf flushing and fruiting patterns on citrus versus avocados. To best manage avocado thrips resistance, it would be ideal to have data from that insect, but unfortunately, one real lesson from resistance scenarios on many different crops and insects is that pesticide resistance is largely a "one-way street" (Roush & Tabashnik 1990, Denholm & Rowland 1992); the point is that once abamectin resistance evolves to a certain stage, it may be quite some time, if ever, before avocado thrips populations (and/or persea mite populations, if resistance is present there) return to baseline susceptibility levels. Most likely, because of the type of resistance that will evolve with abamectin (Clark et al. 1994), this may never happen once resistance evolves beyond a certain point (Denhold & Rowland 1992, Groeters et al. 1994, Tabashnik et al. 1994).

What should be done to prevent abamectin resistance from developing to the point where resistance will be stable and make this product ineffective? Basically, it comes down to using abamectin in moderation on avocados (regardless of whether the target is avocado thrips or persea mite). Now that we have effective products to rotate with abamectin (Table 1), we strongly suggest that growers and PCAs use abamectin <u>no more often than once every 3 years</u> at a particular site. A fair amount of research has shown that the rotation of alternative pesticide chemistries is a better approach than using mixtures of various products (Immaraju et al. 1989b, Tabashnik 1989). We still have a fair amount to learn about the alternatives to abamectin and what the strengths and weakness are of each of these products. We suggest that now is the time to start learning about these alternatives in the field and to treat abamectin as a "limited resource", reserved to deal with the (hopefully) occatrunks, and fruit. Alarmingly, almost nothing is known about the majority of these pests despite them being native to some of the world's largest avocado exporting nations. This situation has been well documented for fruit feeding moths (Hoddle & Hoddle 2008a, b, Adamski & Hoddle 2009, Brown & Hoddle 2010, Hoddle and Brown 2010, Gilligan et al. 2011) and similar studies are urgently needed for other pests, especially weevils attacking fruit and the woody parts of trees. It is almost certain that the California avocado industry will suffer an incursion from another serious pest, and the worse case scenario would be a species that feeds internally on the fruit.

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were available to take basic research findings, apply them, and assess what happened in the field. (5) Guy Witney, others in the CAC, and the California Avocado Society (CAS) put together research symposia, field meetings, and assisted in the rapid dissemination of research and extension information to the industry (e.g., via AvoResearch). (6) UC Riverside built websites on persea mite and avocado thrips to provide information on these pests (www.biocontrol.ucr.edu)

However, the industry also benefited from several fortuitous situations. (1) Although we knew nothing about avocado thrips when it was first introduced, several of us had worked on a similar thrips, i.e. citrus thrips on citrus, and much of what had been done on citrus could be translated to avocado thrips management on avocados. (2) A group of motivated researchers, advisors, and PCAs were available to work on developing solutions to the avocado thrips situation. (3) We were extremely fortunate that a unique product like abamectin was available for control of avocado thrips and had the unusual properties of being extremely persistent in its activity and effective, even when applied via helicopter. It was also minimally disruptive to natural enemies (leading to few if any pest upsets) and provided sufficient control of summer and fall persea mite populations so that a second helicopter application was not needed in many situations.

We believe growers and PCAs have gotten somewhat complacent using abamectin over the past 14 years on avocados. Some don't wish to believe that abamectin resistance will appear. We are strongly convinced that the beginnings of abamectin resistance <u>are already present in the field</u>, work is underway to demonstrate this experimentally, and it is only a matter of time before we have control failures if we continue to use this product nearly every year in many groves. We strongly suggest that users immediately start rotating in other chemistries and use abamectin no more often than once every three years.

Turning to invasive species other than avocado thrips, one sobering point to keep in mind is that there are many additional avocado pests waiting to invade California. The risk of new pests entering California is increasing yearly as free trade agreements increase the volume of fruit and other commodities entering the U.S. from increasingly diverse parts of the world. Increasing tourism also increases the risk of unwanted pest introductions. Surveys in the native range of avocados have clearly indicated that there is a rich insect fauna attacking leaves, stems, branches,

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