EVALUATION OF ALTERNATIVE PHEROMONE DISPENSING TECHNOLOGIES FOR CODLING MOTH

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ABSTRACT

Two new types of hand-applied pheromone dispensers, "meso-emitters", were developed in collaboration with Suterra that increased the pheromone release rate per dispenser and decreased the number of dispensers per acre to only 12. Realized emission rates per dispenser only achieved 15-33% of the desired release rate. Further modifications are planned for 2007 to increase these release rates. In spite of the low release rate, the program suppressed traps from 92-100% compared to traps in conventional plots regardless of pressure from codling moth. Damage in plots that combined the meso-emitter with their standard insecticide regime in general had less damage than plots using only their conventional treatments, but the differences were not statistically significant. Extreme temperatures in 2006 also damaged the wax matrix meso emitters and may have impacted release rates as the season progressed. Ground applications of the Hercon flake using a custom blower did not provide effective distribution of the flakes within the tree canopy due to the high speed of ejection and subsequent bouncing off from the foliage. Use of flakes filled with a pear ester plant volatile did not provide additional clear damage suppression when combined with existing pheromone programs or as a stand-alone program. However, modifications of the custom applicator planned for 2007 are expected to increase retention rates. Preliminary use of a program modified from the Pacific Northwest that relied on the use of the granulosis virus (Cyd-X), spinosad (Entrust), and mating disruption provided improved control over the grower standard.

INTRODUCTION

Pheromone mating disruption has now become the standard conventional program for many pear and apple orchards in California, but specific regions or larger canopied crops such as walnuts have proven more difficult. Data are presented from both pear and walnut orchards because patterns in the data are more easily seen and differences in codling moth pressure between the orchards also provide different insights. The most common means to deploy the pheromone has been the use of hand-applied dispensers in the tree canopy. Recently, issues have arisen with availability of labor late in the season such that harvests have proven difficult to impossible. One concern is that reliance on large labor pools at different parts of the season may prove problematic in the future. Similarly, differential pay scales for labor in the US and abroad place California growers at a disadvantage. Efforts to develop a less labor intensive and hopefully more cost-effective means to deploy pheromone disruption devices included development and testing of 2 alternative hand-applied dispensers called "meso-dispensers". In addition, we evaluated an alternative approach using a pear volatile to either reduce time spent searching mates or to disorient female host location. Efforts also were made to build our capacity to evaluate alternative pheromone treatments during the winter under lab conditions. Finally, preliminary studies were undertaken to evaluate the partial use of organically approved codling moth tactics within programs that blend organic approaches with conventional strategies such that the overall program can be "softened" without loss of quality or increased risk of damage.

*Meso-emitters – Pheromone Mating Disruption***.** Two devices were explored as alternatives to traditional hand-applied dispensers. Both new dispensers were targeted to have an emission rate ca. 25 times greater than traditional emitters such as the Isomate or Checkmate dispensers. These units, which were deployed at 12 dispensers per acre, should result in a significant savings in labor costs through reductions in the size of the labor crews required and more rapid placement especially in taller tree canopies. Our presumption for walnut orchards is that less than 15 dispensers per acre can still be applied in a cost-effective manner using hydraulic lifts. Two different types of "meso-emitters" were examined in 2006, but the concept can be applied with modifications to other types of dispensers currently on the market. In 2005 we conducted a series of "proof of concept" studies to explore the potential of using a reduced number of pheromone units per acre. The prototype "meso-emitter" in these initial trials deployed 12 units per acre and was constructed from a wax emulsion developed in earlier research. Additional work on release rates conducted in the winter of 2005-6 assisted in the design of a meso-emitter for the 2006 season. Two formulations of meso-emitter were obtained for small plot field trials conducted in 2006. One was a modification of the Checkmate CM-XL dispenser, the other an experimental wax matrix shaped into a block that could be hung by hand. The impact of applications in walnut and pear orchards was measured by codling moth trap catch and nut and fruit damage. Additionally, we sampled dispensers as they aged for analysis of emission rates through time.

Hercon Flake – Ground Applications of the Pear Ester and Pheromone. Growers continue to express interest in pheromone applications that can be applied mechanically, so as to limit their reliance on labor and its associated costs. Therefore, a specialized ground unit developed by the Hercon Corporation was evaluated as a possible means to deploy their laminated flakes. The ground unit allows for rapid application given that it is mounted on ATV units and coverage of all foliage is not as important of a consideration. Given that the flakes do not have to provide perfect coverage, the speed of the ATV can be faster than an airblast sprayer. The Hercon laminated flake can be loaded with either the codling moth pheromone (codlemone) or a plant volatile. Both pear and apple volatiles have been shown to lure codling moths.

The primary emphasis in 2006 was to evaluate the application method as well as the potential use of pear ester filled flakes as potential competitive lures. Because this was the first year using larger plots, only a few orchards with multiple plots were evaluated until greater confidence in the application process was achieved. In essence, the hope is that the flakes with the pear ester would disorient codling moth from egg laying or distract both sexes from time spent mating. The pear ester was only used within this research as an experimental "proof of concept", whereas the pear ester as a commercial product has been developed by a team of researchers from TRECE Corp. and the USDA.

Capacity Building at UCB – Behavioral and Electrophysiological Apparatus. Understanding the behavior and responses of codling moth to various odor sources is becoming increasingly important for researchers because of the diverse methods for deploying codling moth pheromone as well as the potential for interactions with host plant volatiles. Therefore, efforts to build a new wind tunnel at UCB were initiated as well as building a more sensitive device to screen odors or combinations of odors that codling moth can detect. Therefore, a lab-based real-time EAG device was built in combination with a device which allows for mixing of up to 4 odors in different orders or ratios. The EAG measures the responses of codling moth antenna to the odor streams electrically. Therefore, the relative response or lack thereof of the antenna to various combinations provides some type of measure at least of the moth's ability to detect specific chemicals.

Blended Management Programs. Recent research efforts in the Pacific Northwest pears have suggested that reliance on approaches typically associated with only organically managed orchards provides effective management of insect pests without loss of quality in some cases and without additional expenses. In addition, the program was marketed under a specific label which provided some financial incentive. Similar approaches may offer walnut growers opportunities for softer management tactics or for creating new market niches. The program and results are outlined in the website at http://entomology.tfrec.wsu.edu/pearent/pcg.htm for their project titled the Peshastin Creek Project. While some of the orchards are certified organic, other orchards in the project are "blended programs" that rely on many of the same organic techniques, but these orchards will supplement the organic techniques as needed with more traditional control tactics. The logic is that more aggressive treatments may not be needed in many cases and that organically approved alternatives might prove as effective under low-moderate pressure situations. Hence, a preliminary trial was initiated late in 2006 to start to investigate the possible porting of the program from WA to CA. In essence, it is just traditional IPM with the possibility of creating a "soft" IPM program that might present a market advantage in the future. In 2006 we explored the impact of granulosis virus plus the organically approved formulation of spinosad, Entrust, in a codling moth control program in two organic orchard sites. Comparisons were made between the grower program with and without the codling moth virus sprays as well as the addition of a 2 materials, Entrust and Surround.

PROCEDURES

Meso-emitters – Pheromone Mating Disruption

Meso-development 2005-2006. Development of a meso-emitter for the 2006 field season was done in cooperation with Suterra (Suterra, LLC, Bend, OR 97702). Information utilized to set a target range for a codlemone release rate included emission estimates of current market products and evaluation of the prototype based on a wax emulsion tested in 2005. Release rates of the 2005 prototype were determined under fixed lab conditions. Six emitters of the 2005 prototype were constructed and submitted to Dr Vince Hebert

(Food and Environmental Quality Laboratory, Department of Entomology, Washington State University, Richland, WA 99354) for analysis. The 2005 prototype emitters each consisted of 55.6 grams SPLAT Cydia 30M-1 (ISCA Technologies, Riverside, CA), a paraffin emulsion formulated with 1.5% ai codlemone, placed into a half of an apple maggot trap. A wire frame was placed over the base of each apple maggot trap and embedded ca. 1 cm below the surface of the emulsion. These were air dried for five days prior to shipment to Washington. In the FEQ Lab at Washington State, a Volatile Collection System (VCS) was used to trap volatile compounds released from each dispenser and these were subsequently subjected to GC/MS analysis. A complete description of the system is given in: Tomaszewka E, Hebert VR, Brunner J, Jones V, and Doerr M. Evaluating chemical release from commercial codling moth mating disruption dispensers. J. Agric. Food chem. 53: 2399-2405 (2005). Based on published data and the results of the SPLAT emission analysis, development ideas were discussed with several parties and Suterra presented two options for emitters that we tested in the 2006 season.

Based on the results of the codlemone emission analysis described above and rates of currently available products, a target emission rate of 25 mg / unit / day was selected. Two formulations of a meso-emitter were produced for the 2006 season by Suterra. The standard Checkmate membrane dispenser was modified to produce a larger unit with greater emission surface and greater reservoir capacity. This “meso” unit exhibited an 8.1-fold greater emission surface area compared to the standard Checkmate CM dispenser with 4.2 gm of codlemone. A second “meso” dispenser formulation consisted of a wax matrix ((1A Base 3/paraplast 1:1 green) loaded with 4.0 g CM.

Field trials utilizing alternative CM dispensers were conducted in both walnut and pear orchards (see Table 1 for listing of treatments, replicates, and crop). Data from both crops are reported in order to identify patterns of response by codling moth which may be applicable in both cropping systems. Walnut sites utilized the membrane type dispensers only. Pear trials included both membrane and matrix type dispensers. All meso-emitters were dispensed at a rate of 12 per acre into 5-acre treatment plots by hanging at approximately mid-canopy (pears) or at approximately 14-15 feet (walnuts). They were placed in a uniform grid pattern within each 5-acre plot. Adult codling moth activity within each treatment and control plot was monitored by a set of five traps. Large plastic delta traps (Suterra) were baited with 1X or 10X Biolures (two traps of each dispenser) (Suterra) or a CM-DA Combo lure (one trap) (Trece, Inc. Adair, OK 94330). Traps were read weekly and lures changed on the recommended schedule.

Codling moth damage was evaluated twice in pear sites (1000DD and harvest) and three times in walnuts (1st generation, 2nd generation, harvest). Pear samples were conducted by sampling the central area of each treatment and control plot. At 1000 DD, samples were completed by inspecting 20 fruit from the lower canopy of 50 trees in each plot (1000 fruit per sample). At harvest, the samples were made by inspecting 10 fruit from the upper canopy and 10 from the lower canopy on each of 50 trees. In all samples, infested fruit were cut to determine age of the codling moth larva. Walnut samples were completed as follows: canopy samples were conducted from pruning towers for 1st and

2nd generation damage assessments by inspecting 1000 nuts (20 per tree X 50 trees) per plot. Harvest samples were made by a random sample of 1000 nuts (40 nuts per tree X 25 trees) from each plot taken after shake. One orchard was sampled again at second shake by taking 500 nuts per treatment plot. Collected nuts were cracked out and damage identified as to source (codling moth or navel orangeworm) and age (exit or larval instar).

Pears. Replicated trials testing the impact of membrane and matrix dispensers were conducted in three pear orchards. Five-acre treatment plots were established in each site for matrix, membrane and grower program plots. Control plots in the abandoned Volman site were untreated 1 and 2 acre plots. Meso-emitter applications of membrane and matrix type dispensers were made April 28 (Lykins, (LY)), May 1-2 (LumBunn (LB)) and May 4-5 (Volman (VO)). Two sites (Lykins and LumBunn) were actively managed under a conventional pesticide treatment program. The 51-acre Lykins orchard received five pesticide applications for codling moth control (Imidan (5/11, 7/15), Guthion (5/31, 6/26), Assail (7/29)). The 80-acre LumBunn orchard received four applications (Imidan (5/17), Guthion (6/2, 6/20, 7/15)). The Volman site received no insecticide treatments.

Walnuts. Replicate trials using the membrane type meso-dispenser were conducted in three conventional walnut orchards in the Stockton area. All sites were mature trees and varieties consisted of Sunland (60 acre block, AB orchard) and Vina varieties (60 acre block at C. Podesta (CP) orchard, and 18 acre block at Prichard orchard (TP)). Membrane meso-dispensers were placed into the upper canopy by use of pruning towers on May 11 (AB) and May 12 (Podesta and Prichard). Grower treatments for codling moth control were uniform across their sites, thus sprays in our treatment and control plots were uniform. AB orchard received two applications of Lorsban (5/19, 7/5) and one of Brigade (8/23); C. Podesta orchard one application of Lorsban (6/30); and Prichard orchard three applications of Lorsban (5/19, 6/13, 8/25), one of Penncap-M (7/3) and Brigade (8/22).

Meso-emitter aging trial. We set up a trial to measure codlemone emission rates through time. Matrix and membrane dispensers were hung in a pear orchard. An initial sample of 4 units of each dispenser type was collected to establish the baseline measurement. Three membrane and four matrix dispensers were subsequently collected at three-week intervals for 18 weeks following deployment. Samples were returned to the Berkeley lab and frozen until collections were complete. The samples have been submitted to Suterra for residual analysis. Data will be used to estimate emission rates at each time (age) interval.

Hercon Flake – Ground Applications of the Pear Ester and Pheromone. A modification of the Disrupt-CM flake (Hercon Environmental, Emigsville, PA 17318) was made by loading the dispensers with pear ester (ethyl 2, 4-decadienoate, Bedoukian Research, Inc., Danbury, CT 06810) instead of codlemone. Flake applications in both pear and walnut sites were made using a ground sprayer provided by Hercon. The sprayer was mounted on a utility vehicle providing a relatively rapid field application. Trials were conducted in both pear and walnut sites. Codling moth activity in each treatment plot was monitored by a grid of five traps as described for the meso-emitter trials with the exception of the smaller control plots in Volman which were monitored by three traps (1X, 10X and CM-DA combo).

Pears. Flake applications were made in two orchards, the LumBunn and Volman sites. In LumBunn, the treatment was made as an addition to a meso-matrix dispenser into a 5-acre plot for comparison to a matrix-only plot and the grower standard. This comparison was replicated in approximately 5-acre plots in the Volman orchard with controls consisting of untreated 1- and 2-acre plots. Additionally, the pear ester flakes were applied to treatments of Isomate (Pacific Biocontrol) and Disrupt-CM (Hercon) for comparison to the base treatments of Isomate and Disrupt-CM. Because of orchard conformation, treatment plots ranged from approximately 3 to 4 acres for these trials. Flake applications were made May 4-5 into the LumBunn and Volman orchards. All flakes (Disrupt-CM and pear ester) were applied at rates of 0.75 lbs formulated flakes per acre. At 82 flakes per gm, ca. 27,921 were applied to the acre such that a planting of 134 trees per acre in pears with a 50% retention would result in 104 flakes per tree. Isomate-C+ was applied at 400 dispensers per acre on May 18. The pheromone filled flakes were formulated such that 22 gm ai per applied per acre, compared to 21 gm ai per acre with the pear ester.

Walnuts. The modified flake dispenser was applied May 26 to three 5-acre plots within a 60-acre Vina block (AB orchard). The application was made at a rate of 0.75 lbs/acre (21 gm pear ester / acre). Codling moth activity was monitored by trapping as described above. Nut damage was assessed by a ground sample for 1st generation and by canopy sample at 2nd generation by sampling 20 nuts from each of 50 trees. Given a planting of 76 trees per acre, 183 flakes were applied to each tree assuming a 50% retention rate. Only the first generation was evaluated as the impact of the pear ester has been shown to vary as the trees mature.

Capacity Building at UCB – Behavioral and Electrophysiological Apparatus. A new wind tunnel structure was completed with the construction of major components consisting of a contraction cone and filter box apparatus at the intake and diffuser and venting for exhaust. Walls were constructed with glass rather than plastic so as to avoid “pheromone loading” on the walls of the unit. The filtering system includes a MERV 11 HEPA functions to remove particulate matter from the air stream and a one-inch thick charcoal bed that removes volatile contaminants. Provisions in the structural design will permit introduction of background odors into the total airflow in future studies. An internally mounted fan in the exhaust diffuser can be used to adjust airspeed in the tunnel. The exhaust air stream of the tunnel is removed from the test room by venting to the building exhaust system. Airspeed within the tunnel can be measured with a immersion mass flow meter (Sierra Instruments, Monterey, CA 93940) inserted through one of several access ports. A patterned surface placed directly under the glass floor of the tunnel provides visual orientation for moths in flight. We are currently developing methods to introduce test odors from a point source at the upstream end of the tunnel. Successful orientation to odor plumes by codling moth has been achieved with current tests focusing on release rates within a wind tunnel environment.

Additional work has proceeded on the EAG device. The EAG control system has now been programmed so that data extraction and analysis can be conducted. We are currently developing a filtered air chamber to isolate the test platform (antenna holder and test unit) from contaminating volatiles that may be present in the lab air.

*Blended Management Programs***.** Field trials utilizing the blended program philosophy focused on inclusion of the granulosis virus, spinosad, and an early season Surround application. The approach was replicated in two organic program orchards, but could be applied as easily to non-organic orchards. Cyd-X was the granulosis virus used in the trial as it received California registration in spring 2006. The 22 acre Eagle Point orchard was set up as a single experimental block of 20 acres with a 2-acre grower standard. The 56-acre Aldrich orchard was set up with two experimental blocks of approximately 10 acres and 6 acres and two grower standard plots. In both sites the grower standard treatments were to be applied to the entire orchard and the designated experimental plots received the addition of virus (Cyd-X at 3 oz / acre), additional Entrust applications or an application of Surround early in the season. The Eagle Point grower program utilized pheromone (Checkmate CM-XL applied 4/24), and a total of eight sprays which included seven applications of Surround (5/3, 5/10, 5/19, 5/26, 6/29, 7/8, 7/29), five applications of Entrust (5/19, 5/26, 6/29, 7/8, 7/14), and six applications of oil (5/19, 5/26, 6/29, 7/8, 7/14, 7/29). Cyd-X was added to sprays for the designated areas on 5/19, 6/29, and 7/8. The Aldrich grower control program utilized pheromone (Checkmate CM-XL applied ca, May 13-20). The entire orchard was treated with Entrust and oil on 5/18 and oil alone on 6/24. The blended program had 2 additional applications of Entrust at 1.5 oz. per acre and oil on July 2 and 15. Cyd-X was applied inadvertently to the 32 acres of the Aldrich orchard on 5/18, and only to the designated experimental plots on 7/2, and 7/15. Codling moth activity was monitored within each treatment and grower standard plot with a set of 5 traps as described in the general methods given elsewhere in this report. Fruit damage assessments were conducted at approximately 1000 DD for first generation and at the approximate harvest time for orchards in the region. In addition, we conducted brush and count leaf samples for mites and psylla in early and late June from each of the experimental and grower standard plots. Each sample was 100 leaves taken from lower canopy in each plot of each orchard at both early and late June samples and a 100-leaf top shoot sample taken from one experimental and one grower standard in each orchard at the late June timing only.

RESULTS AND DISCUSSION

Meso-emitter prototype emission analysis. The initial 2005 prototype emitter loaded with SPLAT released an average of 6.7 mg (±0.67mg) codlemone per 24 hours at test conditions of 20°C (±0.2°C). Emission rates of polyethylene tube and membrane type dispensers have been determined by the same VCS methodology. Published trials indicate the release characteristics of each dispenser type changes with age of the dispenser. However, dispensers in the age range from >28 days to about 100 days showed release rates ranging from approximately 0.8 to 2.7 mg per day (Tomaszewka E, et al., 2005) for dispensers that are deployed at rates of 200-400 per acre, depending on type. As our goal for the meso-emitter is to reduce point sources for the hand applied units, we did not want the release load per acre to be a limiting factor that might impact the program concept. Thus, we set a release rate goal of 25 mg per day per emitter (300 mg /acre/day). Development ideas were discussed with several parties and options presented by Suterra were developed for our trials in 2006.

The results of the aging trial in 2006 suggested that the wax matrix dispensers were releasing approximately 8 mg per day over the course of the season. However, the dispenser also showed a “thinning” over time and a high variability in final weights. Surveys of the product at the end of the season determined that 40% of the units had failed to survive the entire season with the wax matrix melting at least partially. At 8 mg per day, the projected emission rate per acre was 96 mg. This total is approximately. 33% of the targeted output and ca. 25% of the pheromone output of the typical Isomate program at 400 ties per acre. Preliminary analysis of the membrane dispensers were determined to be only 5.1 mg per day. The projected total output per acre for 12 dispensers would be 61.3 mg per acre which is only 15% of a standard Isomate program at 400 ties per acre.

Moth Flights. The orchards within the study provided a large range in pressures across sites based on the season total codling moth counts in traps baited with 1X and 10X lures (Fig. 1 and 2). Seasonal flight patterns are expressed as codling moths captured per day so as to correct for differences between sample periods over the season. Within the grower standard plots treated with varying numbers of insecticide applications and no mating disruption, total moth counts ranged from less than 0.5 moths in the VO plots to greater than 800 total moths in the LY plots (Fig 1). Insecticide treatments were made to the entire orchard as deemed necessary by the PCA or grower. Similar patterns and counts were observed with the 10X lures in the pheromone treated area with less than 10 moths in AB and VO for the season and >600 in LY (Fig 2). Unfortunately, this meant that for the 2 orchards for which the greatest effort was expended (AB and VO) with multiple treatments, the pressure was too low to make meaningful comparisons (see Table 1 for allocation of treatments by orchard). In addition, the counts for LB and LY were great enough to predict that pheromone MD programs would not succeed without multiple insecticide applications as supplements.

Overall, trap suppression based on the contrast of the 1X lures in the pheromone treated areas to the untreated areas was greater than >92% in all plot regardless of density of codling moth (Fig. 1). For the 2 lowest population counts (AB and VO), no percent suppression results are reported, given the trivial counts in the standards. For orchards at the mid-level of pressure from codling moth (64 and 108 seasonal totals for TP and CP, respectively), trap suppression was 100%. Despite the fact that the pheromone emitters were putting out less than 33% of the targeted totals per acre, effective trap suppression came fairly easily.

As examples, the flight curves for 4 of the orchards with higher counts are shown for the 1X lures (Figure 3, 4, 7, and 8). For the pear orchards, the traps were hung late in 2006 given that the modified dispensers were not available earlier in the year. In addition, the flights were unusually late in 2006. Strong flights were observed earlier in the season for most orchards, but orchards typically experiencing difficulties saw strong resurgent flights later in the year as well. The flight of codling moth before the hanging of the meso-emitters may have allowed successful, unrestricted mating by the females. For the orchards with the highest pressure levels of codling moth (LY and LB), low but consistent breakthrough was observed in the traps baited with 1X lures suggesting inadequate control would be expected. Complete trap suppression of traps with 1X was observed in the walnut orchards with moderate levels of codling moth pressure (Fig. 7 and 8). While some flight occurred before the hanging, the proportion of moths early in the season appears to be less. Thus, damage suppression should have been better in the walnut orchards.

The results from the 10 X lure are shown in Figures 5, 6, 9, and 10. The flights appeared to have the same codling moth pressure in all plots in the LY and LB orchards. A key point was the fact that the program was started a bit late as evidenced by the high trap counts (>15 moth per week in LY and >6 / week in LB) for the pear plots, whereas the counts in the CP and TP orchard initially had ca. 1 moth per trap per week. Similar results were observed in the walnut orchards, but the overall pressures were less.

Damage Suppression. Overall, no statistically significant effects were observed in any of the trials. Average first generation damage was virtually identical for the grower standard compared to the membrane plus grower standard in pears, whereas the matrix MD may have added some additional suppression (Fig. 11). The results from the individual orchards are shown in Fig. 12 with the best results obtained in the LY orchard, whereas the LB orchard membrane MD addition faired the worst. A trend towards increasingly strong effects was observed at harvest, but again the effects were non-significant ($P > 0.05$). The effects of the additions are most easily seen by showing the differences between the plots (Fig. 13) for the first and second evaluations. The VO ranch was not evaluated at final harvest because of extremely low damage levels in preliminary evaluations.

The effects on codling moth damage in individual walnuts are shown in Fig. 14 for all sampling periods. For the first 2 generations, the addition of the pheromone MD appeared to provide some benefit compared to the insecticide, but these differences were not statistically significant when compared across all treatments and crops ($P<0.05$). Only one orchard had measurable damage, “CP”, with highest damage levels observed in the untreated control. The addition of the membrane compared to the insecticide alone plot did not suggest significant control enhancement. If the differences between the plots are shown (Fig. 15), then all plots with MD performed as well or better than the insecticide alone plots for the first 2 evaluations. However, this pattern was lost at harvest despite no clear flight by codling moth. This suggests that the membrane MD program failed to suppress increasing populations which might be expected given the overall low emission rates of the dispensers.

Hercon Flake – Ground Applications of the Pear Ester and Pheromone. Difficulties were found with the application by ground because the high ejection speed from the ground rig resulted in many of the flakes bouncing off of the tree canopy. Only the early season period was evaluated, given the changing odor profiles in pears and walnuts as the trees mature. Late in the season, changes in the attractiveness of the pear ester have been observed.

Despite the research investment, codling moth counts from plots in the pear orchard (VO) are not reported here given the very low flights. No clear reduction from adding the pear ester flakes for trap suppression was observed in the higher pressure orchard (LB) in Fig. 4. In addition, no significant pattern or differences were observed for additional damage suppression from the pear ester flakes (Fig. 16).

Mean codling moth trap counts in the 3 pear ester trial plots are shown in Fig. 17 for the plots using the 1X pheromone lure, the 10X lure, or the combo lure. However, the greatest effect of the treatment was observed with the combo lure which might be expected given that potential direct effects of the pear ester flake treatment on the odor profile of the walnut orchard. No significant differences were observed in the total number of moths or in peak flights between treatments ($P>0.05$; Fig 18 and 19). Given that peak flights only reached ca. 5 moths per trap per week, the trend towards lower counts in the pear ester treated plots are presumed to be just statistical noise. A slight but non-significant depression ($P>0.05$) was observed the pear ester treated plots, but the overall damage levels again were too low to provide a meaningful contrast (Fig. 20).

Blended Management Programs. Trap counts from the grower standard and blended programs for the EP plots are shown in Fig 21 and 22. The relative pressures are shown to be fairly high with a peak capture of 10 moths per day (70 per week) early in the season in the blended plot. Total seasonal counts averaged 390 in the 10X baited traps in the blended program. However the counts in the two treatments became roughly similar later in the season. Low, but consistent, breakthrough in the 1X baited traps also suggested that complete control of codling moth would be difficult. Fairly high trap counts did occur late in the season despite control efforts.

Conversely, the AL orchard experienced much lower pressure for much of the season (Fig. 23 and 24), but numbers did increase in the grower standard plot over time in the 10 X baited traps. A similar pattern was not observed in the blended program. However, much of the increase was in one portion of the orchard which was later subdivided for damage assessments.

The effects of the program on damage are seen in Table 2. The blended program appears to have added additional suppression compared to the grower standard in the AL plot as hoped. While 0.25% damage was observed on average for the blended program in the AL orchard, the grower standard did experience an overall increase in some parts with the one sub-plot having 5.2% damage. Higher damage levels might be predicted for 2007 given the increasing pressures over time in this plot. The inclusion of the virus and additional Entrust applications appears to have continued to suppress the population adequately to commercially acceptable levels despite the “organic” nature of the applications.

For the EP plot, the blended program did have a lower infestation at harvest with a mean of 3.25% compared to 7.4% in the grower standard. Despite an aggressive treatment program, the high densities of codling moth prevented complete damage suppression using just organic approaches. The additional virus applications which are the primary distinction between the treatments provided additional damage suppression, but obviously also additional costs. The effects of the program on mites are shown for rust mite (Fig. 25) and European red mite (Fig. 26). The additional inclusion of the virus plus oil might have had some suppressive effects in the AL plots, whereas the EP orchard did not have any significant populations. Conversely, the European red mite was not an issue in the AL orchards, but more so in the EP plots. No clear reason seems evident for why the blended program should have higher European red mite counts, but populations were rising in both plots.

These data suggest that for low pressure orchards, reliance on these softer alternatives may provide a reasonable alternative depending on cost. Additional benefits for worker re-entry of 4 hours may provide an additional incentive to their use under specific conditions. The approach developed in the Pacific Northwest is actually just traditional IPM tactics but with the emphasis on the use of the softest alternatives first. However, the willingness to use conventional (non-organic) tactics also limits the program's risk if populations appear to be increasing. Because the orchards used in these trials were certified organic, the option of using more aggressive tactics was limited. However, potential benefits for different pricing schedules may also warrant the high levels of damage than typically found in conventional orchards.

Capacity Building at UCB – Behavioral and Electrophysiological Apparatus

Construction of the new wind tunnel (Fig 27) is allowing for more behavioral assays to be conducted that focus more on understanding how to improve mating disruption or how to use plant volatiles as alternative attractants. Similarly, construction of the new EAG unit in conjunction with the wind tunnel will provide additional insights into codling moth responses to odor cues (Fig. 28).

Table 1. Pheromone mating disruption treatments in 2006 by orchard.

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Orchard	Crop	Membra	Wax Ma	Conv. In	Pear Est	Matrix M	Hercon	Isomate	Wax Ma	Membra	Isomate	Hercon F	Untreated Controls
AB	Walnut	X		4X	3X								
TP	Walnut	X		X									
CP	Walnut	X		X									X
LY	Pear	X	X	X									
LB	Pear	X	X	2X		X							
VO	Pear				X	X	X	X	X	X	X	X	2X

The number adjacent to the "X" refers to the number of replicates witin the orchard

Table 2. Percent fruit damaged by codling moth for trial sites using virus (Cyd-X) plus Entrust for codling moth control.

			Orchard	
Sample time	Treatment	Block	AL	EP
1st generation	Blended	Block 1	0.0%	0.2%
		Block 2	0.10%	0.1%
	Grower	Block 1	0.0%	0.0%
		Block 2	1.0%	
harvest	Blended	Block 1	0.1%	4.7%
		Block 2	0.4%	1.8%
	Grower	Block 1	0.0%	7.4%
		Block 2a	0.0%	
		Block 2b	5.2%	

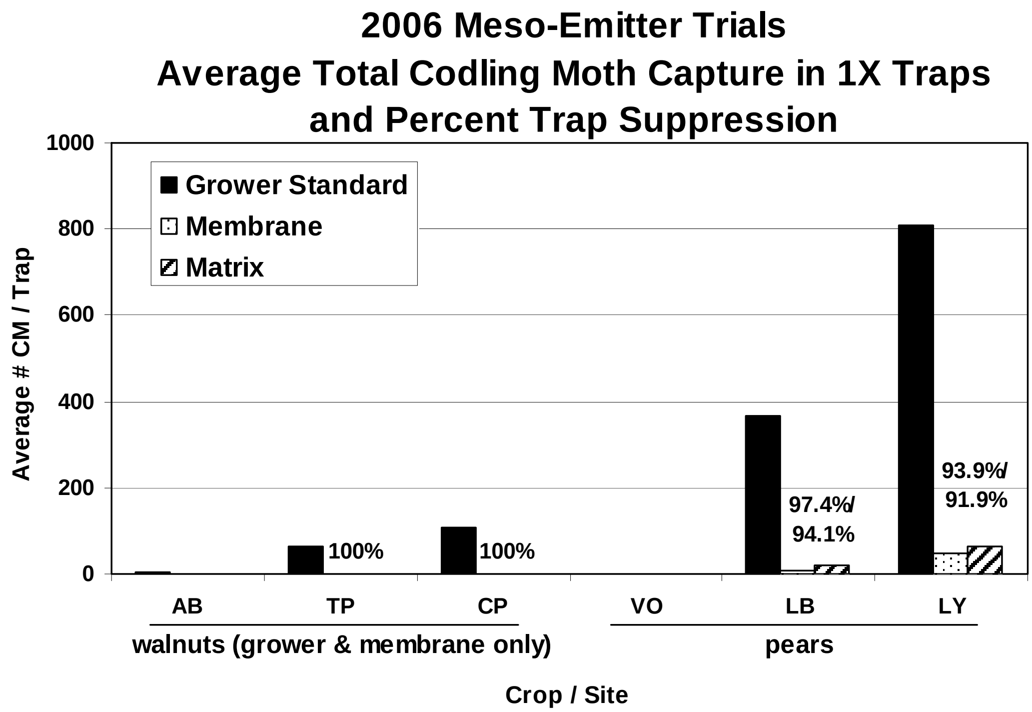


Fig. 1. Total seasonal codling moth counts and percent trap reduction (counts in MD plots versus conventional plots) for 1X pheromone baited traps for 3 walnut and 3 pear orchards.

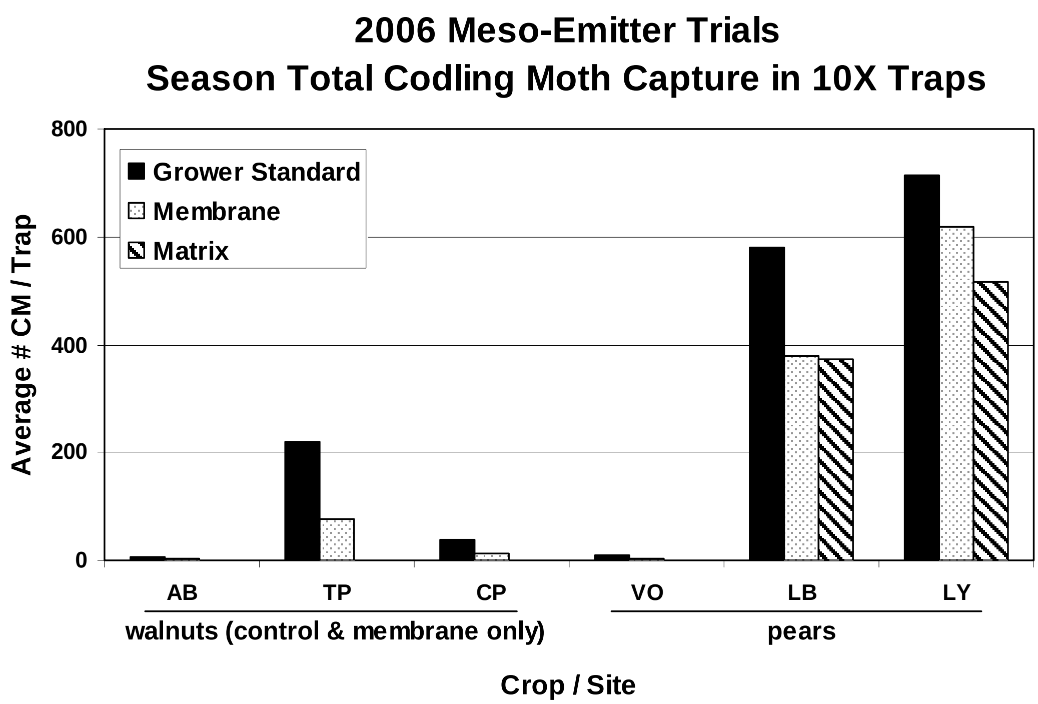


Fig. 2. Total seasonal codling moth counts for 10X pheromone baited traps for 3 walnut and 3 pear orchards.

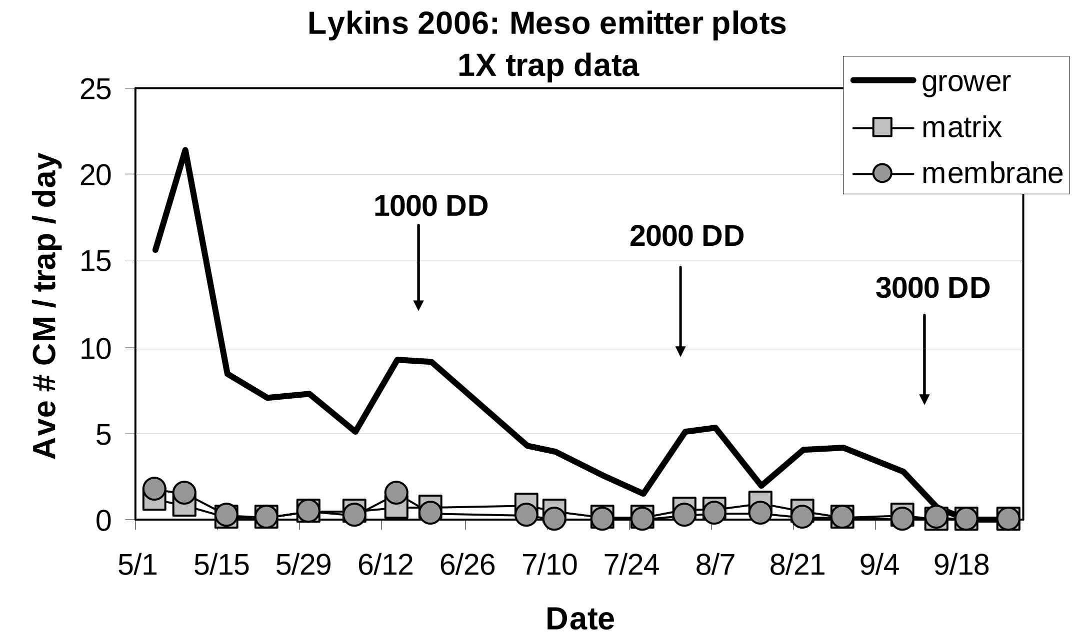


Fig. 3 Codling moth trap counts per day in 1X pheromone lure baited traps for the conventional grower standard, the mating disruption (MD) wax matrix + grower standard, and the MD membrane dispensers plus grower standard plots in the Lykin orchard.

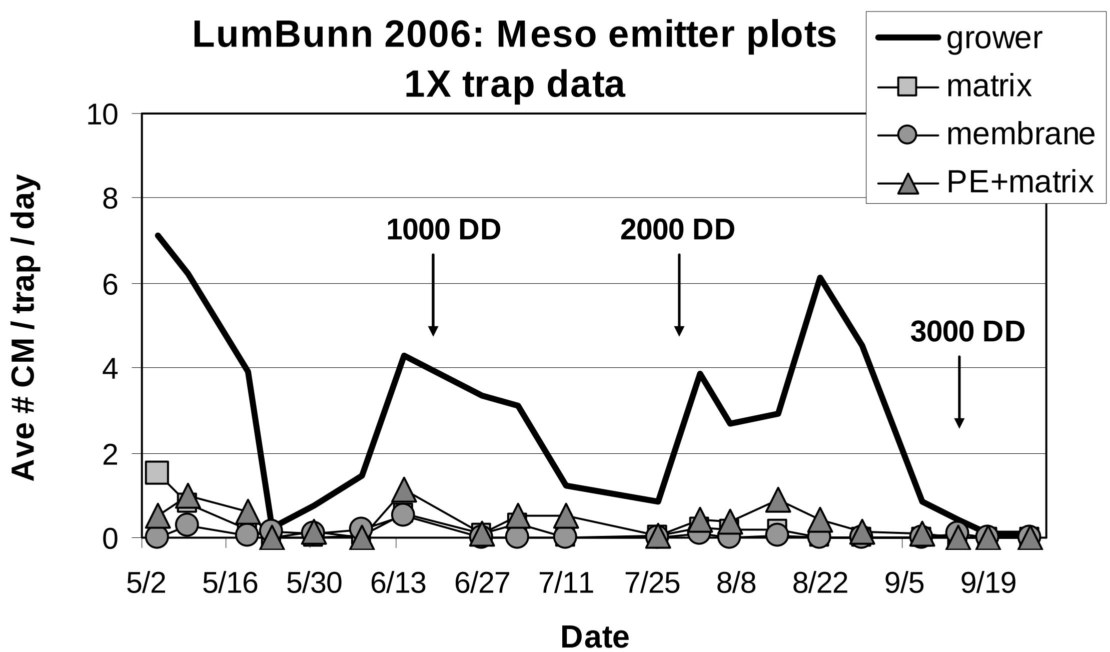


Fig. 4. Codling moth trap counts per day in 1X pheromone lure baited traps for the conventional grower standard, the mating disruption (MD) wax matrix + grower

standard, MD membrane dispensers + grower standard, pear ester flakes (PE) + MD wax matrix + grower standard in the LumBunn orchard.

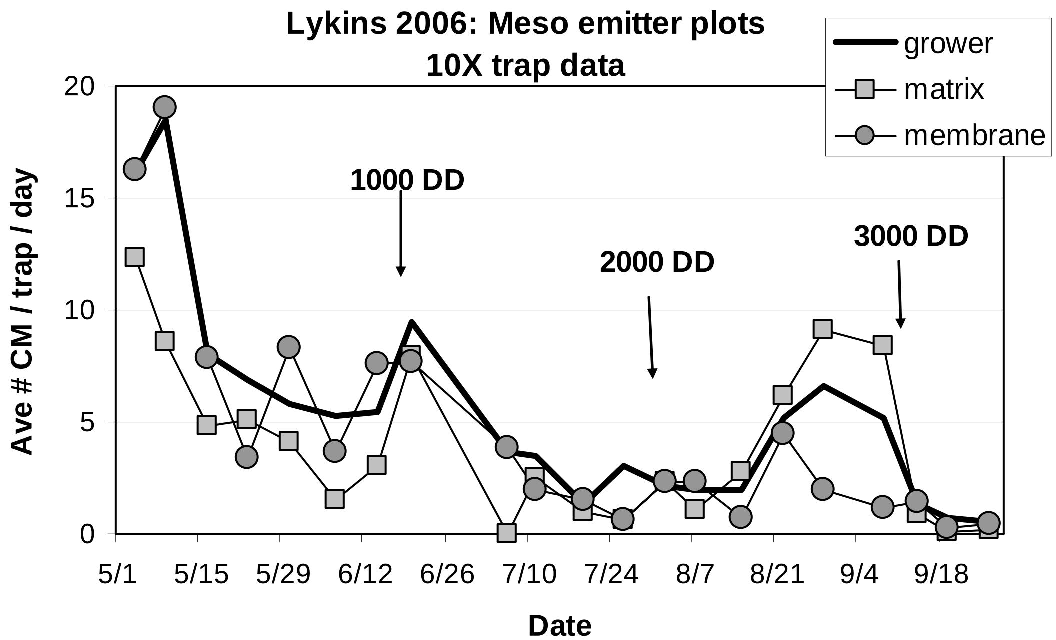


Fig. 5. Codling moth trap counts per day in 10X pheromone lure baited traps for the conventional grower standard, the mating disruption (MD) wax matrix + grower standard, and the MD membrane dispensers plus grower standard plots in the Lykin orchard.

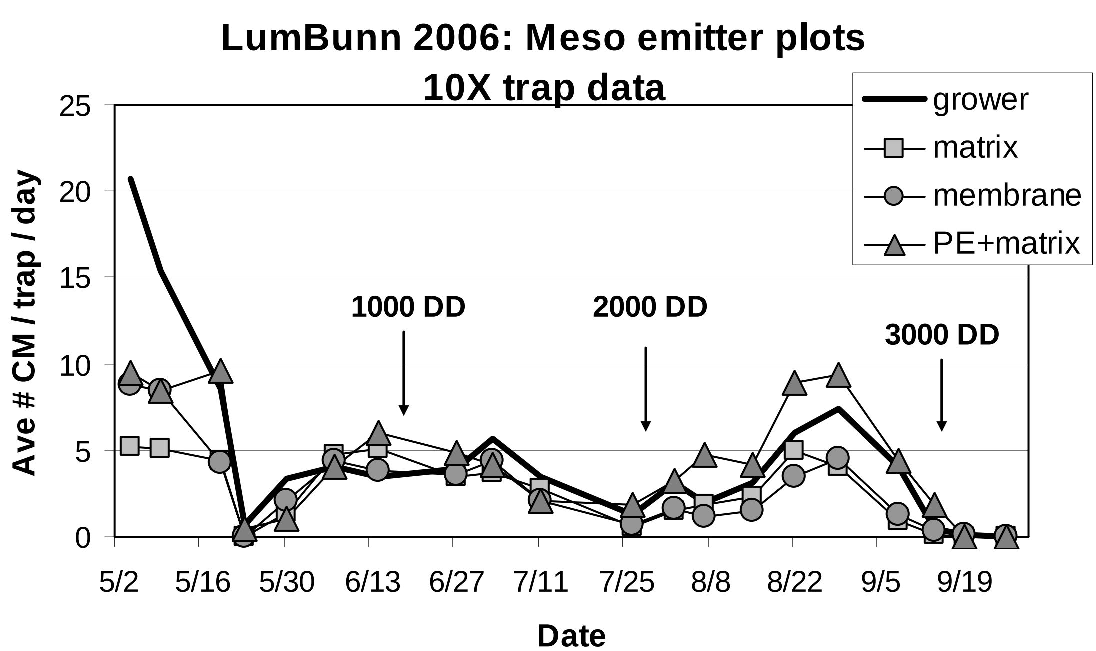


Fig. 6. Codling moth trap counts per day in 10X pheromone lure baited traps for the conventional grower standard, the mating disruption (MD) wax matrix + grower

standard, MD membrane dispensers + grower standard, pear ester flakes (PE) + MD wax matrix + grower standard in the LumBunn orchard.

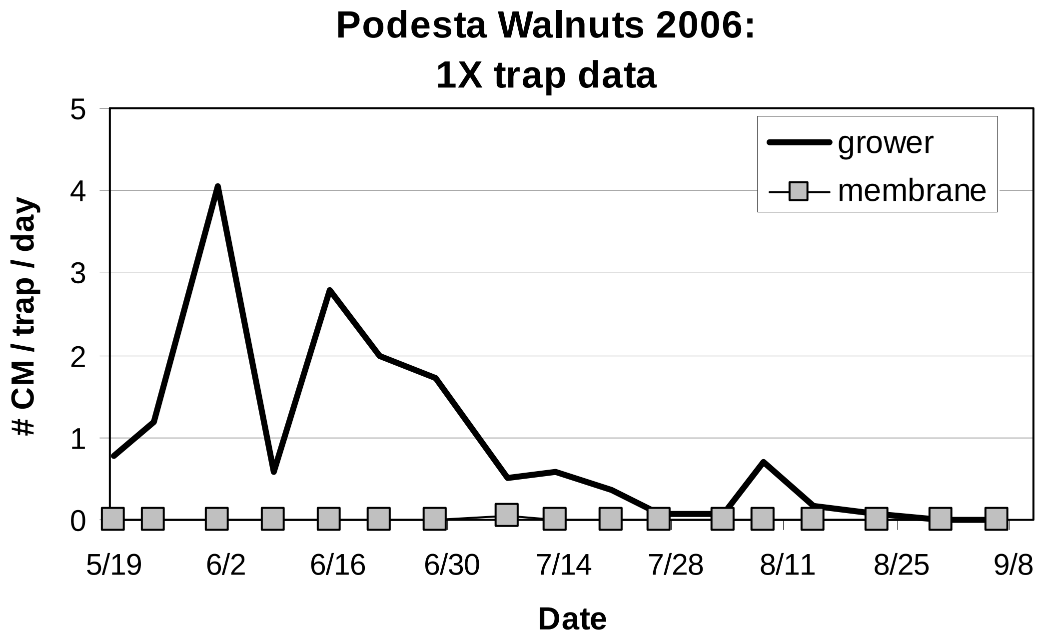


Fig. 7 Codling moth trap counts per day in 1X pheromone lure baited traps for the conventional grower standard and the MD membrane dispensers plus grower standard plots in the Podesta orchard.

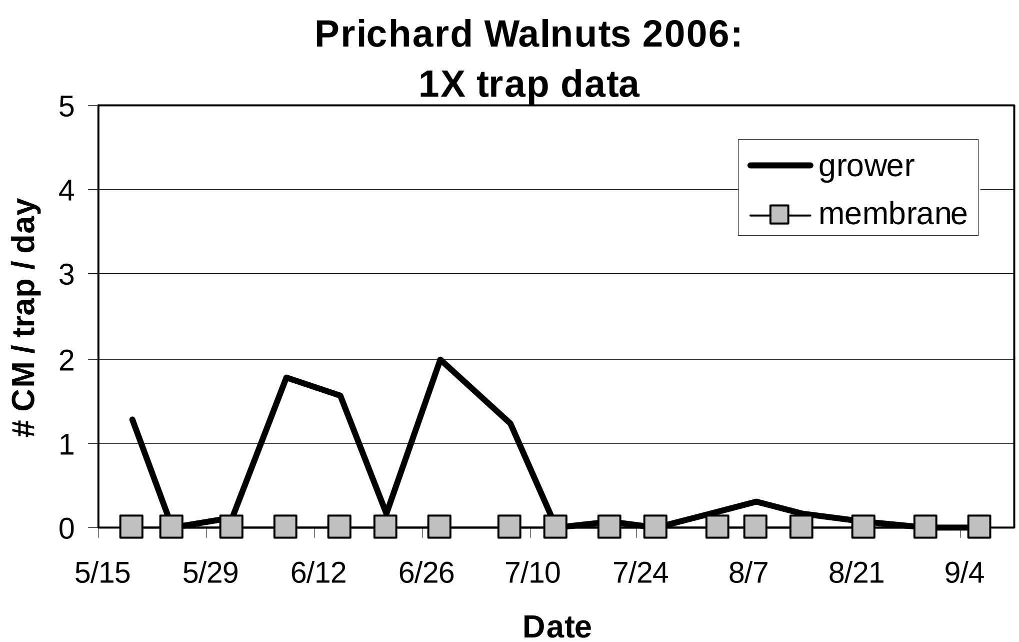


Fig. 8 Codling moth trap counts per day in 1X pheromone lure baited traps for the conventional grower standard and the MD membrane dispensers plus grower standard plots in the Prichard orchard.

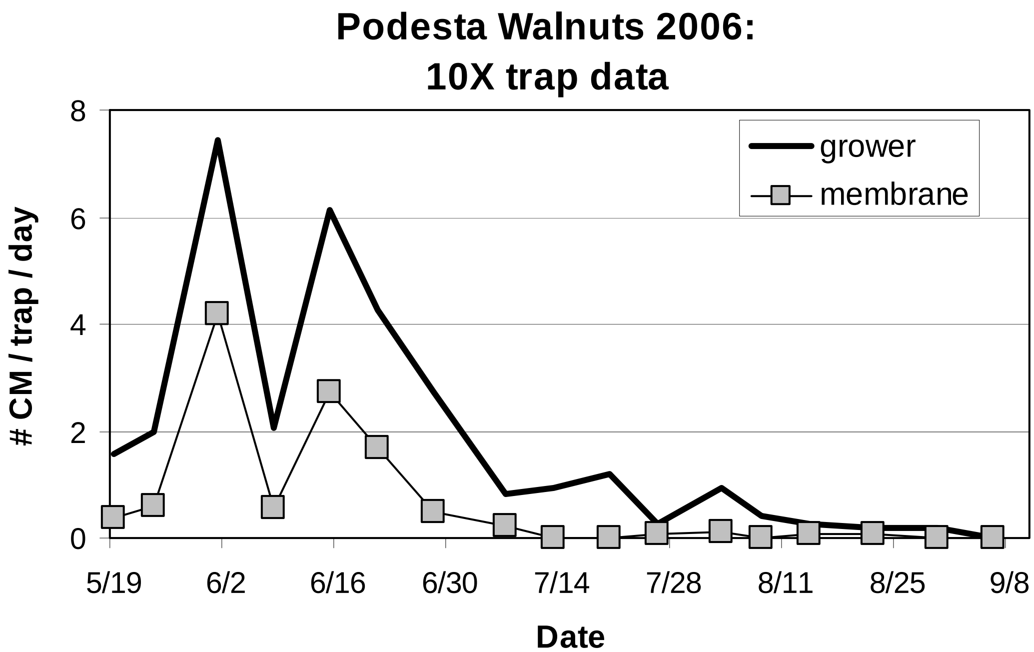


Fig. 9. Codling moth trap counts per day in 10X pheromone lure baited traps for the conventional grower standard and the MD membrane dispensers plus grower standard plots in the Podesta orchard.

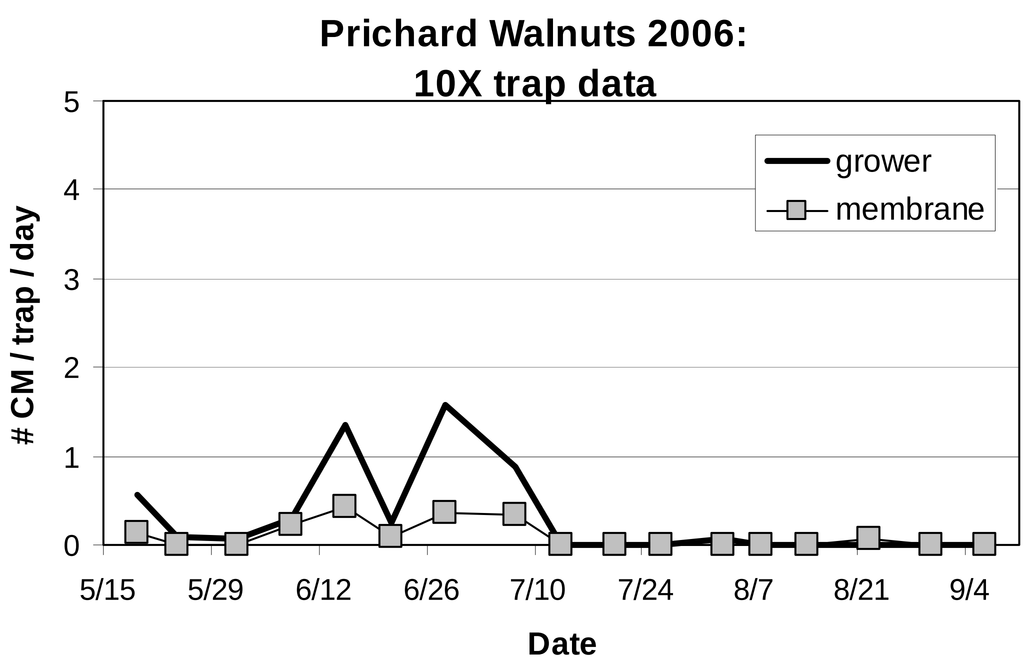


Fig. 10. Codling moth trap counts per day in 10X pheromone lure baited traps for the conventional grower standard and the MD membrane dispensers plus grower standard plots in the Prichard orchard.

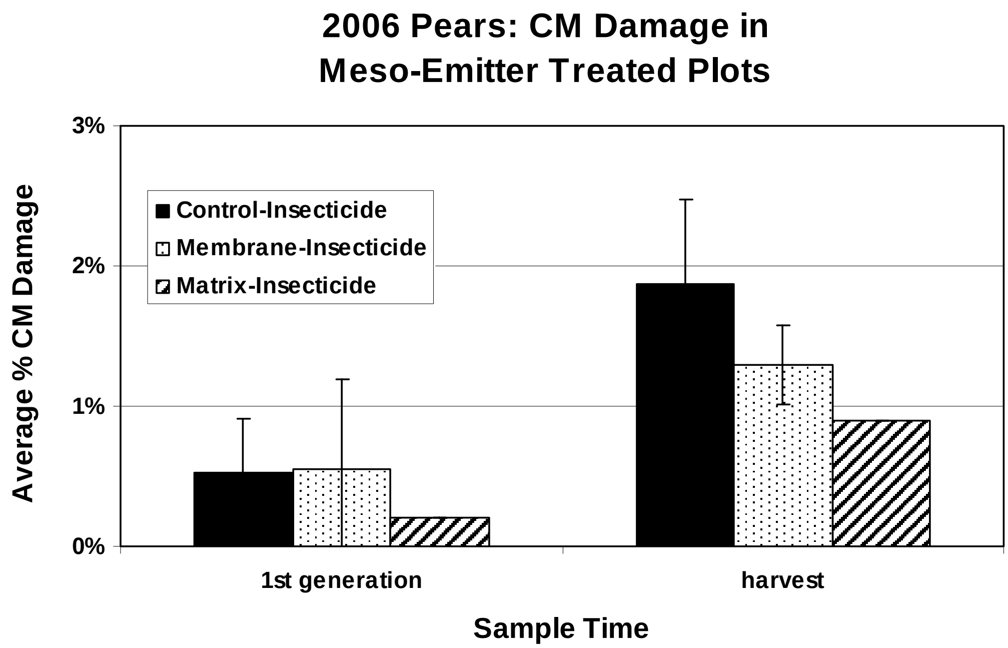


Fig. 11. Mean codling moth damage in meso-emitter treated plots (wax matrix and membrane dispensers) plus insecticides compared to standard insecticide program.

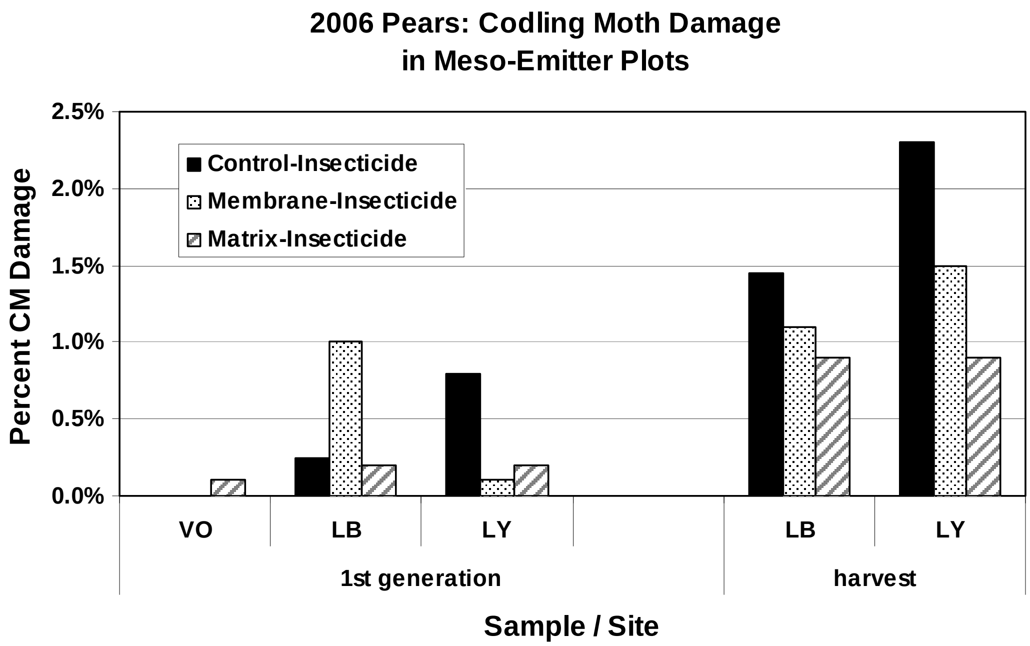


Fig. 12. Mean codling moth damage in individual meso-emitter treated plots (wax matrix and membrane dispensers) plus insecticides compared to standard insecticide program. VO was not treated with insecticides, whereas LB and LY received full seasonal insecticide programs.

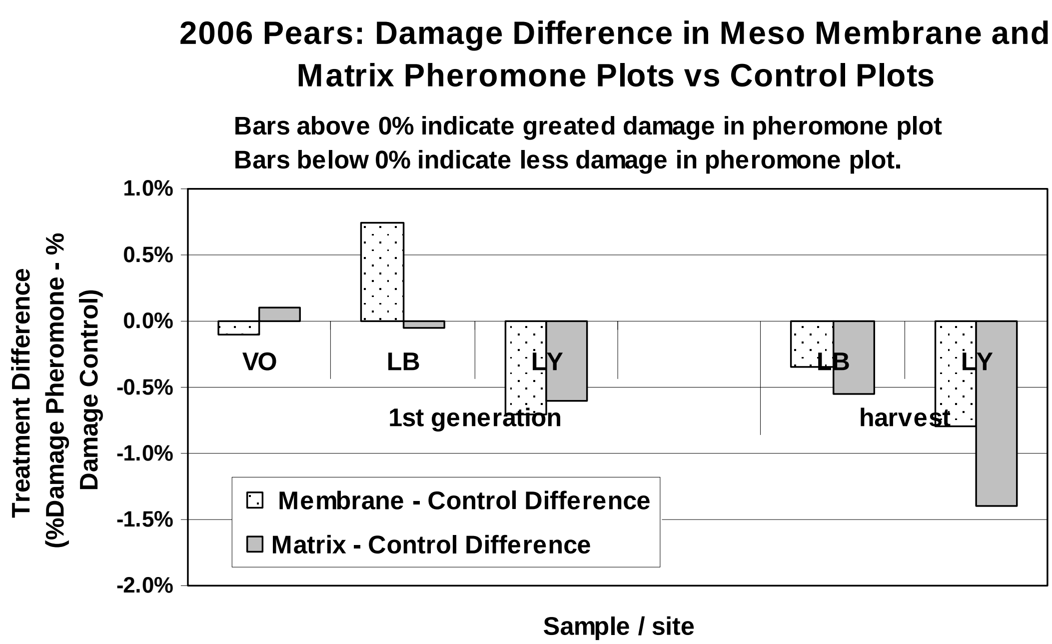


Fig. 13. Difference in codling moth damage between MD plots versus conventional plots. Bars rising above the 0% line suggest no treatment benefit, whereas bars sinking below the 0% line suggest additional suppression.

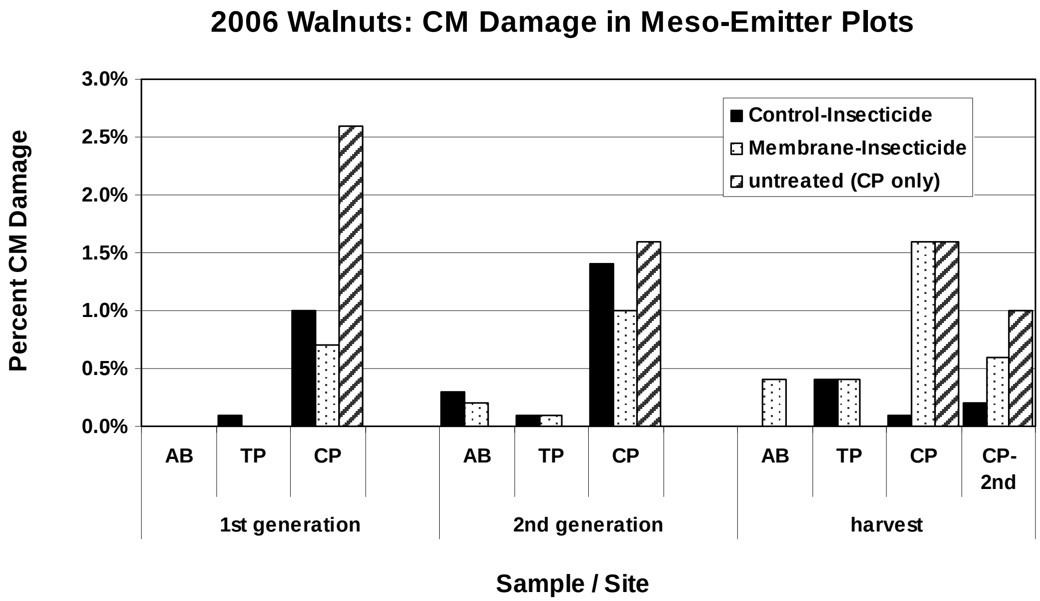


Fig. 14. Mean codling moth damage in individual meso-emitter treated plots (wax matrix and membrane dispensers) plus insecticides compared to standard insecticide program in pears. All plots with the orchard received the same insecticide regimes.

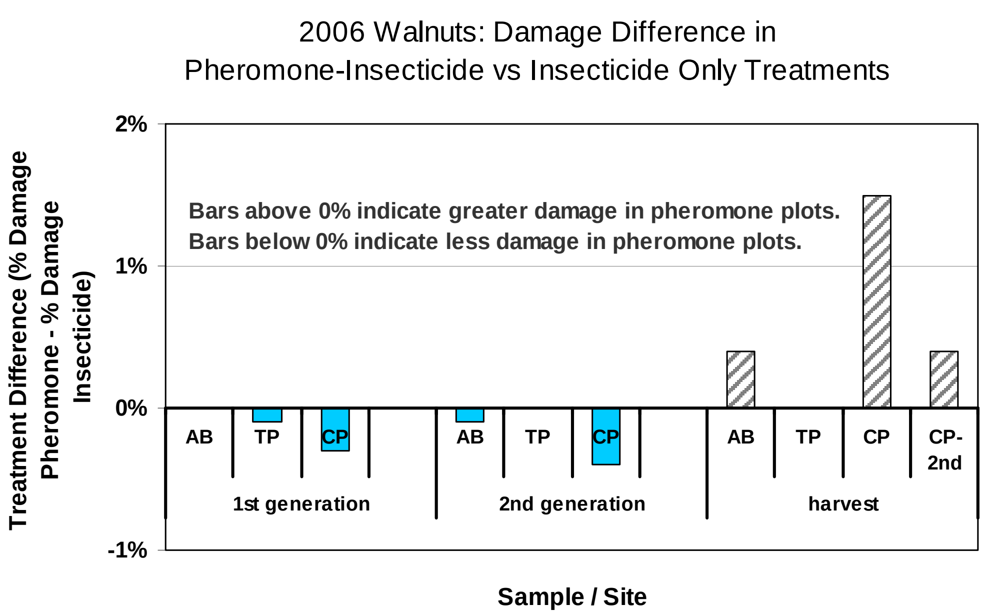
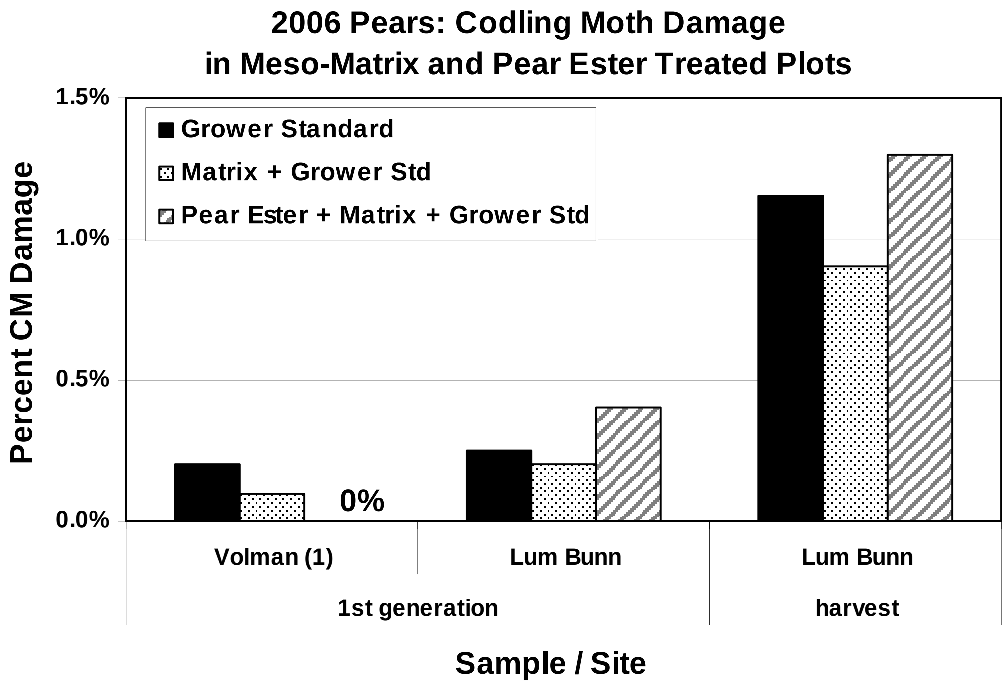


Fig. 15. Difference in codling moth damage between MD plots versus conventional plots in walnuts. Bars rising above the 0% line suggest no treatment benefit, whereas bars sinking below the 0% line suggest additional suppression.



(1) Volman orchard had no sprays in the grower standard.

Fig. 16. Codling moth damage in plots treated with supplements of either the Matrix MD dispensers or Matrix and pear ester filled flakes.

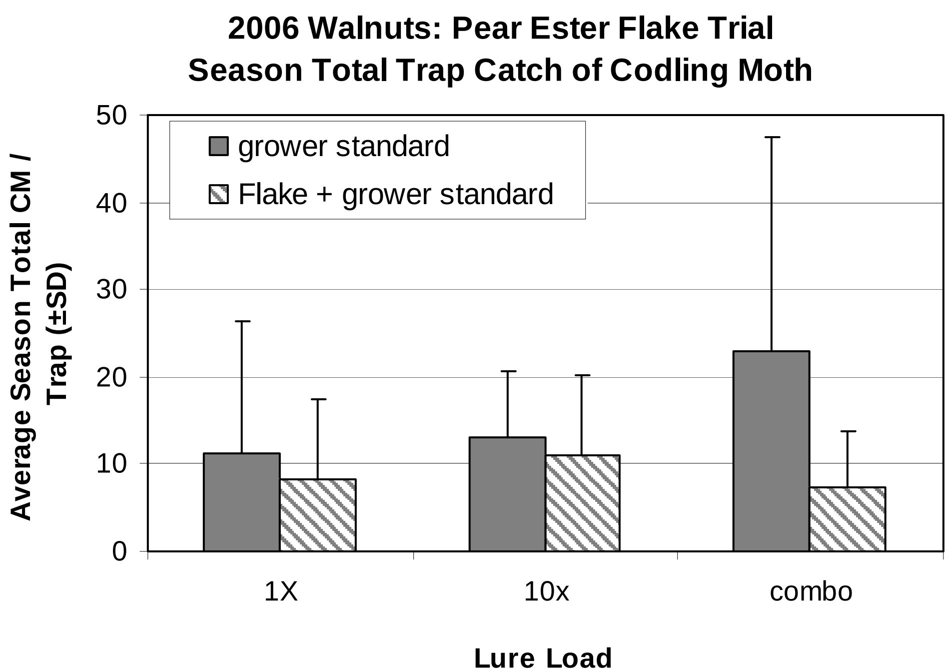


Fig. 17. Average seasonal totals in traps baited with 1X, 10X, and combo lures for plots treated with either the grower insecticide standard or the standard plus the pear ester flakes.

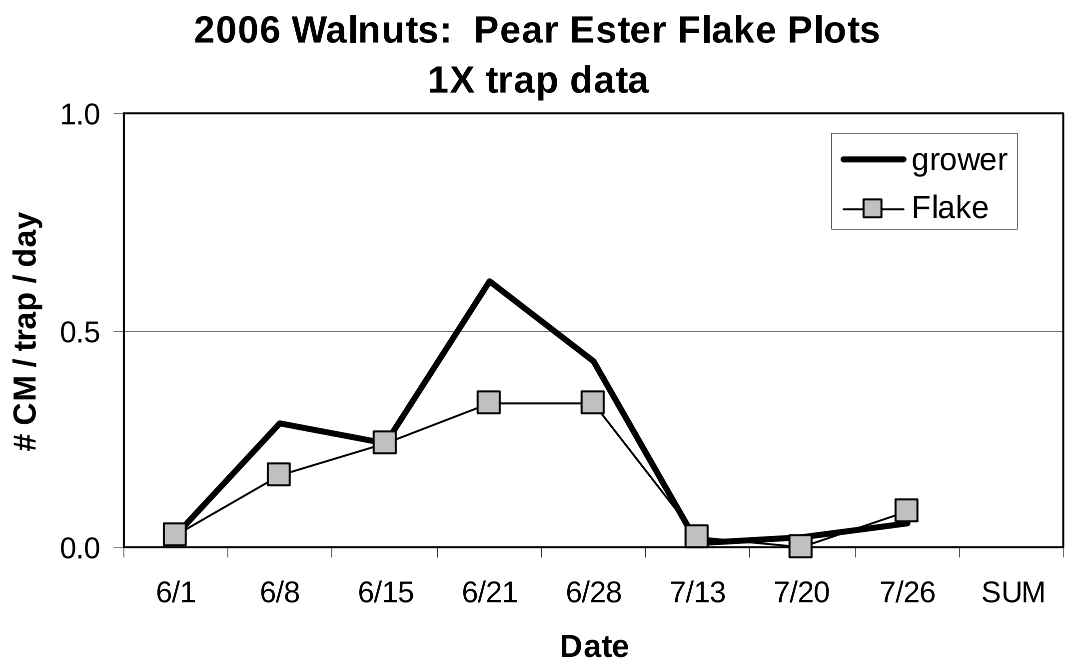


Fig. 18. Coding moth flights per trap per day in 1X baited traps in plots treated with the grower standard or the grower standard plus the pear ester flakes.

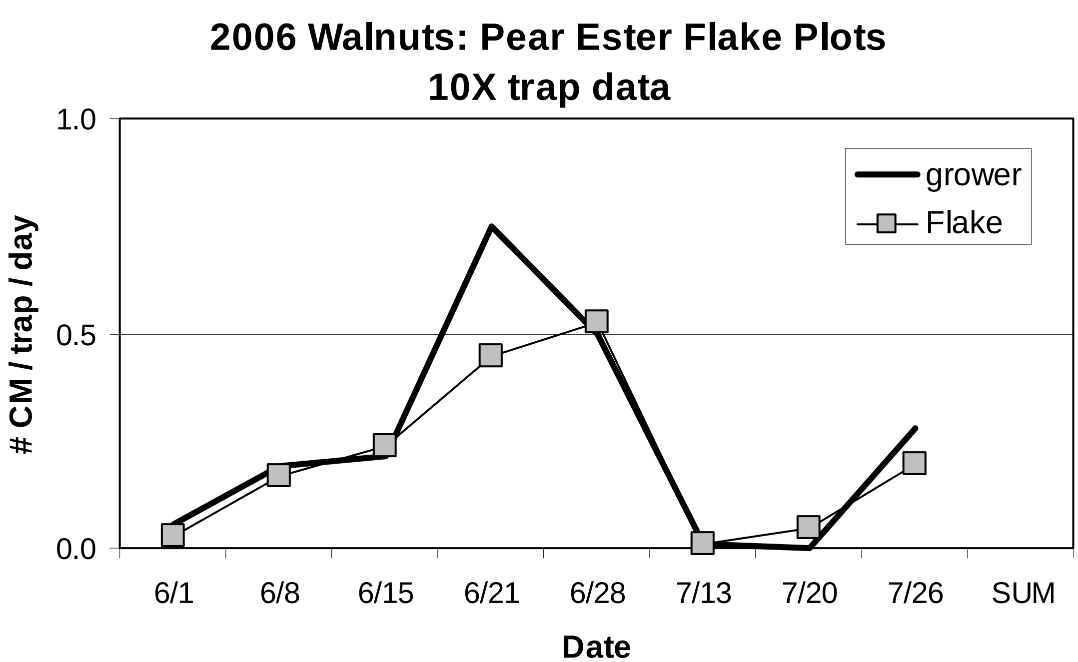


Fig. 19. Coding moth flights per trap per day in 10X baited traps in plots treated with the grower standard or the grower standard plus the pear ester flakes.

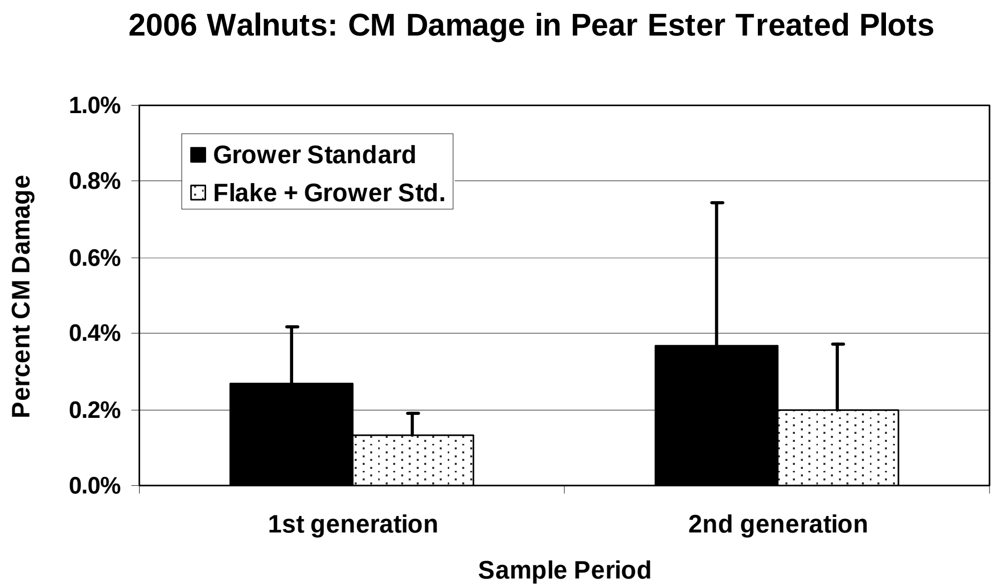


Fig. 20. Codling moth damage after the first and second generation flights in the grower standard plots or plots treated with the grower standard plus the pear ester flakes.

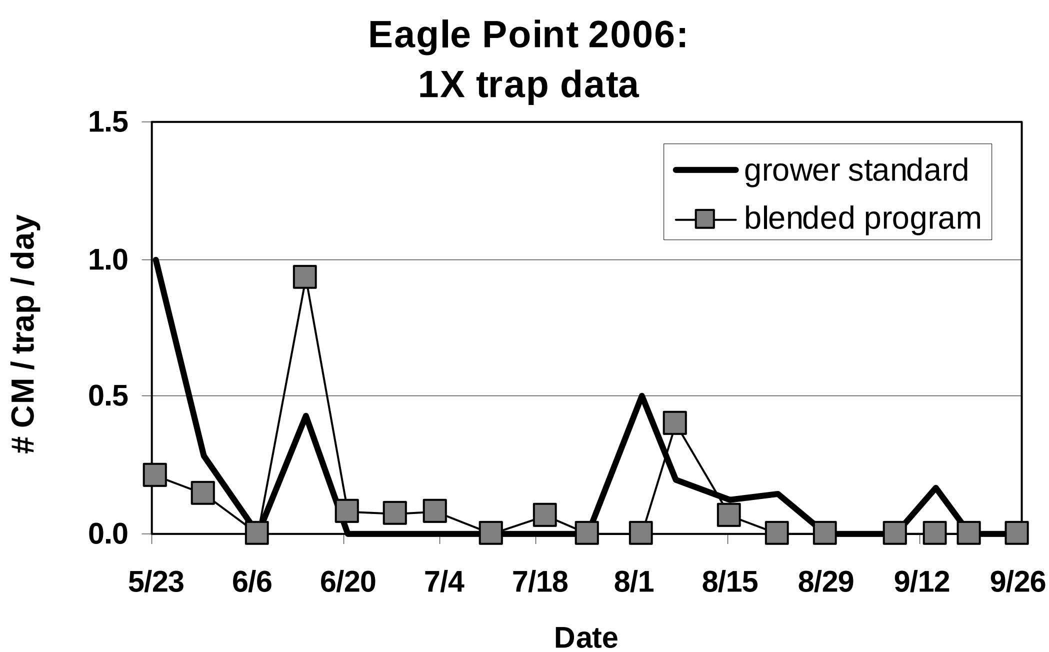


Fig. 21. Codling moth trap capture in traps baited with 1X lures for the standard grower program compared to the standard grower program plus applications of the granulosis virus, Cyd-X.

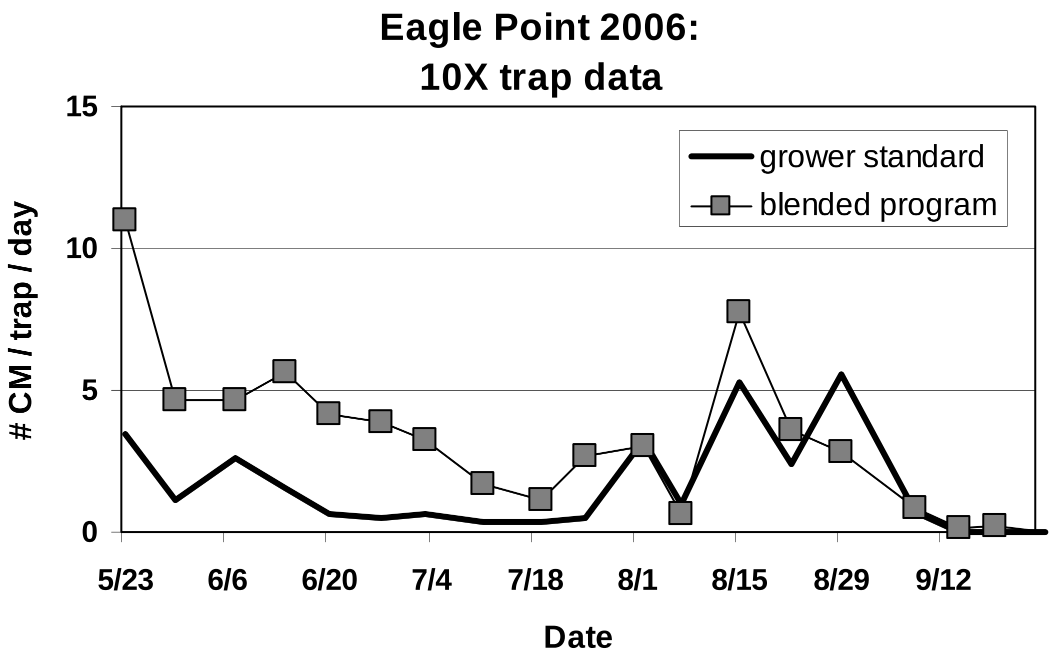


Fig. 22. Codling moth trap capture in traps baited with 10X lures for the standard grower program compared to the standard grower program plus applications of the granulosis virus, Cyd-X.

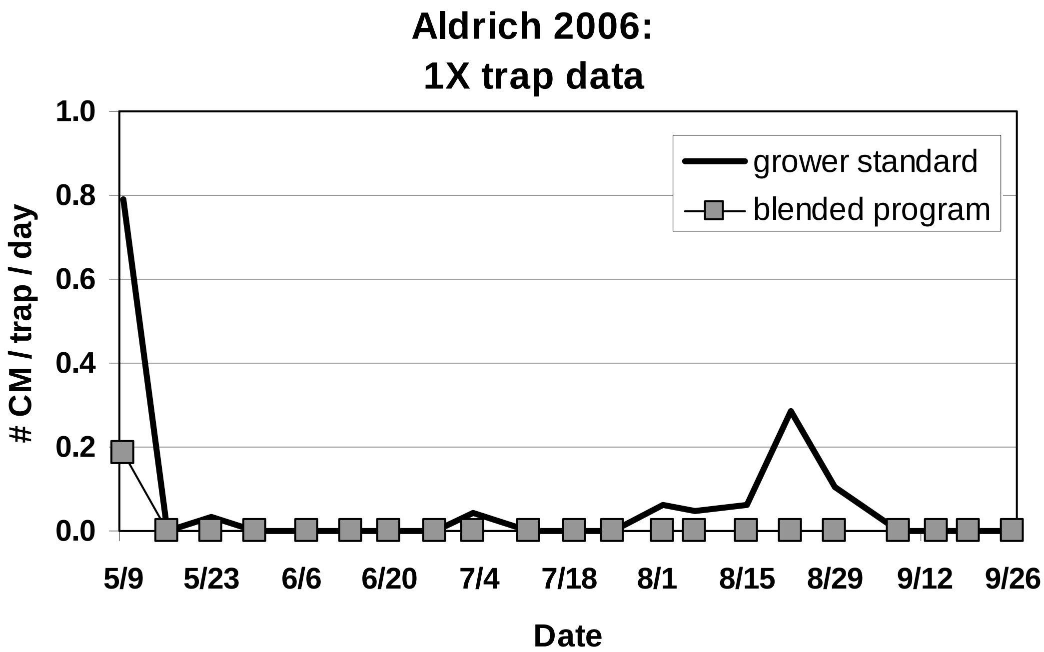


Fig. 23. Codling moth trap capture in traps baited with 1X lures for the standard grower program compared to the standard grower program plus applications of the granulosis virus, Cyd-X, Entrust, and oil.

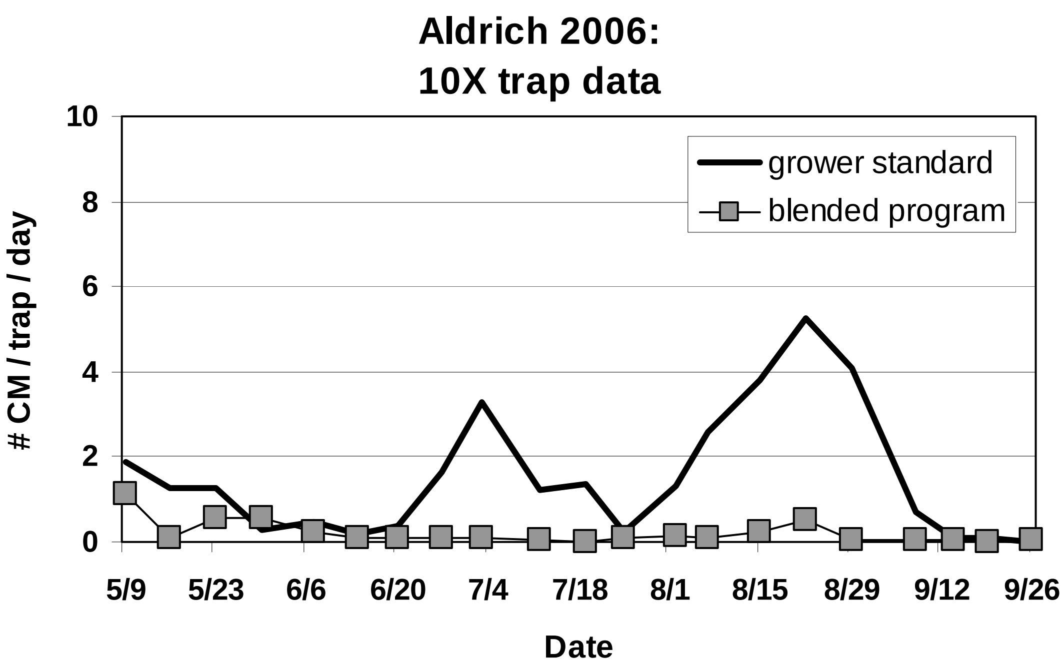


Fig. 24. Codling moth trap capture in traps baited with 10X lures for the standard grower program compared to the standard grower program plus applications of the granulosis virus, Cyd-X, Entrust, and oil.

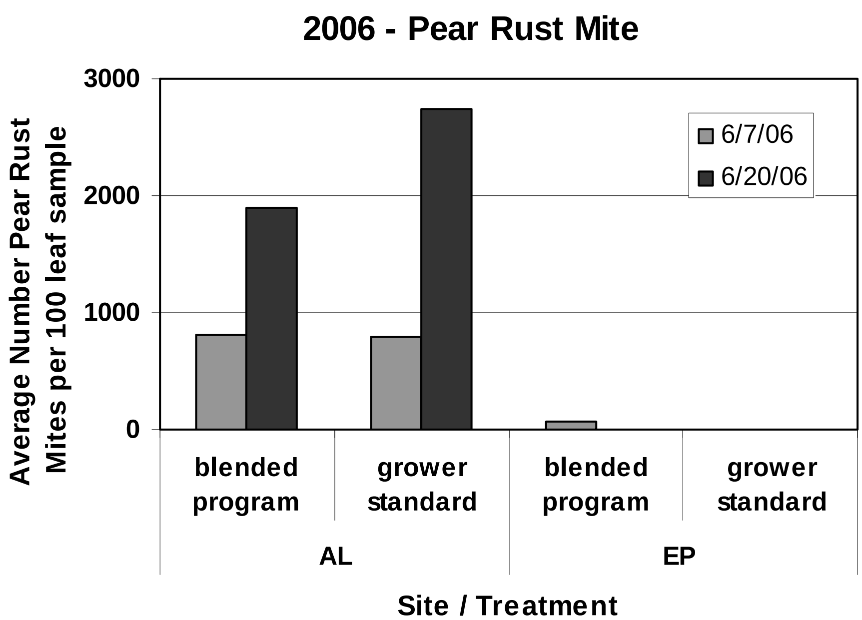


Fig. 25. Comparison of the blended and standard programs for effects on the pear rust mite.

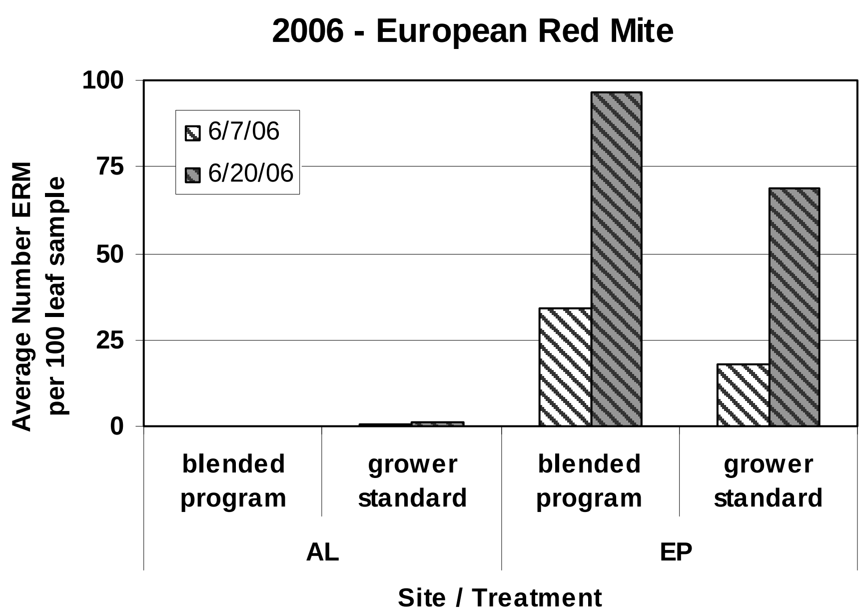


Fig. 26. Comparison of the blended and standard programs for effects on the European red mite.

Fig. 27.   Wind tunnel for assessing flight behavior of codling moth.

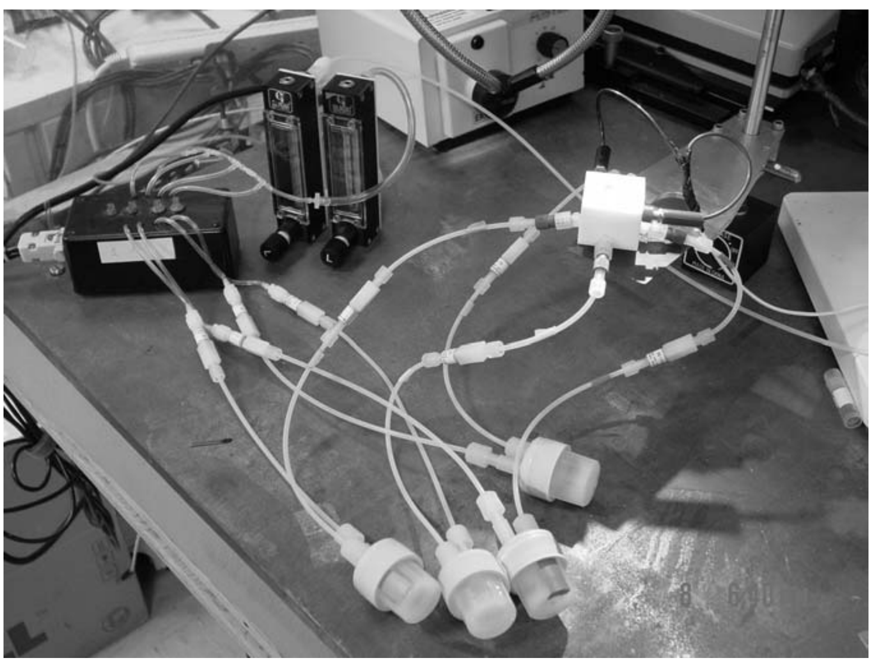


Fig. 28.   EAG apparatus for assessing codling moth antenna responses to odor stimuli.