Development of codling moth management strategies in pears

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Abstract

1. Resistance to azinphosmethyl appeared to increase in general with some of the highest levels of resistance noted to date. Statistically significant resistance to Assail and Danitol were found in 4 orchards in the Sacramento Delta, yet levels remain relatively low and the potential impacts on control efforts are unknown at this time.

2. Development of programs that use pheromones as supplemental treatments to existing programs provided mixed results. The addition of sprayable pheromones to existing insecticide programs did not result in enhanced performance.

3. Use of an electroantennogram to detect potential pheromone emissions from treated discs over time suggested that the sprayable pheromone provided reduced, but detectable emissions after 6 weeks for discs placed in darken environments. Discs exposed to full sunlight did not produce detectable signals after 7 days for a trial conducted in August, 2002. A repeat of the study could not show statistically detectable signals by Day 11 in a study conducted later in Oct. 2003.

4. Use of "puffers" as supplements to existing programs appears to have yielded better results with improvements suggested in all plots except those with extremely low damage in the non-supplemented plots. The puffer treatments were applied at very low rates (1 puffer per 4-5.4 acres) with the grower standard program expected to provide the majority of control. The relative enhancement in performance from the supplementation with puffers increased with increasing pest pressures in the orchard. As damage levels in the standard programs reached higher levels (e.g. > 0.6%), the combination program. appears to have performed better on a relative scale. The cost of implementing a supplement with puffers compared to a full puffer program was dramatically reduced by 75-84% because of the reduced number of puffers per acre. Given that the program only enhances existing control programs, additional risk is minimized.

5. Positive results in attractancy trials were obtained for trials using fibers from Scentry. Traps baited with Scentry fibers that were allowed to age continued to provide similar attractiveness compared to non-aged fibers. The positive results obtained in 2003 suggest that further development is warranted despite difficulties with specialized application needs.

Introduction

Pear pest management continues to be hampered by issues of resistance to insecticides in codling moth. Similarly, pressures to reduce production costs are increasing due to a variety of market forces, which places increased emphasis on reduced costs for pheromone-based mating disruption systems. While the two efforts may appear unlinked, the two factors of insecticide resistance and the performance of pheromone mating disruption programs are interconnected. The connection stems from the fact that pheromone mating disruption programs have proven most effective against low to moderate population levels of codling moth. As such, pheromone mating disruption programs require periodic intervention to reduce populations that are starting to increase beyond manageable levels. If insecticide resistance increases to levels that prevent rapid and effective knockdown of increasing populations, then the ability of growers to rely on pheromone based programs becomes more tenuous.

Therefore, surveys were conducted to 1) assess for changes in azinphosmethyl resistance (Guthion) in key orchards that may have had management difficulties 2) assess potential problems for newer chemistries that have been introduced for control of codling moth (either primary or secondary target) and 3) preliminary studies to look at combination programs of insecticides plus minimal pheromone programs.

The combination programs with supplemental pheromone treatments had several potential benefits (potential reduced costs compared to full pheromone programs or increased performance in high pressure situations). As such, different options are being explored to accommodate different economic situations or levels of risk aversion by growers. However, all programs tested in 2003 decreased risk in that any additional pheromone used in the trial only supplemented their full existing program rather than act as a substitute. The difference between the “value-added” program in their orchard and their grower-defined program provided an estimate of the additional control provided by the supplementation.

Additional trials were conducted to develop means to estimate product performance using lab based performance assays (eg. use of electroantennogram equipment for primary testing of pheromone dispensers). The hope is that these approaches will allow for quicker comparison of products early in development without extensive field trials that are complicated by orchard variables (e.g. inconsistent flights; patchy infestation patterns).

Objectives

1. Field evaluation of combination programs using selective insecticides and low rates of sprayable pheromone and reduced deployment rates of puffers to reduce overall costs and improve control
2. Evaluation of insecticide resistance to Danitol for field collected codling moths
3. Development of baseline resistance data for Assail plus preliminary evaluations of field populations in regions with known Azinphosmethyl resistance

Materials and Methods

Resistance Assays - Materials and Methods

Resistance assays were conducted for Guthion, Danitol, and Assail. Moths from four delta orchards were tested with all three compounds. Two of these sites were sampled for Guthion resistance in late 2002 and those data are included here as reference.

All other assays were conducted in 2003. Data from the delta populations were compared to a susceptible population collected from abandoned apples in Anderson Valley.

Assays were conducted with Guthion, Danitol, and Assail using protocols developed over past years. Pheromone traps using modified liners were used to collect male moths. Liners coated with approximately 1.5 ml Tanglefoot were placed in Trécé Delta VI traps. Traps were baited with a 5x codlemone lure. Standard procedure was to place approximately 120 traps in a site before dusk and collect the traps at daybreak the following morning. Liners with moths were removed from traps, stacked in an ice chest to keep moths cool, and returned to our Berkeley lab where they were treated with a dose series of pesticide in order to establish a dose response line. Each collection of moths was subdivided and treated with one of four or five concentrations of pesticide or a zero concentration control. The pesticide was delivered to individual moths by application of a 1 microliter aliquot to the ventral posterior abdomen of each moth. Treated moths were then held 48 hours at 15^{o}C. Mortality was assessed by brushing the moth with a fine camel hair brush; moths that failed to respond with vigorous leg movement were scored as dead.

Probit regression lines and LC_{50} values were estimated using the probit option of POLO (LeOra Software, Berkeley, CA). A lethal concentration ratio test (LCR) was used to compare regression lines for significant differences.

Resistance Assays – Results

Resistance levels overall appear to have increased in general in the orchards sampled in 2003 (Figure 1). Resistance levels in the susceptible orchard used since the early 90s was 0.09 µg / µl in 2002 compared to earlier values ca. 0.06 µg / µl collected from this orchard and from historical data from the 60s. The most susceptible orchard in 2003 was found in Anderson Valley at 0.15 µg / µl per moth. As such, there appears to be a general increase in the background even in orchards with typically susceptible populations. Resistance levels to azinphosmethyl of 0.81 and 0.86 µg / µl per moth, which are some of the highest values found to date. The general upward, but relatively slow, trend in azinphosmethyl resistance appears to be continuing.

Resistance ratios in 2003 (ratio of LC50 values for a test orchard compared to the LC50 values in the most susceptible orchard tested in the same year) are less than in 2002 despite increasing absolute resistance levels (Figure 2). The reduction in resistance ratio occurred because the most susceptible orchard in 2003 had increased its ability to tolerate azinphosmethyl by 1.64 fold. Given that this orchard in 2003 was used as the denominator in the comparison, the higher tolerance level in the susceptible orchard makes the azinphosmethyl tolerant orchards have a lower resistance ratio

Statistically significant resistance was found to Assail and Danitol in 4 orchards in the Sacramento delta (Figure 2). Resistance ratios ranged from 1.9 to 8.1 for Danitol, whereas resistance ratios to Assail ranged from 1.7 to 4.8 fold. All resistance ratios were significantly different from 1.0 at $P < .05$. The increased resistance to Assail and Danitol were statistically significant, yet were still relatively low. The Anderson Valley orchard was used as the susceptible orchard given that it had the lowest values for Assail and Danitol as well.

Graphic correlations between the level of Guthion resistance and resistance to Danitol and Assail are shown in Figure 3. No statistically significant correlation was observed between azinphosmethyl and either Danitol or Assail (P = 0.37 or 0.38, respectively). However, one orchard (SU) with the highest level of Guthion resistance had the lowest values for both Assail and Danitol resistance, which made the correlations very poor (as indicated by arrows). Several conclusions might be drawn: no correlation exists between the materials or the last set of data points in one orchard may suggest that different mechanisms are operating in different locations if the trends for the 4 other orchards are real. Conversely, a very tight correlation between Assail and Danitol was observed ($r2 = 0.96$; Figure 4). Given that correlations never prove causality, these types of data are not sufficient to draw any real conclusions about cross resistance which requires a greater understanding of the specific biochemical mechanisms and genetic underpinnings of the relationships. However, they do suggest potential relationships for further, more definitive studies.

Value Added Program – Pheromone Supplement to Grower Defined Programs

The "Value Added"program was designed as a low rate, low cost pheromone supplement to enhance a grower-defined codling moth control program. The grower program could be either pheromone-based or insecticide-based. Participating growers utilizing a pheromone program of rope dispensers or sprayables received a supplement from a low density deployment of aerosol emitters. Those relying on insecticide controls received a supplement of either aerosol emitters or sprayable pheromone applied at low rates with the grower's insecticide treatments so as to incur no additional application costs.

Standard Program	Supplement Added to Standard
Conventional Insecticide	Low density of Puffers (1 orchard) or Low rate of Sprayable Pheromone (5 gm ai per acre) 4 orchards
Hand-applied Pheromone Dispensers	Low density of Puffers (1 orchard)
Sprayable Pheromone	Low density of Puffers (2)

All puffer supplements used the Paramount aerosol emitters (Suterra LLC., Bend, OR 97702) loaded with NOW/CM canisters. The NOW (navel orangeworm component) was included only because these types of canisters were provided by the company, rather than included as a specific part of the management program. It is assumed that the NOW pheromone had no significant effect on any portion of this trial.

While a standard placement rate for puffers is 1-2 units per acre when used as a primary control, we were testing a low density deployment program as a supplement rather than the primary means of control. Thus, puffers were deployed into the upper canopy of trees at a density of one unit to every 4 to 5.4 acres depending on plot size and orientation relative to wind direction. Units were programmed to emit a standard rate of 7.05mg ai (codlemone)/puff (338.4 mg ai per day) during a 12 hour "on" period from 6 pm to 6 am each day. The logic behind the program was to have the conventional programs (insecticides or sprayable) be the mainstay of the program, whereas the puffers were just adding supplemental suppression at a reduced costs. Inclusion of puffers at 1 unit per 4 to 5.4 acres is ca. 18 to 25% of the use and cost of a puffer program as a stand-alone program.

All sprayable pheromone supplements (Checkmate CM-F, Suterra LLC or MEC-CM, 3M Company, St. Paul, MN 55144) were applied at 5 gm ai / acre with insecticide applications at the timing determined by the grower. Because the timing of the treatments were determined by the PCA for optimal insecticide treatments, the timing was less appropriate for the pheromone treatments. This decision was made because the treatments were only viewed as supplements rather than the mainstay of control. Additional costs due to additional applications were not desired.

Adult codling moth activity was monitored by a grid of traps (Pherocon Delta VI, Trécé, Inc., Adair, OK 74330) in each trial site. Traps baited with CM standard lures (Trécé 3111) were hung low, while those baited with 10X lures (Trécé 3160) were placed at about 10 to 12 feet. The traps were monitored weekly and lures were changed every two weeks.

Codling moth damage assessments were conducted three times during the season; at approximately 1000 degree days, early harvest (July 8-14) and late harvest (July 23-29). At the first evaluation, multiple sites within an orchard plot were sampled by inspecting 500 fruit from each site; 10 fruit from the lower canopy of 50 trees. The early and late harvest samples were conducted by inspecting1000 fruit from each sample site; 20 fruit from each of 50 trees. A sample site was typically 1.2 to 1.5 acres. The number of sites sampled within a trial plot ranged from two to eight depending on plot size. All infested fruit were cut to determine the age of the larva and a subsample of 20% of all fruit inspected were cut to look for cryptic infestation.

Puffer function was monitored at two to four week intervals by weighing units, checking battery power, checking that the unit would “puff”, and by inspecting the housing for excessive wear at the hang point. Emission rates were calculated from weight data to identify units blowing either excessive amounts or unacceptable low rates of pheromone. Dysfunctional units, batteries, and aerosol canisters were replaced as needed.

Pears: “Value Added” Puffer Sites

The Sutter Ranch (SU) is a 95-acre orchard near Courtland, CA. The grower and PCA for this site planned on a soft program based on sprayable pheromone with inclusion of newly registered insecticides if available and needed. The entire orchard was treated with Checkmate CM-F (sprayable pheromone) four times: April 2 (5.75 gm ai / acre), May 7 (10 gm ai / acre), June 9 (18.3 gm ai / acre) and July 2 (18.8 gm ai / acre). The grower/PCA initiated further treatments with Assail on June 9 (3.3 oz/acre) and Intrepid on June 19 (15.83 oz/acre). The eastern six blocks encompassing 42 acres received a puffer added pheromone supplement to the sprayable pheromone program. Eight puffers were placed total, with seven along the south and west boundaries of the plot at approximately 380 to 440 foot intervals, and the eighth near the center of the supplemented area. This approach resulted in a puffer supplement of 1 puffer for every 5.25 acres. Two traps (one each 1X, 10X) were placed in each of the six treated blocks. Twenty acres of the adjacent west blocks served as a grower-treatment control (same sprayable program plus insecticides) and were monitored by eight traps (four each 1X and 10X).

Another orchard (adjacent Sutter Ranch), referred to as SS, selected sprayable pheromone for its primary codling moth program. We utilized two blocks totaling 50 acres for a supplemental puffer treatment, and the adjacent upwind 17 acres was a grower-program control. Nine puffers were distributed along the south and west boundaries of the treatment area and three additional puffers were placed in the interior. This configuration resulted in 1 puffer for every 4.16 acres. Sixteen traps (eight each 1X and 10X) were placed in the puffer treatment area and four (two each 1x and 10X) were set in the upwind control region. Four treatments of Checkmate CM-F were applied on March 28 (5.5 gm ai / acre), May 1 (10.3 gm ai / acre), June 3, July 3 and August 7(three sprays at 16.5 gm ai / acre). Grower treatments of Assail (June 3, July 3) at 3 oz/acre and Guthion (August 7) at 3 lbs/acre were also applied.

A 40 acre orchard, near Hood, CA, (referred to in text as CA) was placed in a pheromone program using rope dispensers at 300 / acre with a 400 / acre border application (Isomate-C Plus, Pacific Biocontrol Corp. Vancouver, WA 98685). We supplemented two blocks totaling 17.66 acres with a puffer treatment of three units spaced across the south and west borders (1 puffer per 5.88 acres). Four CM monitoring traps (two each 1X and 10X) were placed in this area and two (one each 1X and 10X) in an upwind control. The grower applied Imidan 70W at 5 lbs / acre May 29 and Guthion at 3 lb / acre on June 7.

The Hood Ranch (HO) is a 45-acre orchard targeted for insecticide treatment as this site has had a high codling moth population in recent years. Insecticide applications were made by the PCA to the entire orchard as follows: Guthion (May 3) at 3 lbs/acre, Assail (May 31, July 19) at 3.4 oz/acre, Imidan (June 21, August 1) at 5.6 lbs/acre, and Danitol (July 7) at 21.3 oz/acre. We supplemented 12 acres in the east block with three puffers placed upwind to the south and west (1 puffer per 4 acres). The grower-treatment only control area was upwind (west) of the puffer area. (A sprayable supplement plot lay to the west of the grower control and is described below.) Four traps (two each 1X and 10X) monitored the added puffer plot and two traps (one each 1X and 10X) were placed in the grower-treatment area.

Pears: "Value Added" Sprayable Sites

The Hood Ranch (HO) and grower treatment layout is described above. We supplemented eight acres on the western edge of the orchard with Checkmate CM-F at 5 gm ai per acre with every insecticide application. Two monitoring traps (one each 1X and 10X) were placed in this area.

A ten acre block of the SM Ranch was treated with Checkmate CM-F to supplement the insecticide program. Contiguous acreage to the east was monitored and sampled as the grower-treatment control. A total of eight traps (four each 1X and 10X) were equally dispersed across the two treatment areas. The insecticide program consisted of the following treatments made to the entire trial site except as noted: Guthion (3 lbs/acre) was applied May 1, Assail (3.4 oz/acre) was applied June 1 and July 23, and Imidan (4 lbs/acre) was applied to only the west half of the Checkmate block on June 14 and to the full trial site on July 3. The June 14 treatment was precipitated by high trap counts in an adjacent non-program area. Spray logistics and the need for a larger treatment buffer necessitated spraying out a portion of the value "+" block. Subsequent fruit damage samples were restricted to the appropriate treatment areas.

A sixteen acre area along the eastern edge of the LB orchard near Walnut Grove was treated with Checkmate CM-F to supplement the insecticide program. Equal acreage on the west side of the property was monitored as the grower-treatment control. A total of 12 traps were used (6-1X, 6-10X), split evenly between the pheromone-added area and the grower-treatment. The orchard received treatments of Guthion (3 lbs/acre) on April 23 and June 14, Assail (3.4 oz/acre) on May 26 and July 13, and a single treatment of Danitol (21.3 oz/acre) on July 1.

An orchard between Courtland and Walnut Grove (KT) provided the opportunity to apply two available formulations of sprayable CM pheromone in a value "+" program in adjacent 20 and 30 acre blocks. Blocks were similar in structure, age, and features with one edge of each block bounded by a levee. Both blocks were targeted for conventional insecticide treatments for codling moth control. These consisted of two applications of Guthion at the rate of 3 lbs (50 WP) per acre on May 16 and again on June 16, and one application of Imidan at 7.13 lbs (70 WSB) per acre on July 9. With each application, the 20 acre block received 3M MEC CM at a rate of 5 mg ai / acre, and the 30 acre block received Suterra Checkmate CM-F at 5 gm ai / acre. The grower-treated area was run on a different program consisting of Confirm 2F (20 oz. / acre) on April 16 and June 14 and pheromone rope dispensers (Isomate-C TT, Pacific Biocontrol Corp. Vancouver, WA 98685). Codling moth flights were monitored with a grid of 12 traps in the 30 acre block (Suterra), 10 traps in the 20 acre block (3M) and 6 traps in the grower- treatment. Equal numbers of 1X and 10X baited traps were deployed in each block.

Pheromone Supplements – Results

The results for the supplemental plots are shown 2 ways: absolute values for damage estimates for the first and second harvests as available or as the difference between the grower program and the grower program plus the supplemental treatment. The harvest values for the 4 orchards using sprayable pheromones are shown in Figure 5. Similarly, the average results for the plots in the orchards using puffers as the supplement are shown in Figure 6.

However, the easiest way to present these data is by showing the differences between the plots since they are paired (grower-defined versus grower-defined plus pheromone supplement) (Figure 7 and 8). If the differences are positive (the bars rise above the line), then the treatment failed to provide any additional suppression. Conversely, if the bars sink below the line, then the supplemental treatment reduced damage by that percentage and measures the added benefit of the treatment. A final component of the outcome is "What is the background level of damage in the "grower-defined" treatment?" If the grower-defined treatment has very low damage (e.g. 0%), then any supplemental program cannot, by definition, make the program any better. Conversely, as damage increased, the value of the supplemental program was predicted to increase.

For the first harvest of the sprayable plots (Figure 5 and 7), all 4 plots did not show any significant increase in control with all plots being 0.2% or less greater than plots which did not receive any supplemental pheromone sprays. However, the opposite pattern was observed for the puffer treatments, where either no effect was observed when damage was negligent in the orchard, or up to 0.8% less damage by first harvest (Figure 6 and 7). A similar pattern was again observed for the orchards for the second harvest (Figures 5, 6 and 8).

In one orchard in Hood (HO), where damage was greatest in the conventional program, the data are shown in an additional figure that includes data from a third collection later in the season (Figure 9). Early in the season, damage was fairly low and little difference was observed between the standard insecticide treatment and the programs receiving supplemental control plus the full insecticide treatment. No real change was observed by July 25, but a significant flight was occurring during this period such that egg laying was occurring within the orchard. The plots from the grower defined standard reached greater than 5%. No additional suppression was observed in plots that had received the additional sprayable pheromone treatments (Figure 9). However, the puffer treated plots had reduced damage despite their close proximity to more conventional plots within the orchard. If these same data are presented over time as the differences between the plots (Figure 10), then the differences between the sprayable and puffer treated plots becomes more apparent. The difference is most acute by early August with a 3.33% reduction in damage between the areas supplemented with the puffers versus the areas without any supplementation. These patterns will need to be confirmed given the low sample size and variation in infestation between orchards. However, supplementation of existing programs with sprayable pheromone at least under these conditions did not appear to provide additional benefits for control.

Longevity of Scentry NoMate Fibers – Materials and Methods

We tested the ability of aged Scentry NoMate Fibers to attract male codling moth. The assumption is that attraction to traps is evidence that pheromone is being released. As fibers aged and discontinued releasing sufficient pheromone to be attractive, then the traps were predicted to not collect moths. Age classes of Scentry NoMate fibers were obtained by setting out fiber samples on a weekly schedule. Trials compared the ability of fibers in age classes ranging from 0 to 26 days old or from 18 to 44 days old to attract moths to traps compared to a standard codling moth lure. Traps (Delta VI, Trécé) were each loaded with five fibers attached to the upper inside surface with Bio-Tac (Scentry, Inc., Billings, MT), or a Trécé 1x lure (3111). Moth captures were scored after one week. The initial trial compared fibers aged 0, 12, 19, or 26 days the second compared fibers aged 18, 30, 37, and 44 days. Traps were placed at a maximum density of one per acre in four replicate blocks. If more than one orchard was used, then fibers of all different ages were placed into each orchard to block for orchard effect. All trials were conducted in conventionally treated Bartlett pear sites.

Longevity of Scentry NoMate Fibers – Results

The relative attractiveness of the fibers for the first trial across 26 days of aging was consistent over this time period (No statistical difference P = 0.58) (Figure 11). Trap counts from fibers that were not aged were not statistically different from traps baited with fibers that were 26 days old. These data suggest that the product should last at least 26 days without any apparent decline in efficacy. The longer trial did not result in useful data given that so few moths flew during this period. These data are consistent with data generated in the Northwest by J. Brunner which supports the idea of a potentially sprayable formulation with 3 or more weeks of consistent emission. Further testing with the EAG unit (see below) will be another way to test this product in the lab, but field trials appear justified at this time for 2004. One difficulty with these types of trials is the more specialized application equipment that is currently required for application of the fibers.

EAG evaluations of sprayable pheromone residues – Materials and Methods

Previous studies of aged 3M product residues conducted by chemical analysis indicated rapid degradation of light exposed residues and better stability of shaded residues (see 2000 California Pear Research Reports). In this study, we are attempting to bring the data closer to field relevance by measuring the ability of codling moth to respond to aged residues. Filter paper discs treated with dilute solutions of sprayable formulations (3M and Suterra) were aged in direct sun or complete shade to provide samples to test the stability of the products. An electroantennogram (EAG) (Syntech, Netherlands) was used to evaluate the ability of codling moth antennae to respond to the pheromone-treated disc samples. The greater the EAG "spike" which is the sum of all receptors in that segment of antenna firing after exposure to the compound, the greater the signal strength. While antennal activity is one measure of release, these data are best corroborated with direct assays for pheromone quantities, behavioral data, and ultimately damage suppression. However, if the discs are not emitting pheromone, then it is highly improbable that the program has potential for success.

Filter paper discs were treated with 3M or Suterra sprayable pheromone (detailed below). These were placed inside aging chambers which were constructed of PVC pipe forming a frame, a wire mesh bottom, and a cover which protected the discs from rain and wind. The filter paper discs were individually pinned to a balsa wood platform which rested on the mesh bottom. The construction of the aging chambers allowed for two protocols, a light exposed and a dark exposed environment. The light exposed chamber had a clear plastic film cover thus exposing the discs to direct solar radiation while the dark chamber had a solid aluminum top cover over a second nested aluminum cover. Each aluminum cover had side vents oriented on different axis to prevent direct exposure to light. A 2-channel HOBO H8 (Onset Computer Co. Pocasset, MA USA) data recorder was placed inside each chamber to record temperature data every 15 minutes both inside and outside the chambers. This indicated there was no differential heating between chamber types impacting rates of pheromone degradation. The chambers were placed on a detached gate (Anchor fencing) set up as a bench to permit airflow and minimize reflective heating of the chambers. Four discs from each treatment (light and dark) and for each compound were collected on the day of setup and at each collection period thereafter. Collected discs were placed individually into sample tubes and frozen until evaluations could be conducted. Two trials have been set up -- the first providing samples over an extended time, the second collecting samples on a finer time scale over a shorter period.

Extended time trial. Discs were treated with 50 micro liter aliquots of 1% dilutions of MEC-CM and Checkmate CM-F sprayable pheromone. The disc samples were subject to the conditions detailed above and collected weekly for eight weeks. This trial was conducted on the Russell Reserve in Contra Costa County starting in August, 2002.

Short time trial. Discs were treated with 50 micro liter aliquots of 1% or 1.6% dilutions of MEC-CM and 1% dilution of Checkmate CM-F sprayable. Because these formulations differ in amount of active ingredient, the more concentrated dilution (1.6%) of 3M product was included so that samples for the two products would start with the same amount of active ingredient (approximately 71 micrograms per disc). This trial was conducted on the UC Berkeley campus beginning late October, 2003 when daylength, light intensity, and temperatures are less than conditions of the extended time trial. Disc samples were collected on the day of setup and after 1, 2, 3, 4, 6, 8, 11, and 14 days exposure and stored as indicated above.

During winter and spring 2002-3, extensive trials were conducted with the EAG to develop protocols for measuring codling moth response to pheromone. These included investigations of antennal recovery times following exposure to an odor source, exposure duration, dosages, impact of reference odors on sample response and development of sampling chambers. Based on these studies, we have arrived at a set of test conditions as follows. A single antenna is removed from a male codling moth, the distal end is cut, and each end is embedded in electrode gel on the contact points of the antenna holder. Controls on the EAG are set as follows: gain = 100, sample and reference times = 0.3 seconds, pause = 10 seconds, TC = 2. A reference odor of green leaf alcohol (product # 101, Bedoukian, CT) dissolved in paraffin oil (5% AI /10 microliter solution) is placed on a polypropylene cap and set in the reference chamber of the EAG. After a stable signal from the antennae is displayed (2-10 minutes), sampling is commenced. Samples were run at two minute intervals to allow the antennae to recover between events. Four sets of six discs consisting of a one disc from each time interval (of five examined) plus an untreated disc were set up for screening and each of these sets was evaluated by a single antennal preparation. Discs were presented in a random order for each of two runs through the set. To date we have evaluated the following disc series: 1) extended time dark exposure series using discs aged 0, 1, 2, 3, 4, and 6 weeks: 2) extended time light exposed series using discs aged 0, 1, 2, 3, and 4 weeks; and 3) short time light exposed series using discs aged 0, 4, 6, 8, 11, and 14 days.

EAG evaluations of sprayable pheromone residues – Results

The results for the six week trial for both the light exposed and non-exposed ("Dark Exposed") discs are shown in Figures 12 and 13 for the Suterra CM-F formulation. Under darkened conditions, antennal activity is unchanged after 7 days compared to the activity at day 0 (Figure 12). The relative antennal depression starts to decline by week 2, yet appears to level off at ca. week 3. Significant activity is still noted after 6 weeks in the darkened chamber compared to the untreated blank disk (Tukey's HSD test). The first significant differences between the aged discs were detected between discs at time 0 and discs from week 3 (Tukey's HSD test).

However, in the light exposed discs, no antennal signal was detectable after 1 week (Figure 13). All samples from 1 week onward were not statistically different from the blank controls (Tukey's HSD test). Obviously, no increase in the signal was observed nor expected during the next 4 weeks of the trial. These data suggest a strong depression in the activity of the material under full sunlight conditions typical of Central Valley conditions in August.

When the study was repeated in October under less intense light conditions and shortened daylengths, the material exhibited a similar pattern for the light exposed discs, but the longevity was improved (Figure 14). No change was observed for the 6 days, but slow decline was observed from day 7 to 14. By day 14, no detectable signal was recorded from most samples. However, significant variation existed between antenna, but given that sets of all sample dates are exposed to each antenna, the effect is blocked from the analyses. The data are not longer significantly different by day 11 compared to the blank control (Tukey's HSD test; $P>0.05$). The 3M samples have not been completed to date, yet are frozen until further analyses are possible.

The data suggest that the materials (capsules) that are exposed to sunlight on the outer surface of the tree canopy are broken down fairly quickly compared to capsules in the interior, shaded portions of the canopy. These finding are consistent with the results across commodities in that superior trap suppression has been seen in walnut orchards in a variety of studies. Walnut orchards typically have much greater light interception with much of the spray deposit under the canopy given the height of the trees. In contrast, pear orchards have more open canopies in many cases which may explain why trap suppression has proven more problematic in pome fruit. The positive news is the relative extended detectable emission over 6 weeks for the shaded capsules and that additional stabilization may provide significant improvements in capsule longevity for sunlight exposed portions of the canopy. Orchards with more open or young canopies would not be predicted to have as successful trap suppression compared to closed mature canopies.

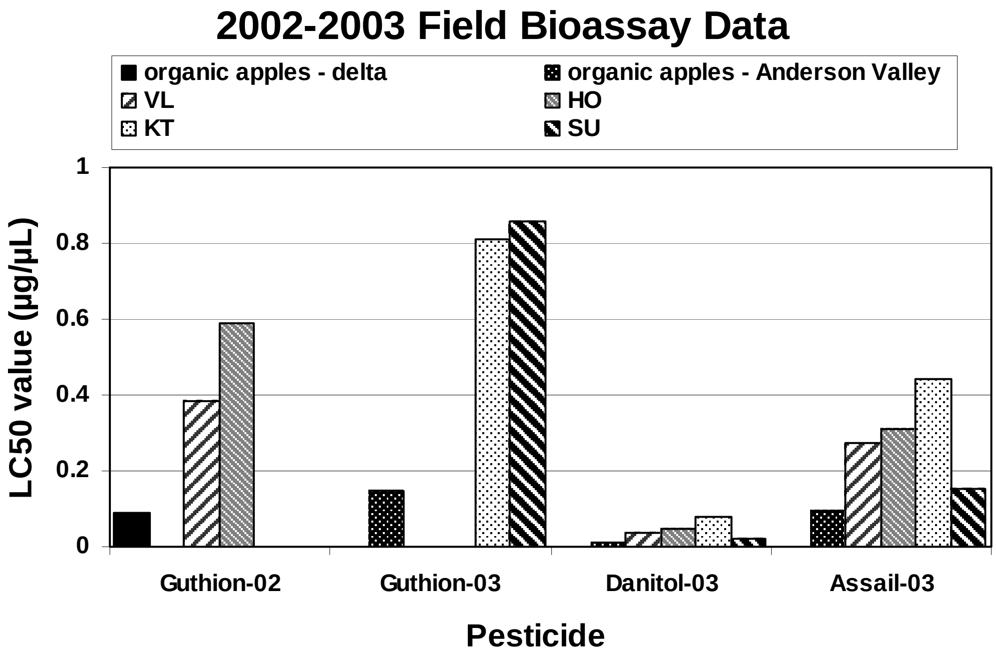

Figure 1. Resistance values (LC_{50}) to insecticides for populations of codling moth in California pear orchards, 2002 and 2003.

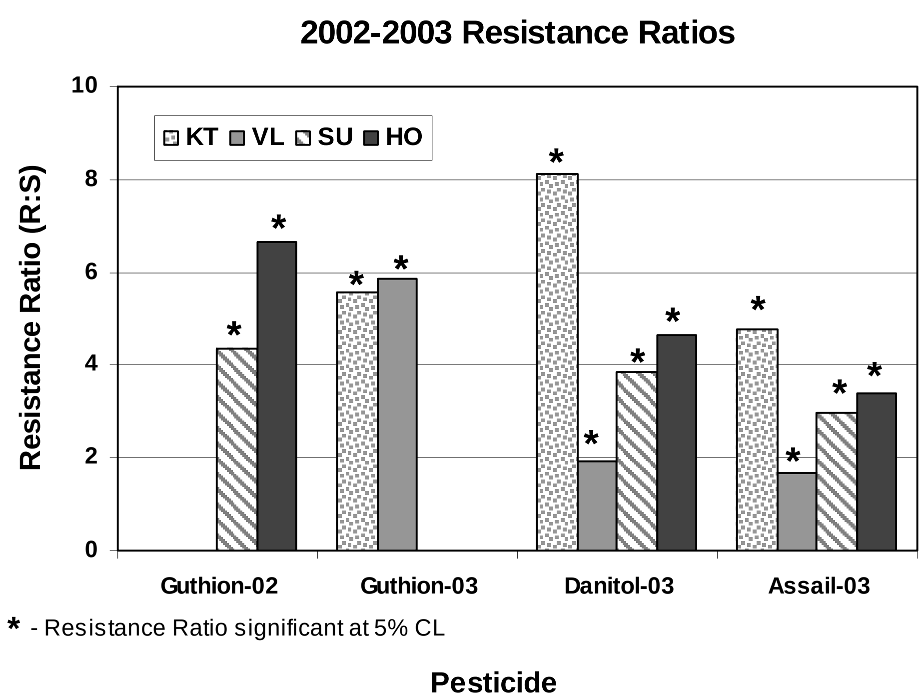

Figure 2. Resistance ratios for Guthion, Danitol, and Assail for codling moth in pears (Resistance ratios (LC_{50}) of test population compared to most susceptible reference population in same year)

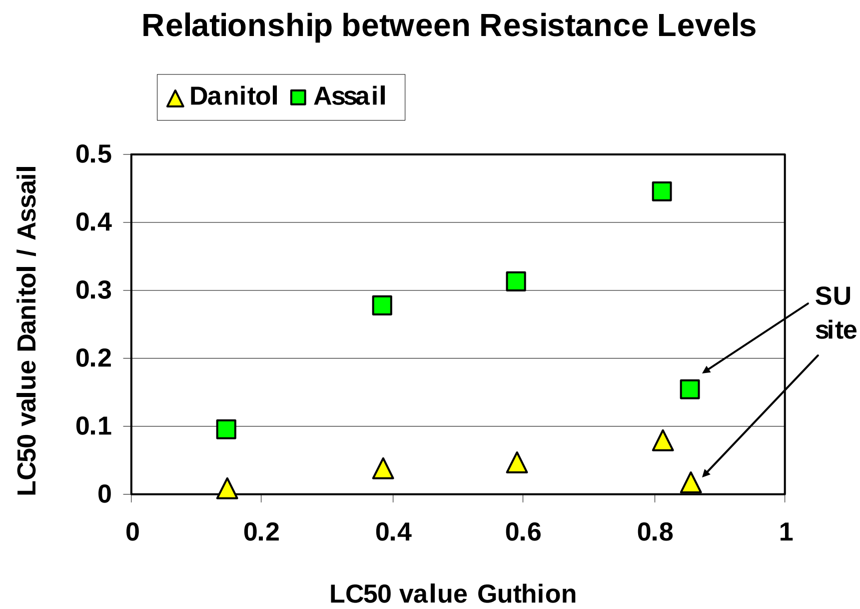

Figure 3. Relationships between Guthion resistance and resistance to Danitol and/or Assail within populations of codling moth. Five pairs represent 5 orchards.

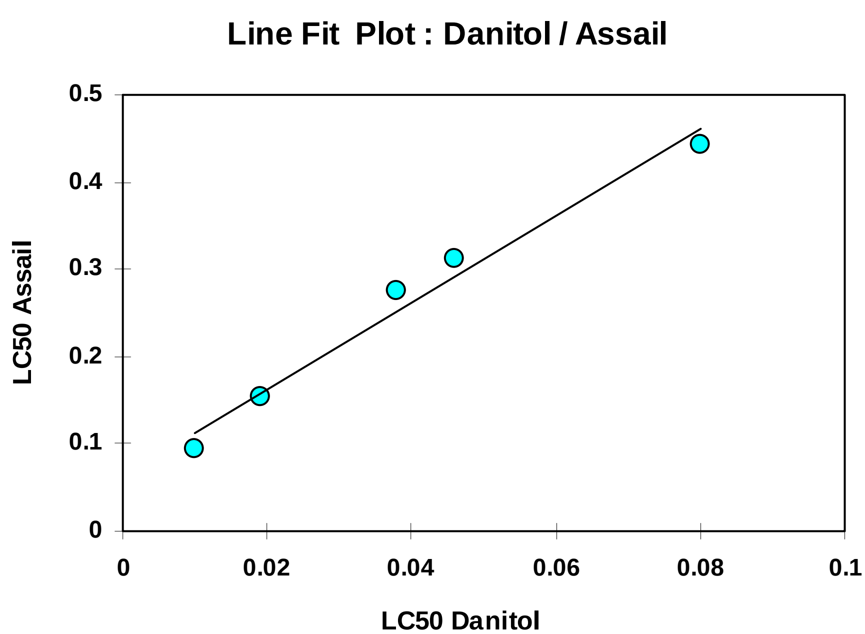

Figure 4. Relationship between Danitol and Assail within 5 populations of codling moth.

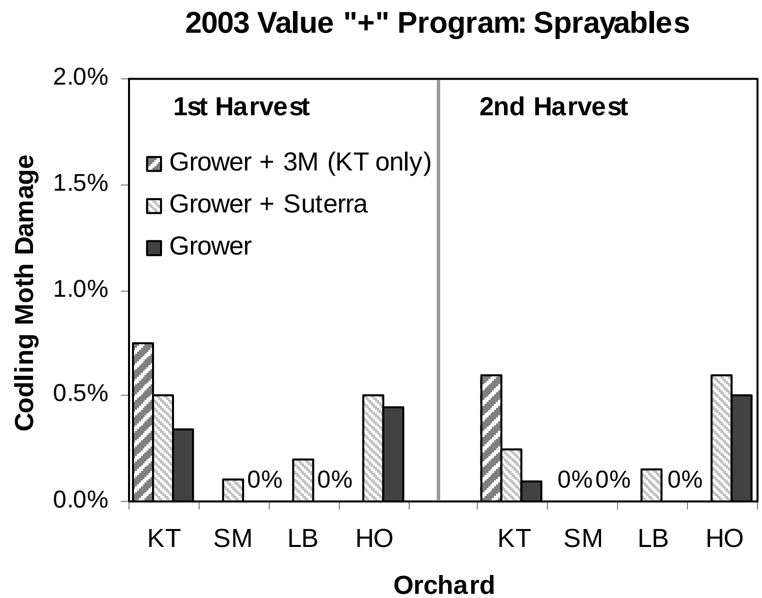

Figure 5. Mean codling moth damage from "Value-added" sprayable programs in 4 orchards using Suttera CM-F or 3M sprayable product.

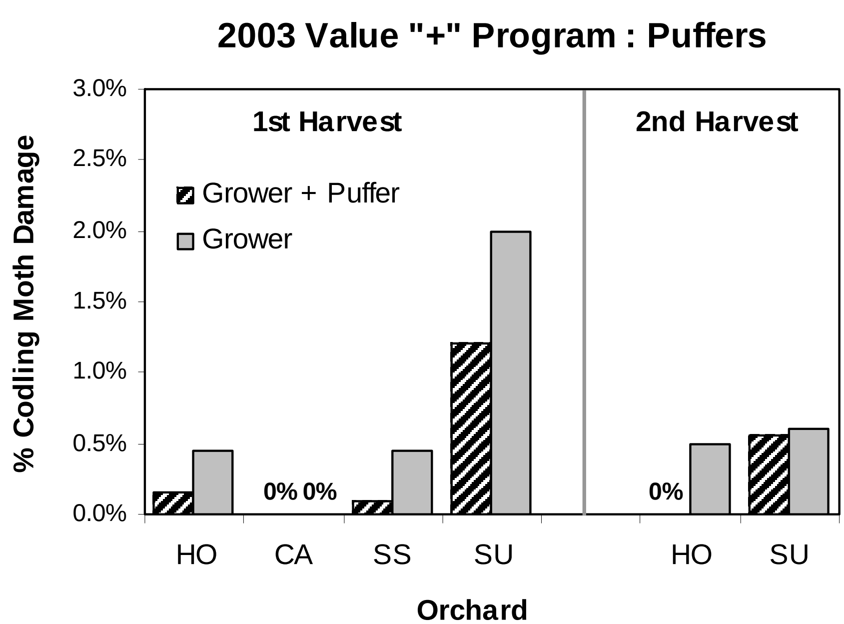

Figure 6. Mean codling moth damage from "Value-added" puffer plots

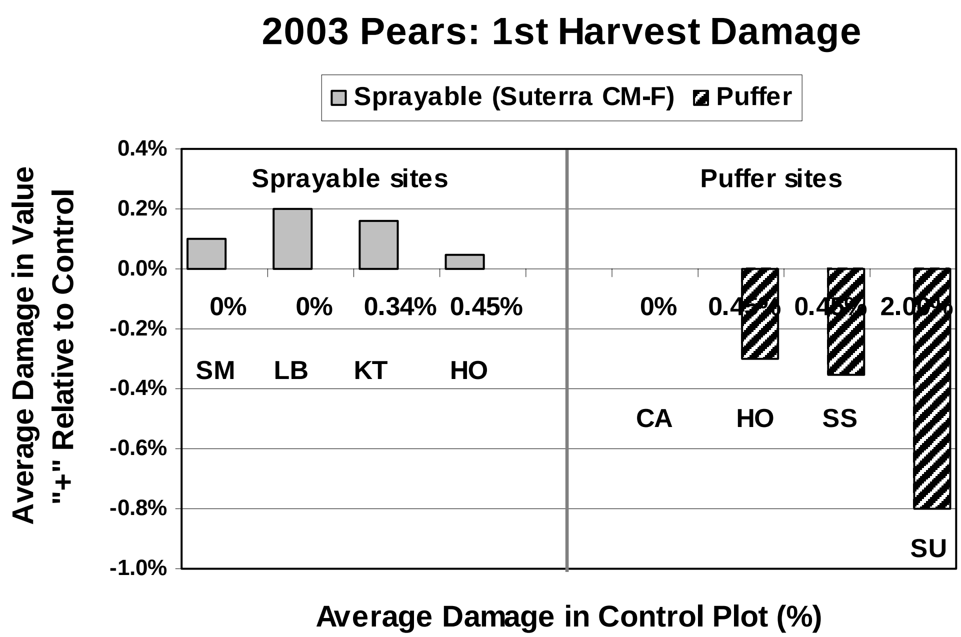

Figure 7. Mean difference in codling moth damage between conventional plot compared to plots treated with conventional program and supplemental pheromone program, first harvest.

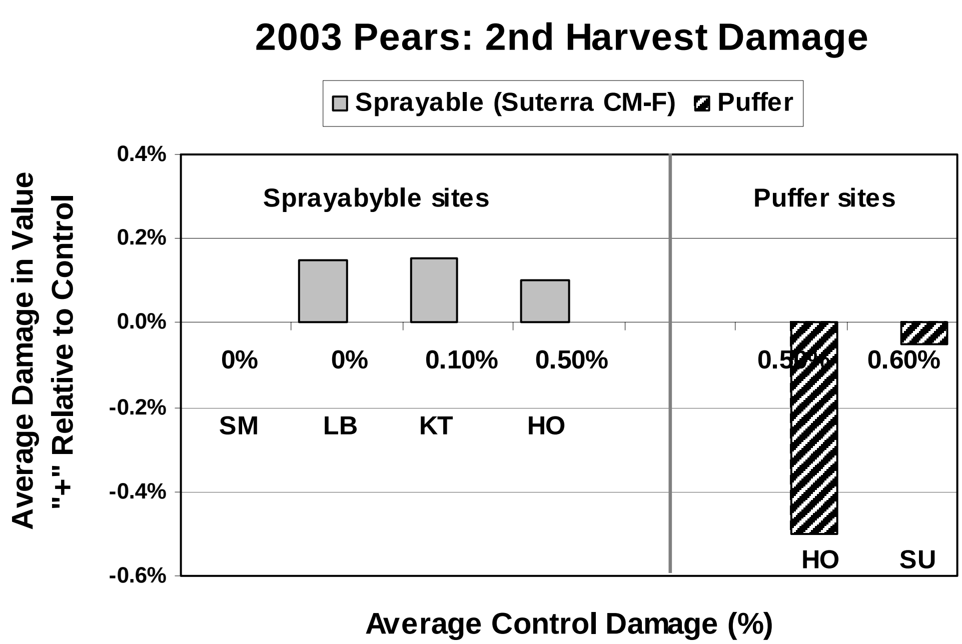

Figure 8. Mean difference in codling moth damage between conventional plot compared to plots treated with conventional program and supplemental pheromone program, second harvest.

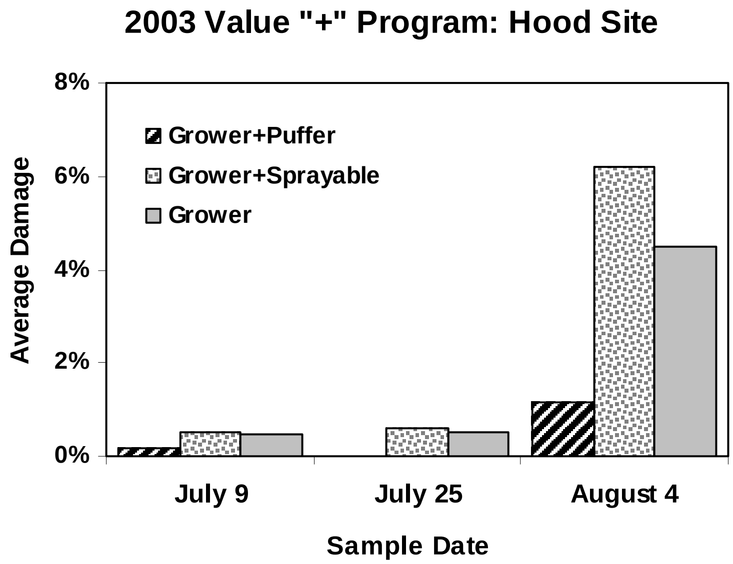

Figure 9. Mean codling moth damage in Hood ranch for first, second, and final fruit evaluations in conventional insecticide program ("Grower") and 2 samples with conventional insecticide program plus supplemental pheromone programs (Sprayable or Puffer supplements) .

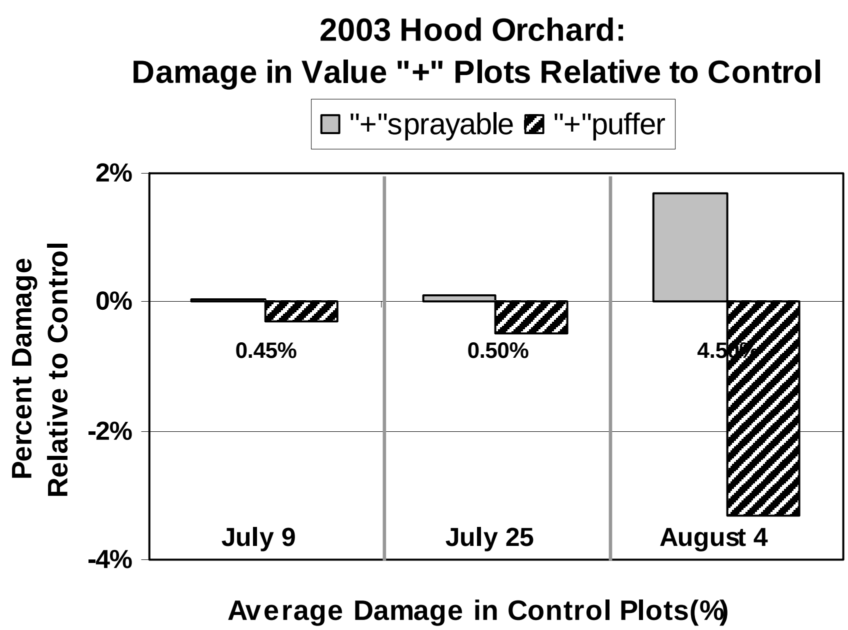

Figure 10. Mean difference in codling moth damage between conventionally treated areas and areas receiving same conventional treatment plus supplemental pheromone programs.

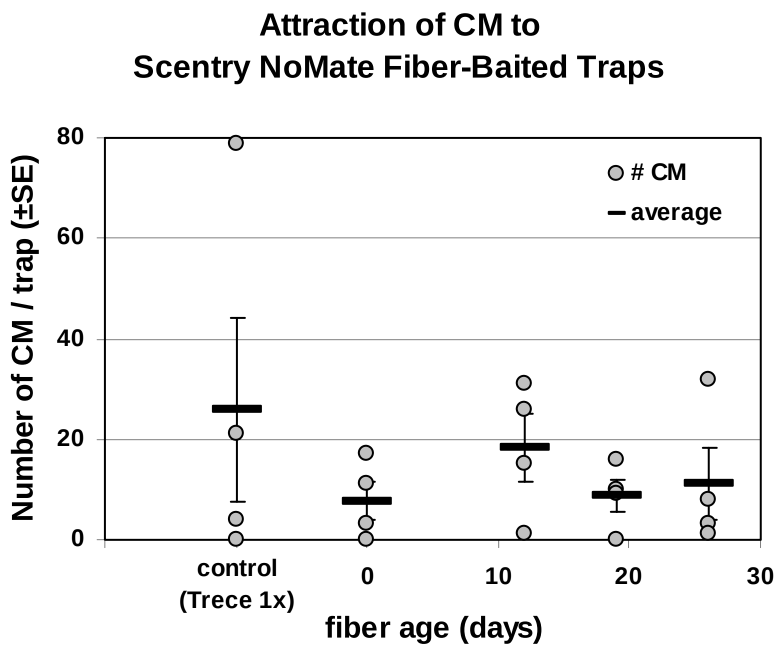

Figure 11. Mean codling moth trap captures for traps baited with field aged Scentry NoMate fibers.

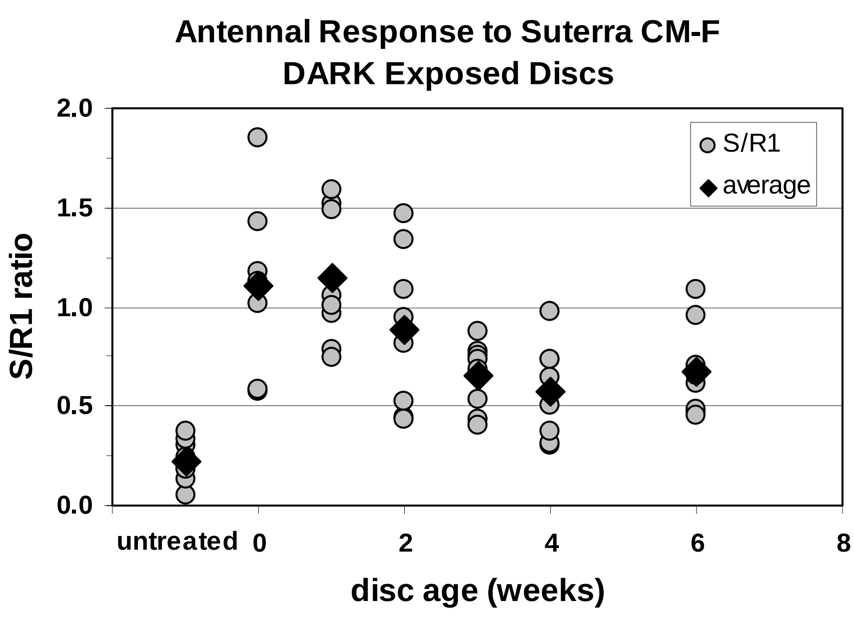

Figure 12. Ratio of electroantennogram responses over time of pheromone treated discs (S-sample) to the reference odor (R1) for filter paper discs treated with sprayable pheromone, but kept under darkened conditions. 2002.

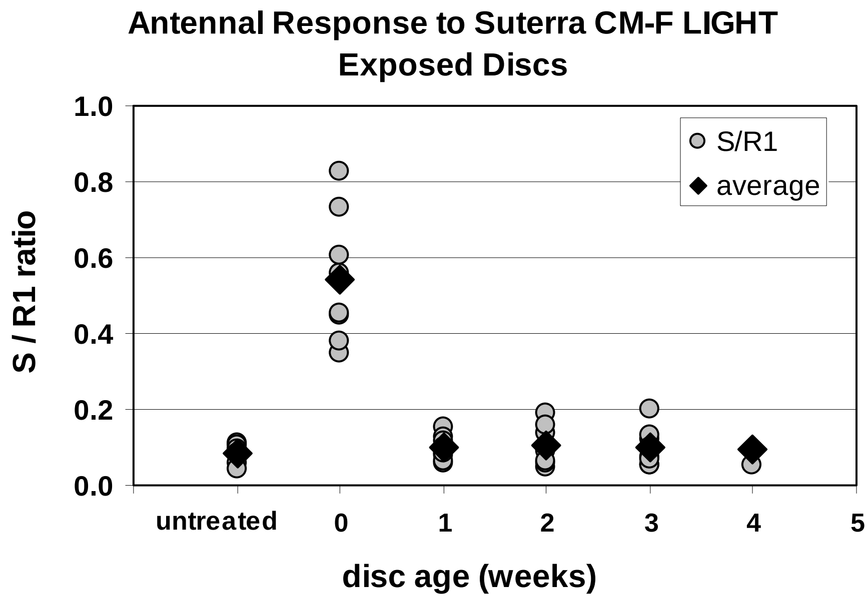

Figure 13. Ratio of electroantennogram responses over time of pheromone treated discs (S-sample) to the reference odor (R1) for filter paper discs treated with sprayable pheromone, exposed to sunlight. 2002

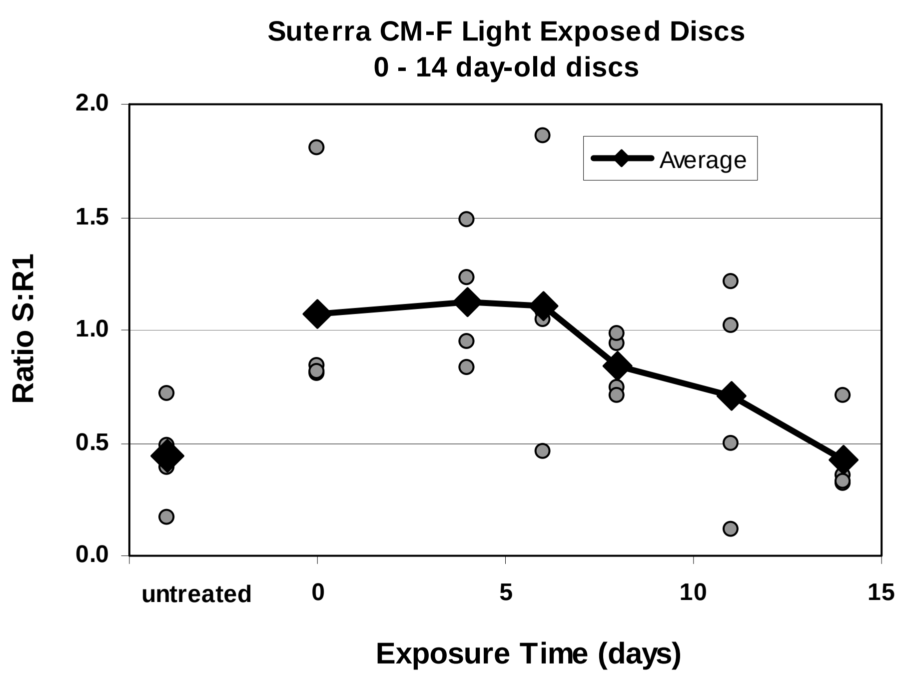

Figure 14. . Ratio of electroantennogram responses over time of pheromone treated discs (S-sample) to the reference odor (R1) for filter paper discs treated with sprayable pheromone, exposed to sunlight, Oct, 2003.