DEVELOPMENT OF COST EFFECTIVE PHEROMONE MATING DISRUPTION FOR CODLING MOTH IN WALNUTS AND PEARS

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ABSTRACT

New pheromone meso-emitters were tested in 2007 that emit higher levels of pheromone per dispenser than current hand-applied dispensers. Based on winter data developed in the lab by Suterra, the meso-emitters were deployed at lower rates of 12-60 point sources per acre compared to the traditional 180 dispensers per acre. Total pheromone emitted per acre exceeded or equaled the emission rate of the conventional Checkmate pheromone program. Extreme codling moth pressure situations were tested in pears with mixed but overall positive results. Within one orchard with excessive populations, both the meso-emitters and Checkmate failed to provide adequate control. Within a second orchard, all plots with the meso-emitter improved control of codling moth, but the differences were not statistically significant. In walnut trials with more moderate pressures, the meso-emitters provided significant reductions in codling moth damage compared to the control. Within a study looking at the effects of number of point sources per acre, no significant advantage was observed when the number of point sources per acre was increased from 12 to 60 points per acre. All plots except one had total pheromone levels per acre that exceeded or approximated those of traditional pheromone programs for the duration of the trial. One treatment using emitters at 18 units per acre but the same total amount of pheromone as a traditional Checkmate program produced comparable results to Checkmate. Both treatments, which also had the grower insecticide management program overlaid, showed a statistically improved control program over the grower insecticide alone program. Other alternative pheromone emitters also were investigated in 2007. A new Isomate meso-emitter using a chain of twin-tube dispensers was evaluated in an unreplicated walnut trial. Both damage and trap suppression were lower than the untreated control. An experimental meso-emitter developed by Trece was evaluated for trap suppression only. The Hercon DISRUPT MicroFlake-CM was applied by ground in a replicated trial in walnuts. Trap suppression was observed though low codling moth pressure presented no damage in control or treatment plots. Application of MicroFlakes at two different ejection speeds indicated greater height was achieved at the higher rate but speed made little impact on distance measures. Retention of flakes and minimization of "bounce off" improved at the slower ejection speed though differences were not significant. Supplementation of an insecticide spray program with the microencapsulated pear ester, DA-MEC, was investigated in large treatment plots. Paired treatments (insecticide vs insecticide plus DA) of Intrepid and two rates of Imidan were applied three times for control of the overwintered and first summer codling moth generations in a replicated block trial. A June canopy sample did not reveal any benefit from the supplement. Harvest samples indicated codling moth damage ranging from 0.2 to 0.6% less in DA supplemented plots than insecticide alone treatments, though differences were not significant. Both full and reduced rates of Imidan provided control levels that were comparable to the grower standard. The orchard did have significant codling moth pressure as evidenced by higher levels of damage in the Intrepid treated plots. Timing of the Intrepid treatments coincided with the Imidan application timings which was not optimal given the different mode of action for Intrepid.

INTRODUCTION

Development of Pheromone Meso-Emitters

Pheromone mating disruption continues to be the backbone of many codling moth suppression programs in pear and apple orchards. The most commonly used dispensing technology, the hand applied dispenser deployed at 150 - 400 units per acre, is a labor intensive application method for any of the codling moth associated crops. While the application continues to be relatively cost effective, increasing concerns about the cost and availability of agricultural labor has generated some apprehension. Similarly, hand-applied dispensers have not proven logistically feasible for large canopied tree crops or orchards since current recommendations suggest placement of the dispenser in the upper 1/3 of the tree canopy.

An alternative dispenser, which is a mechanical aerosol emitter commonly referred to as a "puffer", is an easier and less costly application process given that the unit is applied at one dispenser for every 1-2 acres. Mechanical issues of the puffer units that were identified in past years have been corrected and the current puffer unit appears more reliable. However, some growers remain reluctant to invest in the puffers for two reasons: a) distrust of a mechanical device that could fail, and b) the fact that effective pheromone plume coverage is difficult with smaller, thin orchards.

Development of a reliable non-mechanical, passive pheromone dispenser that also had reduced application costs would be highly desirable for some operations. The development of a "meso emitter" which would release codling moth pheromone at higher rates per unit than the traditional hand-applied dispensers was hoped to be deployed at fewer dispensers per acre than conventional hand-applied programs. Initial development of meso-emitters was started two years ago in my lab using prototypes made from a wax emulsion. Positive results, as seen by trap shutdown, were observed using these emitters at only 12 units per acre. Two experimental products developed by Suterra (Suterra LLC, Bend, OR 97702) the following year included a wax formulation and an enlargement of the standard hand-applied Checkmate device. Field trials were conducted with both products in 2006 using an application rate of 12 units/acre and the assumption that these units would emit approximately 25 mg ai/day. The units fell short of the target emission rate of 25 mg ai per day when an actual rate of ca.5 to 8 mg per day was realized. In spite of these shortcomings, we observed excellent trap suppression (>93%) in all treatment plots regardless of codling moth densities. Likewise, we observed damage suppression in all plots where the meso emitters supplemented the grower standard insecticide program compared to standard insecticide program alone until late in the growing season.

Our trials in 2007 have focused on continued development and testing of a "meso-emitter", having a higher emission rate per unit and reduced application rate (units/acre) than the traditional hand applied dispensers. Emission rate analysis of the 2006 emitters pointed to the need to improve the pheromone release rate to better match our original goal of a 25-30 mg/day release rate. Subsequent development by Suterra provided a number of units from which we selected one that better matched our criteria for use in 2007 field efficacy studies. Additionally, using other funding sources, we were able to utilize the different experimental emitters being tested by Suterra to conduct preliminary trials to determine the optimal number of pheromone release points needed to provide trap and damage suppression. We report on the results for both pear and walnut field trials as the overall result patterns may be more easily identified and each crop may provide different insights into the issues around new technologies. Similarly, pears represent a much more susceptible crop to codling moth, whereas walnut typically is able to sustain higher background levels of codling moth without such dramatic economic consequences. Therefore, each crop type provides a different set of insights and hopefully, more rapid development of an alternative approach. Two other meso-emitters were evaluated in 2007 including a series of "chained" CTT dispensers by Pacific Biocontrol and a novel emitter by Trece.

DISRUPT MicroFlake-CM Studies

Efforts to develop a ground application unit for distributing small micro-flakes containing codling moth pheromone were continued in 2007. One effort focused primarily on understanding means to improve the distribution and retention of flakes within the tree canopy, whereas the second effort examined the effects of a seasonal treatment program on codling moth flights and damage to walnuts. The ground applicator can adjust the angle of the ejection as well as the wind speed of the application. As such, 2 wind speeds were evaluated for their effects on tree canopy distribution and on proportion of the flakes that are retained in the tree canopy. Considerable "bounce-off" of the flakes from the foliage had been noted in the past so the hope was that reduced ejection speed might increase retention without appreciable changes in flake distribution.

DA-Supplement to Conventional Insecticides

A plant volatile was identified by Doug Light, USDA_ARS, as a strong attractant for codling moth in walnut orchards. The pear ester has been micro-encapsulated by Trece Inc. such that the compound is slowly released from the capsule over time. Dr. Light has shown in replicated single tree trials that significant increases in damage suppression were achieved with the addition of low rates of the micro-encapsulated (MEC) pear ester to traditional insecticides. The hope is that the addition of the MEC pear ester would either lower the rates of traditional insecticides that could be used without loss of efficacy or that the performance of more selective materials might be improved. The effect of adding the pear ester to 3 insecticide treatments was evaluated in larger trials using commercial air-blast sprayers. The three insecticide treatments, 2 rates of Imidan and 1 rate of Intrepid, were compared with and without the DA additive. All treatments were applied at the Imidan timing rather than the earlier timing need for materials like Intrepid.

OBJECTIVES

1. Field age emitters and determine release rates through the field season.
2. Field test "best available" modified "meso-emitter" for control of codling moth damage (pears and walnuts).
3. Field trials to indicate optimal number of pheromone release points (at constant per acre pheromone rates) for codling moth control (walnuts).
4. Field trial testing the impact of DA-sprayable as a supplement to insecticide treatments (walnuts).
5. Application of Hercon DISRUPT MicroFlake® CM in a replicated field trial and evaluation of flake applicator parameters (walnuts).

PROCEDURES

Emitter aging trials. Emitters were hung in a pear orchard and sampled at regular intervals in order to evaluate emission rates through time. Fifty dispensers of each of seven emitter types (Isomate C+, Checkmate CM-XL1000, and Suterra experimental units F004, F004.1x, F007M, F007MDD, and F007M.1x) were set out. Four dispensers of each type were collected at each time interval beginning at week 0 (initial deployment), and then at 2, 4, 6, 9, 12, 15, 18, 21, and 24 weeks after deployment. Emission data was highly variable with the small sample size. Thus, data are presented as a 3-day running average to better illustrate the trends over time. Additionally, we measured the weight of each dispenser when it was hung and again when it was collected from the field.

Standardized meso-emitter application for codling moth control. Suterra continued development and lab testing of modified meso-emitters during winter 2006-7. Modifications in the polymer membrane and release surface area were made with the goal of achieving a release rate of 25-30 mg ai per day per unit. This release rate for units deployed at a density of 12 per acre would achieve a per acre release rate comparable to traditional hand applied dispensers. Emitters were aged at 30°C in the Suterra labs and emission rates calculated at different time points. Based on this data, the emitter that best matched our criteria was selected for 2007 field trials. Lab data of the selected unit suggested emission rates that exceeded our goal through day 45, after which time it appeared emissions might drop below our per unit target. To compensate for the decline in emission rates seen as emitters aged, we opted to increase the density of emitters in field trials such that our minimum target field load (per acre) was achieved throughout the entire season.

Based on the winter laboratory data, meso-emitters were deployed at the rate of 24 dispensers per acre into experimental plots using Suterra experimental emitters numbered F007MDD or F007M. These two emitters were the same membrane type and size but differed in the method by which pheromone was loaded into the reservoir. All meso-emitters were hung in the upper third of the canopy in pears or mid-canopy or higher in 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 four traps. Large plastic delta traps (Suterra) were baited with 1X or 10X Biolures (two traps of each lure) (Suterra). Traps were read weekly and lures changed on the recommended schedule. Additionally, delta traps baited with the Pherocon® CM-DA COMBO™ (Trécé, Inc, Adair, OK 74330) lure were used in some sites as a secondary monitoring system. In walnuts, codling moth damage was assessed by canopy counts conducted in late June and mid August (Modesto plots) or late July (Linden), by examining 500 nuts/plot from a pruning tower. Harvest damage was assessed by crackout of 1000 nuts/plot and damage or a present worm was carefully examined to identify codling moth from navel orangeworm. In pears, fruit damage was assessed for first generation codling moth (all sites) and at the approximate harvest timing (Hood orchard only) by inspecting 500 or 1000 fruit in each plot.
Walnut sites. Replicated trials using the F007M emitter (24 dispensers/acre) were conducted across two walnut orchards. Two treatment plots and two grower standard plots of five acres each were located in a 100-acre block of mature Ashley variety walnuts in the Modesto orchard (Figure 1). Two five-acre plots were treated with Checkmate CM-XL1000 for a standard pheromone treatment comparison. A single treatment of five acres and untreated control of 1 acre were located in an 18-acre organic block of mature Payne variety nuts in the Linden orchard (Figure 2). Two additional experimental treatments were included at the Linden site. Five-acre

treatment plots were treated with the Suterra F007.1x emitter applied at 48 dispensers/acre or with the Isomate twin-tube "chain" (Pacific Biocontrol Corporation, Vancouver, WA). The Isomate "chain" was made of two five-dispenser CTT units joined together to make a 10-CTT chain that was placed into the upper canopy. Twenty of the "chains" were dispensed across the 5-acre plot for a total of 200 CTT equivalent units. . Due to the small size of the control, moth activity was monitored by single 1x and 10x traps. Pheromone applications were made April 25-27 in the Modesto site and on April 26-27 in the Linden plot. The Modesto block was treated by the grower with Asana (16 oz rate on alternate rows (8oz/ac), ca. April 27-29 and May 3-5,), Lorsban (4 pts/acre rate, alternate rows (2 pts/ac), ca. May 26-28), and Penncap-M (6 pts/acre, every row, ca. August17-19). The Linden organic block received no supplemental insecticide treatments.

Pear sites. Replicated trials evaluated the effect of the meso-membrane emitters in two Bartlett pear orchards. Five-acre treatment plots were established in each site for the experimental emitters and untreated control plots. One of the more consistent difficulties in pear codling moth research has been locating orchards with enough codling moth pressure to have significant damage as well as a grower willing to sustain that level of damage. Two orchards were identified early in the season, but uncertainties with the management of one orchard precluded early season setup. Three replicated plots of the Suterra F007MDD emitter and three untreated control plots were established in the Hood orchard (Figure 3). Within a second orchard (Eagle Point), two replicate plots of the Suterra F007M emitter and two replicates of Checkmate CM-XL1000 (200 dispensers/acre) were deployed (Figure 4). A single control plot in the Eagle Point orchard was 1.5 acres. Due to the smaller size of this control, the plot was monitored by single 1x and 10x traps. Despite plans to not farm their orchards commercially in 2007, both growers generously provided access and support of the project. Emitter applications were made on March 28 (Hood blocks 1 and 2), April 6 (Hood block 3), and May 1-2 (Eagle Point). The late application at Eagle Point resulted from the ambiguity over possible orchard management changes. Neither orchard was managed for commercial pear production in the 2007 season and thus no insecticides were applied.

Optimized Point Source Number Trial. We set our initial target emission rate at approximately 320 mg ai /day/acre based on standard programs using 200-400 ties per acre. While some programs may use fewer points (ca. 100), the 200-400 tie programs appear to provide the most robust treatment option for varied situations. Suterra had developed a range of products during winter 2006-7 that differed by emission surface area and membrane type. Emission rate data generated by Suterra from lab aging trials was used to develop an experimental protocol that would permit us to use the different emitter types at different application rates (numbers/acre) but maintain similar per acre pheromone rates (Table 1). Thus, we could vary the number of pheromone point sources while keeping the per acre pheromone emissions similar. Six pheromone point source rates were compared in replicated 5-acre plots. One of these treatments was designed as a half pheromone load treatment (target rate 160 mg/day/acre) to provide at least an initial trial examining the quantity of pheromone needed per acre. Checkmate CM-XL1000 applied at 180 dispensers/acre was included as a pheromone standard and two 5-acre grower standard plots were included as controls. Application of the pheromone products were made April 24-27 by placing dispensers approximately mid-canopy or higher with the use of pruning towers and extension poles. The trial was conducted in a single 100 acre block of mature Ashley variety walnuts near Modesto (Figure 1). Given that Ashleys are a susceptible variety and this block would generally have codling moth damage at harvest, our pheromone treatments were tested as a supplement to the grower spray program. The grower program included insecticide treatments of Asana (16 oz rate on alternate rows (8oz/ac), ca. April 27-29 and May 3-5), Lorsban (4 pts/acre rate, alternate rows (2 pts/ac), ca. May 26-28), and Penncap-M (6 pts/acre, every row, ca. August17-19). Given the size of the walnut trees, the study was predicated on the assumption that the pheromone supplements would have a measurable positive impact over the grower's insecticide control programs. Codling moth flight and damage assessments were made as described earlier.

Table 1. Point source application rates and treatment identifications.

Treatment	# dispensers / acre	Target pheromone load mg/day/acre*
F007M	12 (2 dispensers/point)	320
F007M	24	320
F004	36	320
F004.1x	60	320
F004	18**	160**
Checkmate CM-XL1000	180	320
Grower standard	0	0

* Target levels were based on estimates generated under laboratory conditions
** Half-rate application.

DISRUPT MicroFlake application in walnuts. Replicated 5-acre plots were established in a 35-acre block of Serr variety walnuts near Stockton, CA (Fig. 5). DISRUPT MicroFlake® CM (Hercon Environmental, Emigsville, PA 17318) was applied at a rate of 1 lb/acre, with Micro-Tac® sticker at 6 oz./acre. Ground applications were made on June 14 and August 15, 2007, using a Turbo-Tac Applicator supplied by Hercon. Three replicates of the treated areas and three adjacent controls were monitored for codling moth using trap techniques described above with the exception that each control plot were monitored by one trap each of the 1x, 10x, and combo lures. Codling moth damage was assessed only at harvest with a sample of 1000 nuts per block. The Hercon product was applied as a supplement to the grower program. The grower made two applications of Lorsban-4E (Dow AgroSciences, Indianapolis, IN 46268) at 4 pts/ac on May 2 and May 28, and a single application of Brigade WSB (FMC, Philadelphia, PA 19103) at 1.5 lbs/ac on July 31.

Evaluation of flake distribution by the Turbo-Tac applicator. Tests were conducted with the Turbo-Tac™ applicator (Hercon Environmental, Emigsville, PA 17318) to evaluate the dispersal of flakes and retention on a vertical surface under different flake ejection speed rates. The applicator was calibrated to deliver flakes at 160 gm/min and sticker at 128 ml/min. All applications were run for 35 seconds. Trials were conducted with the ejection cannon directed approximately 30° from vertical. The blower engine was run at full throttle, and speed was adjusted by changing the opening of a bypass hose, thus altering the volume and speed of air through the ejection cannons. With the hose closed, all air was directed through the cannons for maximum speed. When the bypass hose opening was half-open, less air was forced through the cannons and ejection speed diminished. Deposition of flakes was made onto collection panels measuring 33 inches square made from 3-mil black plastic bags stretched over PVC frames. The number of flakes adhering to each panel was counted after each application. Panels were laid end to end on the ground away from the applicator to measure ejection distance (two replicates). Panels linked end to end by cable ties and hung on a pulley system between two walnut trees measured height distribution of the flakes (4 and 5 replicates). Flake retention was measured using a modified box and panel setup that was placed at three heights between trees on the pulley system. For this trial the sprayer was 80 inches horizontal distance from the vertical line (or fall) of the panels and panels were set 66, 99 and 132 inches on center above the height of the spray nozzle. Thus, actual spray distance from nozzle to panel was 104, 127, and 154 inches, respectively. The trial was designed to measure "bounce off" from a vertical surface. Modified panels were made to add approximately nine inches of depth such that flakes passing the frame opening were captured and there was no loss of flakes from "bounce off". Plastic sheeting was mounted center and vertical on the frame such that half the opening area was covered and presented a vertical surface. Thus, half of the frame opening was covered with plastic and half opened to the deep box (see Fig. 6). We assumed the number of flakes encountering the "box" and "panel" portions of the unit would be the same and that any difference was attributed to "bounce off". A retention value was calculated at each height and ejection speed as the ratio of the number of flakes on the flat vertical surface versus the number of flakes collected in the adjacent deep box area. Estimates were based on six replicates.

DA-MEC Sprayable supplement to insecticide applications. We looked at the impact of the microencapsulated formulation of pear ester when used to supplement insecticides in a 78-acre block of Ashley variety walnuts near Modesto (Fig.7). A total of six treatments, Intrepid (20 oz/ac), full rate Imidan (6 lbs/ac) and reduced rate Imidan (3.6 lbs/ac, 60% rate) applied with and without DA-MEC (0.71 gm ai/ac) (Trécé, Inc., Adair, OK) was replicated three times in a random block design. Imidan tank mixes were buffered to pH 5.0 using Tri-fol buffering agent (Wilbur-Ellis Company, Fresno, CA). Experimental treatments were applied by speed sprayer (100 gal/ac) three times through the season, on May 1-3, May 28-29, and July 9-12, 2007. Each treatment plot was 3.3 acres and was monitored for codling moth activity by two 1x-lure baited traps. Additionally, 10x-baited traps (1 trap/plot) were placed in the block closest and downwind of a pheromone trial as an indicator pheromone blow-over from that trial. Damage was assessed by a June canopy count and harvest damage assessment as described earlier. The area adjacent the spray trial but in the same orchard block was used as the grower control for damage samples. Grower applications to areas outside the experimental plots were Asana (16 oz/ac, every row May 3-5) and Lorsban (4 pts/acre rate, alternate rows (2 pts/ac), ca. May 26-28) A pre-harvest application of Penncap-M (6 pts/acre, every row, ca. August17-19) was applied across the entire orchard block.

RESULTS AND DISCUSSION

Emitter aging trials. Residual pheromone analysis for emitters aged up to 169 days has been completed. Based on this data, we projected the per acre pheromone load rates used in our point source optimization trial (Figure 8). The target emission rate is shown by the dotted line. Residual data was highly variable between collections. Thus, a three point running average was used to indicate trends in emission rates of the dispensers. The data indicate an initial "blow off" of pheromone after field application which stabilizes for relatively consistent emission rates for most emitters through day 169. Our target emission rate of 320 mg/ac/day is met by only by applications of the F007 and F004 emitters. The intended half-rate application of F004 (at 18 dispensers/acre) fell below target beginning by day 107, though emission rates appeared to match the Checkmate CM-XL1000 rates at days 145 and 169. All treatments matched or exceeded the Checkmate CM-XL1000 application for except the F004.1x which fell below expectations by day 127.

Standardized meso-emitter application for codling moth control. Based on lab-generated emission data on emitters aged at 30°C, we selected the F007 experimental emitter for standardized trials across walnut and pear sites. Though our application rate of 24 dispensers/acre was above our initial target rate, we wanted to assure that adequate pheromone product was released into orchard plots such that we could evaluate the concept of a reduced point source application rate.

Application efforts using traditional pole setups from the ground were documented in the pear plots. Application took our crew approximately 12 minutes per acre (5 acres per hour) whereas more experienced field crews would be expected to be even faster. Applications were made to the walnut orchards using hydraulic lifts, which took much longer, but the time was not documented.

Walnuts-trap data. Codling moth pressure indicated by moth capture in 10x traps indicated variable pressure across orchards and treatment plots in the standardized meso-emitter (Suterra, F007 emitter) trials (Figure 9). Only light to moderate pressure was indicated in the Modesto orchard sites with season total capture ranging from <5 up to 70 moths per plot. The Linden orchard indicated a much greater pressure (>170 moths) in the control plot compared to the meso-emitter plot (<4 moths). However, a significant moth population was present in the meso-emitter plot as indicated by season total capture of 108 moths in a CM-DA combo trap. Suppression of 1x traps in the meso-treated walnuts plots was 100% as no codling moths were captured in these traps (Figure 10). Codling moth flight behavior is shown in Figure 11 for the Modesto orchard site and indicates similar patterns across the plots.

Walnuts-damage suppression. Late season canopy samples performed in all treatment areas found greatest infestation levels in control plots (Figure 12) which experienced 1.2% and 4% damage in the Modesto and Linden orchards respectively. On average, infestation was reduced by about 60 to 80% in the meso-emitter treated plots, compared to the grower treatments.

Patterns of infestation remained similar through harvest with significantly less damage ($P<0.01$) observed in the meso-emitter treated plots (Figure 13). Infestation in the grower treatment sites averaged 2.9% compared to 0.6% in the meso-emitter treatments. Control provided by the meso-emitters was comparable to the Checkmate treatment at 180 dispensers per acre (see point source treatments 24 and 180 in Figure 27). One important point to note again is that the meso-emitter treated plots also were treated with the same insecticide sprays as the "grower control". In a separate trial at the Modesto orchard, plots operated by the same grower with the same varieties, age, and management practices averaged a total 6.3% damage in plots treated with 3 applications of Intrepid for codling moth control (range 5.2% to 7.7%). Thus, the orchard did have the codling moth pressure to produce significant damage levels.

Pears-trap data. The pheromone application in two Hood plots was made at biofix, with the third site added about a week later. Uncertainty about management and the potential for experimental conflict delayed implementation of our program in the Eagle Point site until early

May. Pears sites demonstrated very high codling moth pressure across all treatment plots (Figure 14). Moth capture in 10x traps ranged from season totals of 284 to 1561 per trap (average) in the Eagle Point orchard and 411 and 645 in the Hood orchard. Totals in the Hood plots were capped when the orchard was removed in mid July, thus terminating our project. Given the historic codling moth pressure from 2006 and the counts from 2007, neither orchard would be considered a good candidate for a stand-alone pheromone program, but both provided two excellent examples for testing extreme conditions.

Despite the extreme moth pressure, trap suppression of the 1x traps was observed in treatment plots of both orchards (Figure 15). In the Eagle Point site, trap suppression in the meso plots (98.8%) was comparable to that of the standard Checkmate application (99.2% suppression). Results in Hood were less dramatic, averaging 85% suppression across the three replicates.

As seen in the flight curve generated by10x trap data for the Eagle Point orchard, the moth population was raging through the entire season with initial capture of 75 moths per week and consistent capture of 50 to 140 moths per week in the control (Figure 16). Despite this pressure, 1x traps in the meso and Checkmate treatment plots were essentially, but unexpectedly, shut down through the entire season (Figure 17). In Hood, the 10x trap data for treatments and controls track well and show a very strong 1st generation flight beginning late June and peaking with an average trap capture of 100 moths / week (Fig. 18). While the 1x traps are suppressed early on, no treatment plots remained shut down through the late June-July flight with the 1x traps averaging 20/week (range 5-73 moths) at the flight peak (Figure 19).

Pear Damage suppression. First generation codling moth damage assessed in the Eagle Point site averaged about 22.8% and 20.3% in the meso-emitter and Checkmate treated blocks respectively (Fig. 20). None of the treatments including the control were statistically different from each other (P>0.05). Damage in the control block was estimated at 37.4%. Given the severe damage in this orchard, further assessments at harvest time were not conducted. Clearly, the late application of pheromone and large codling moth population predisposed this orchard to control failure. The lack of acceptable control in the Checkmate plot supports this notion, given that this product has been used commercially on a large scale for many years.

Damage estimates in the Hood plots were variable, though all meso-treated plots indicated reduced infestation levels both at 1st generation and harvest (Figs. 21-22). First generation damage averaged 2.4% compared to 7.5% in the controls, but no statistical difference was detectable (P>0.05). In fact, infestation in meso-emitter treated blocks 1 and 2 was only 0.8 and 1.2%, respectively, while block 3 infestation was 5.2%. Control plots indicated damage levels of 0.8%, 10.8% and 11% and for blocks 1, 2, and 3. Reasons for control 1 to indicate low infestation remain unclear. The meso-emitter aging study reported elsewhere in this report was placed in an upwind block and may have produced a pheromone plume that impacted the site. However, such impact was not indicated by suppression of the 1x traps in this control block. Damage patterns remained similar by standard harvest timing, though the magnitude of infestation had increased in response to the large first summer flight (Fig. 22). Infestation in the control blocks now averaged 28.2% compared to the average of 11.7% in the treatment blocks. Meso-emitter treated blocks indicated damage levels of 2.2%, 3.4%, and 29.6% while control plots had damage levels of 2.8%, 40.6% and 41.2%. High plot variability rendered treatment effects statistically insignificant (P >0.05).

Walnuts-Multiple meso-emitter comparisons in the Linden orchard. Alternative meso-emitter treatments applied in the Linden orchard included the Suterra F007.1x at 48 dispensers/acre and the Isomate chain at 20 dispensers/acre in addition to the Suterra F007 reported above. We assume codling moth pressure was similar throughout this small (18 acre) orchard block as 10x baited traps averaged a season total of 24 and 27 moths in the Isomate and F007.1x treatments, respectively, and the CM-DA combo traps collected season totals of 108 and 122 moths in the F007 and F007.1x treatments. Suppression of 1x baited traps was nearly 100% in all three treatments with only a single moth captured the entire season in the Isomate treatment. At harvest, all pheromone treatments suppressed damage levels compared to the control (Fig. 23).

Optimized Point Source Number Trial.

Point source trial. Codling moth capture in 10x baited traps was low to moderate in all treatment blocks with large variation between plots (Fig. 24). Season total trap catch ranged from an average of 2.5 to 69 moths depending on site location. All pheromone applications impacted moth behavior to the extent that 1x baited traps were suppressed almost 100% throughout the season (Fig. 25). The first generation canopy sample conducted in June found little damage in any treatment plot and are not shown here. Maximum damage of 0.2% was observed in three plots (control, F004.1x at 60 dispensers/ac, F007 at 24 dispensers/ac), and no damage was observed in the remaining eleven plots.

In August, following a late season codling moth flight, we detected damage rates ranging from 0 to 1.2% in the late canopy evaluation. Observed infestation levels for each treatment plot are shown in Figure 26. Much of this was detected as new, early instar infestation. The first shake for harvest was completed in mid September and the impact of the late season moth flight was expressed in the nut samples as late instar worms or exits. All pheromone treatments significantly reduced codling moth damage in contrast to the grower treatment (Fig. 27). There was no apparent trend with increasing the number of point sources from 12 to 180 per acre. The highest level of damage at 0.8% was observed in plots with 12 point sources per acre, but this damage level was not statistically significant from all other pheromone treatments.

One important point to stress is that the plots treated with 18 dispensers per acre using the F4 emitter had a total pheromone emission rate per acre that was comparable to the Checkmate plots. Damage levels were equivalent for these two treatments.

Similar to conventional pheromone mating disruption programs, the meso-emitter approach provided significant reductions in trap counts and codling moth damage for orchards with more moderate population levels. The emitters were able to provide intermediate emission rates that exceeded target levels for the entire growing season. The lack of any strong response to increasing the number of point sources per acre for emitters releasing at higher pheromone release rates supports the meso-emitter concept. The cost advantages and reduced labor requirements for this hand-applied dispenser should prove attractive to growers. Additional testing in multiple orchards with a range of codling moth pressures in 2008 will need to be conducted in 2008 as part of the validation process. Similarly, the effect of the total amount of pheromone per acre will need to be considered as well as part of a cost-reducing strategy.

DA-MEC Sprayable supplement to insecticide applications. Codling moth distribution across all insecticide spray treatment plots was variable with no clear treatment or block pattern indicated by season total capture in 1x-baited traps (Fig.28). Trap data indicated flight peaks in mid-May and early-July with a strong late season flight that peaked in mid-August (Fig. 29). Codling moth damage found in the canopy sample made late June offered no indication that the DA-MEC supplement had improved insecticide control of any of the three materials used (P>0.05) (Fig. 30). Evaluation of harvest samples was complicated by the late season flight that peaked in mid-August. The last experimental application was made on July 9-12, more that 30 days preceding the late flight, and beyond the period one could expect residual control. Despite the pre-harvest Penncap-M treatment applied by the grower for potential navel orangeworm and late codling moth damage, we encountered new infestation in the nut samples collected from the ground after shake. As recent infestation was not a measure of the efficacy of the experimental treatments we did not include recent infestation in the calculations of harvest damage for our treatments. Figure 31 shows the percent codling moth damage attributed to early season infestation. While damage estimates for all insecticide treatments appear to indicate modest improvement (range 0.2% to 0.6%) with the addition of DA-MEC, these differences are not significant (P>0.05). Because the Imidan alone treatments provided excellent control of codling moth, the ability of this trial to detect differences between the DA supplemented and the DA alone treatments was 70% based on a power analysis. Though Intrepid provided significantly less control than Imidan in this trial (P<0.01), recommended application timing for the compounds differ and comparison of efficacy between them is unwarranted by this trial. It can be noted however, that both rates of Imidan provided control comparable to the grower standard program of Asana, and Lorsban. The overall harvest damage from early and late codling moth damage are shown in Figure 32 to show overall pressure was strong in this orchard, but again, these data are as relevant to this study. However, the pattern remained largely unchanged.

DISRUPT MicroFlake application in walnuts. Codling moth pressure in the Stockton site was light as indicated by average total capture between mid-June and mid-September of 5.3 moths per 1x trap and 11 moths per CM-DA combo trap in the grower plots (Fig. 33). In pheromone treated plots, impact on trap capture was observed as no codling moths were trapped in1x-baited traps while trial total numbers in 10x traps averaged 2.8 moths and in CM-DA combo traps averaged 2.3 moths. Damage assessments made at harvest revealed no codling moth damage in any Hercon treated or grower standard plot. While the observed impact on 1x trap capture is promising, the lack of damage in the entire block precludes any analysis of efficacy for this application trial.

Evaluation of flake distribution by the Turbo-Tac applicator. Flake distribution was estimated at two ejection speeds. The horizontal throw of flakes at the two speeds indicated only a slight increase in distance at full speed (Fig. 34). The flake throw distance at reduced ejection speed appeared to peak at 149 inches while the full speed application was fairly flat across the 116 to 182 inch distances. Both treatments dropped rapidly between the 182 and 215 inch (15 and 18 foot) distances. A greater distinction is observed in height that the flakes are thrown when ejected at the two speeds. Figure 35 shows the vertical distribution of flakes retained on panels when treated at the two speeds. At reduced speed, the greatest number of flakes was captured at a height of 194 inches while at full speed the greatest number was captured at 260 inches. At reduced speed, more than 70% of the flakes were deposited at a height of 162 inches or less while the full speed indicated capacity to deposit 50% of the flakes above this height.

Capture of flakes in the canopy has been a clear concern as inspection of the orchard floor following application generally reveals many flakes on the ground. “Bounce off” of flakes off the leaf surface when they hit at high speed can be seen if one watches the application process. We tested the impact of reduced ejection speed on this loss of product due to the “bounce off” effect. Figure 36 shows the percent of flakes captured on vertical panels placed at different heights for two ejection speeds. Average retention values did not significantly differ for the two speeds though the trend appears to favor reduced speeds at all heights. The absolute potential gain in retention would most likely be offset by the reduced distribution in the taller canopies typically found in walnut orchards.

In short, our lab is currently trying to develop multiple options for growers considering implementing more selective management strategies for codling moth. One option that appears very promising for larger orchards has been the development of “puffers” at only 1 per 2 acres as a cost-effective alternative to pesticides. The size of larger farming operations allows for effective overlap of pheromone plumes and less “edge” than smaller orchards with higher edge to area ratios. Smaller operations of less than 40 acres or with more narrow orchards may find the meso-emitter approach more attractive given the more point sources are used per acre as well as the passive, non-mechanical nature of this type of dispenser. While only 18 dispensers per acre offers a significant time and cost saving compared to the traditional 100-400 units per acre, the early season effort is still not trivial. The hope is that the advantages of a season-long, highly selective management tactic early in the season would prove attractive because of reduced risks, easier labor management during the growing season, no disruptive effects on natural enemies, and little additional impacts on other farming operations.

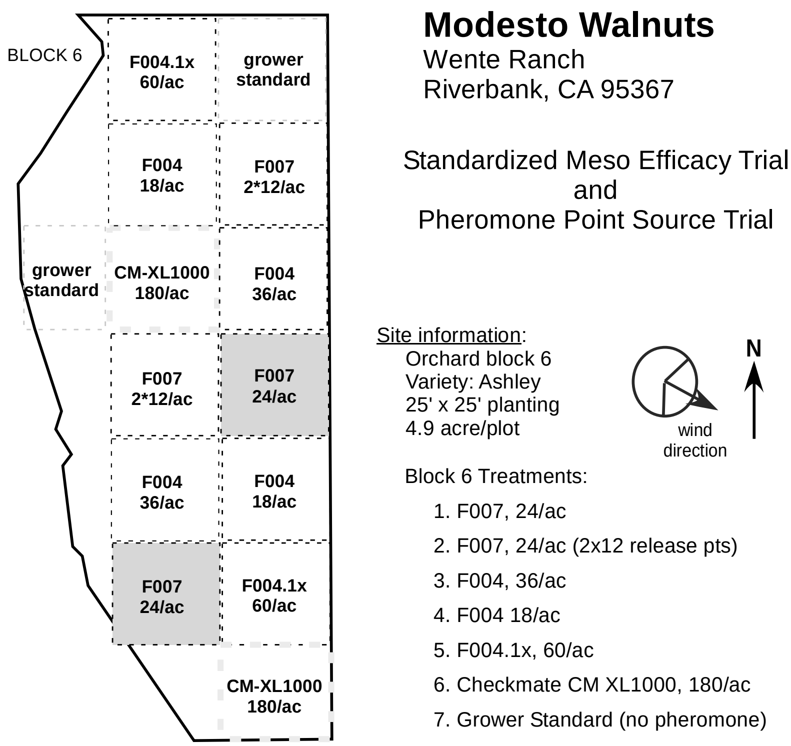

Fig. 1. Plot map for the Modesto walnut orchard site and locations of treatments for a) standardized meso-emitter trials with the Suterra F007 dispensers, and b) the point source number optimization trial utilizing six emitter type and application rate combinations.

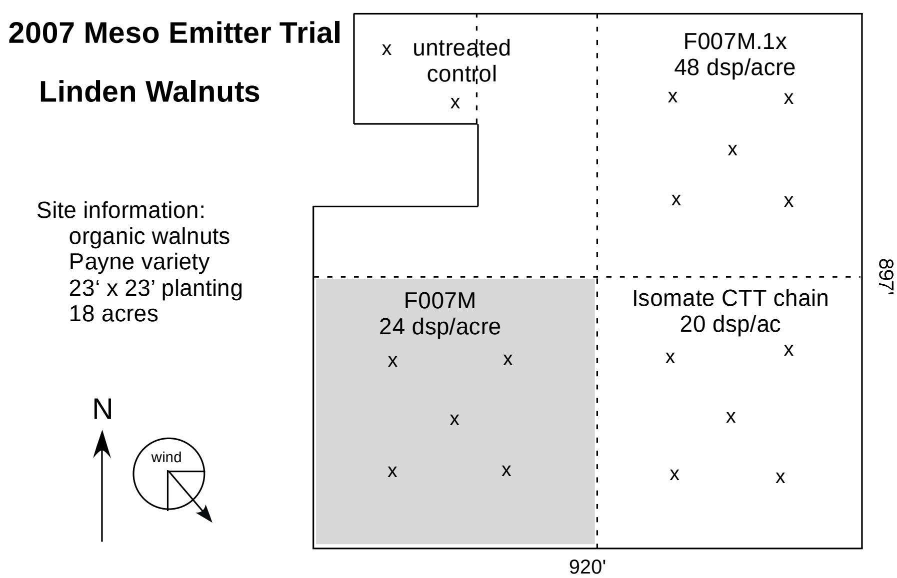

Fig. 2. Plot map for the Linden walnut orchard showing treatment locations for a) standardized meso-emitter trial (Sutera, F007 at 24 dsp/ac) and b) unreplicated alternative meso-emitter trial.

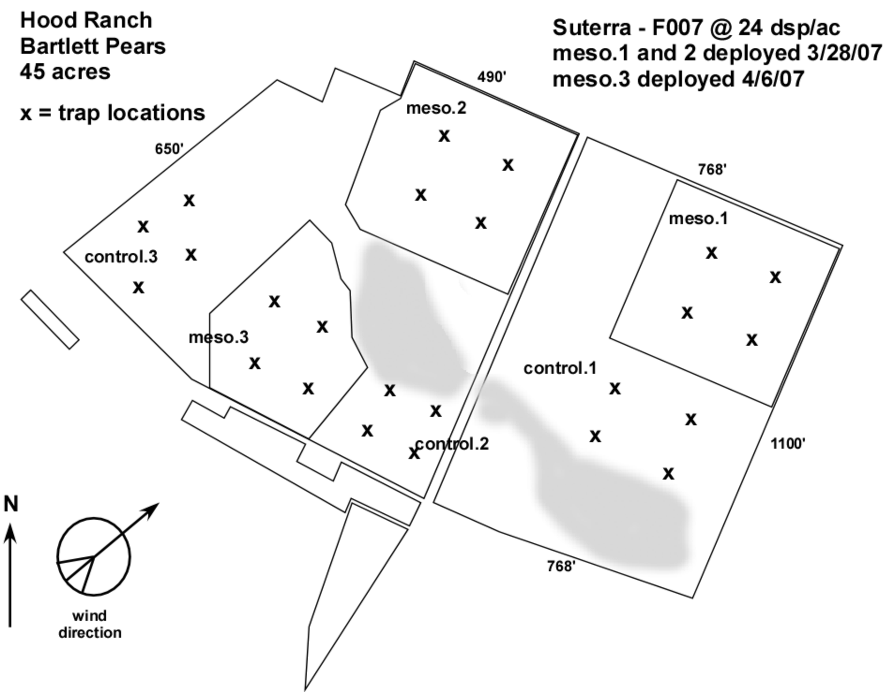

Fig. 3. Plot map for the Hood pear orchard showing locations of three meso-emitter treatment and three control plots.

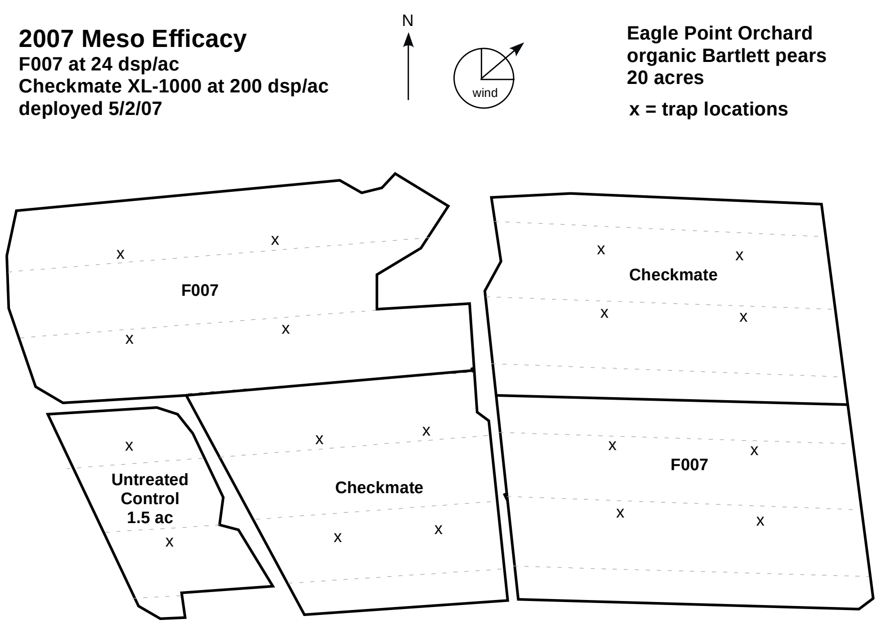

Fig. 4. Plot map for the Eagle Point pear orchard showing locations of meso-emitter and CM-XL 1000 plots and an untreated control.

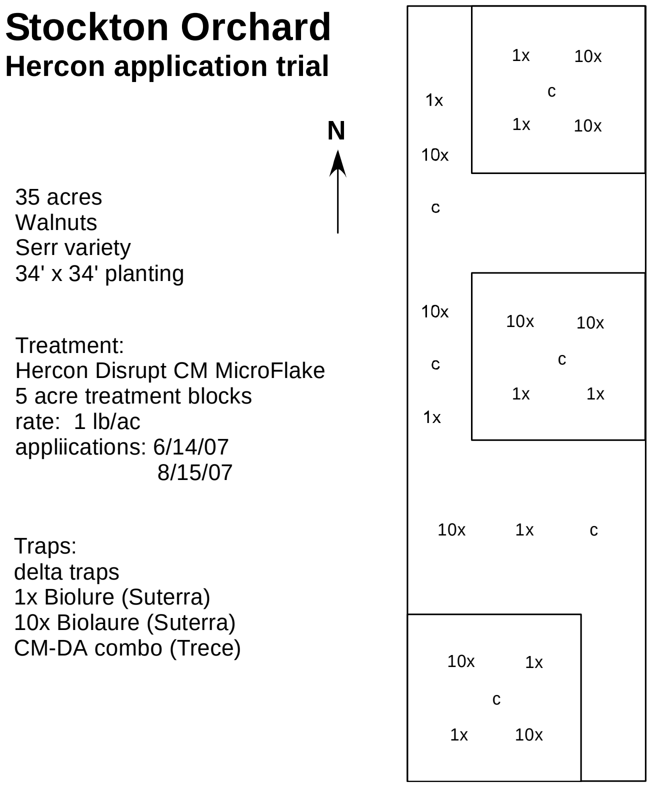

Fig. 5. Map of the Stockton walnut orchard block used for the Hercon DISRUPT MicroFlake-CM trial.

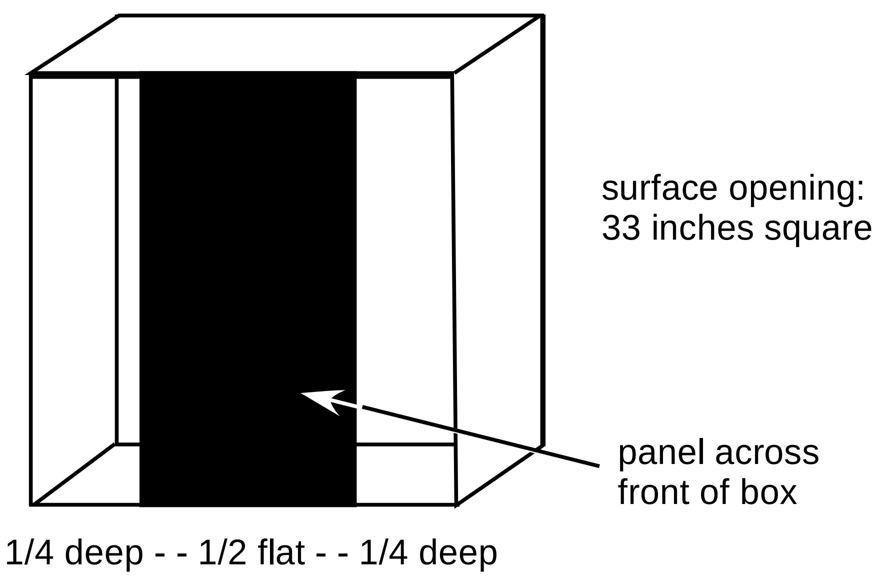

Fig. 6. Diagram of panel and box designed to estimate the number of flakes that were retained after striking the surface of the vertical panel. The box portion with a surface opening equal to the area of the center panel captured all flakes that entered, while only a portion of the flakes that struck the vertical center panel were retained.

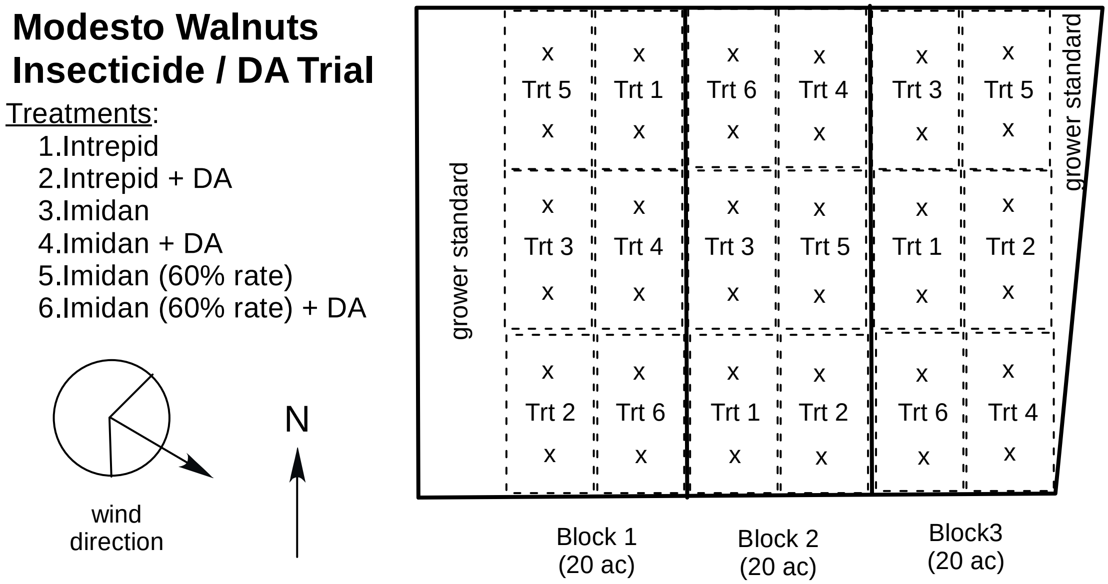

Fig. 7. Map of the Modesto orchard DA-MEC spray supplement trial.

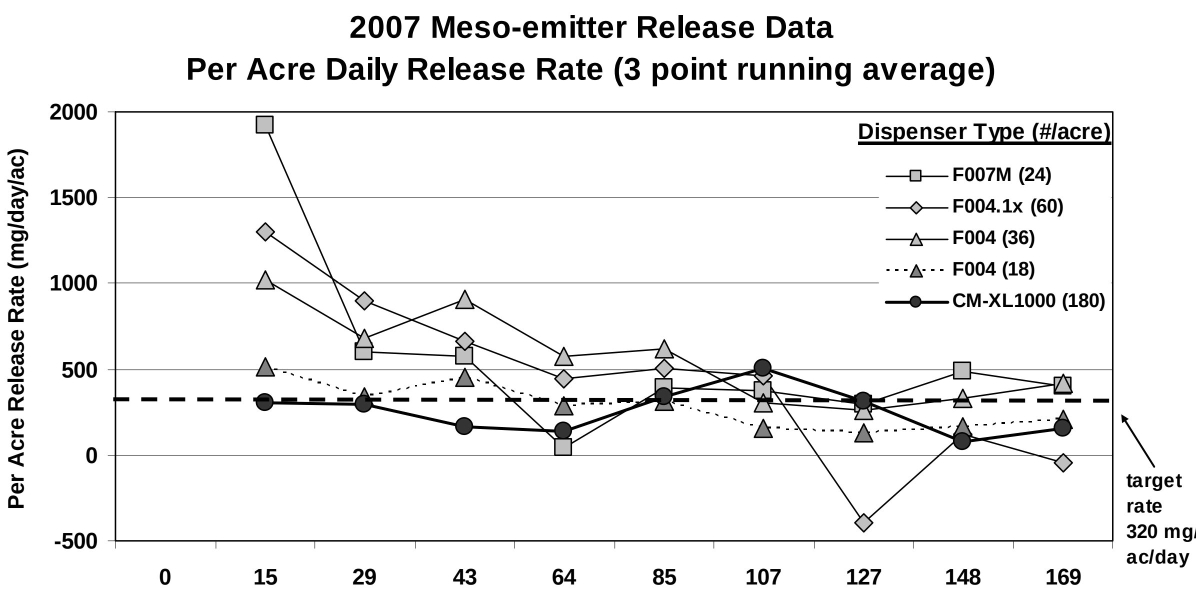

Fig. 8. Calculated daily emission rate on a per acre basis for different formulations and application rates (dsp/ac) of meso-emitters. Emission rates were calculated from residual analysis of dispensers collected at indicated time intervals after placement in a pear orchard.

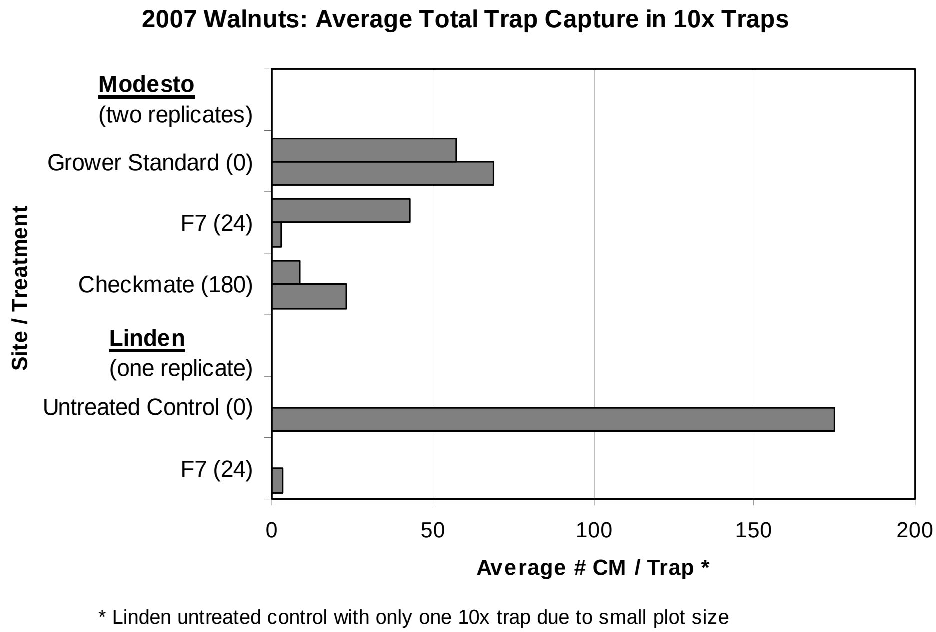

Fig. 9. Codling moth capture in 10x-baited traps of all treatment plots of the standardized meso-emitter trial.

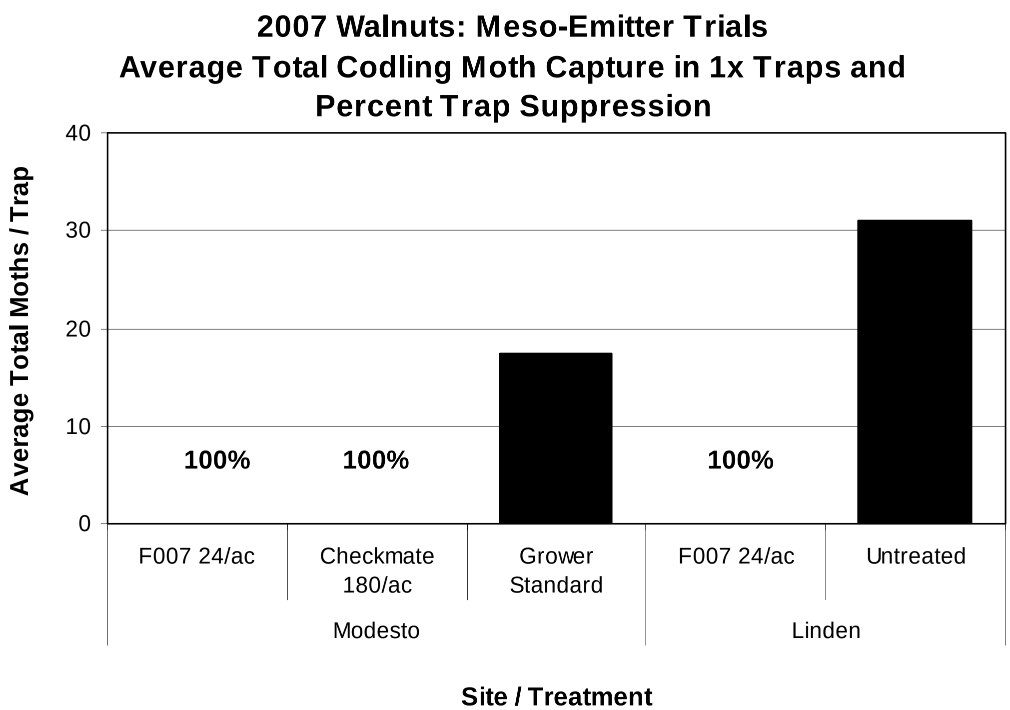

Fig. 10. Average season total number of codling moth captured in 1x baited traps and degree of trap suppression in standardized meso-emitter trials in walnuts.

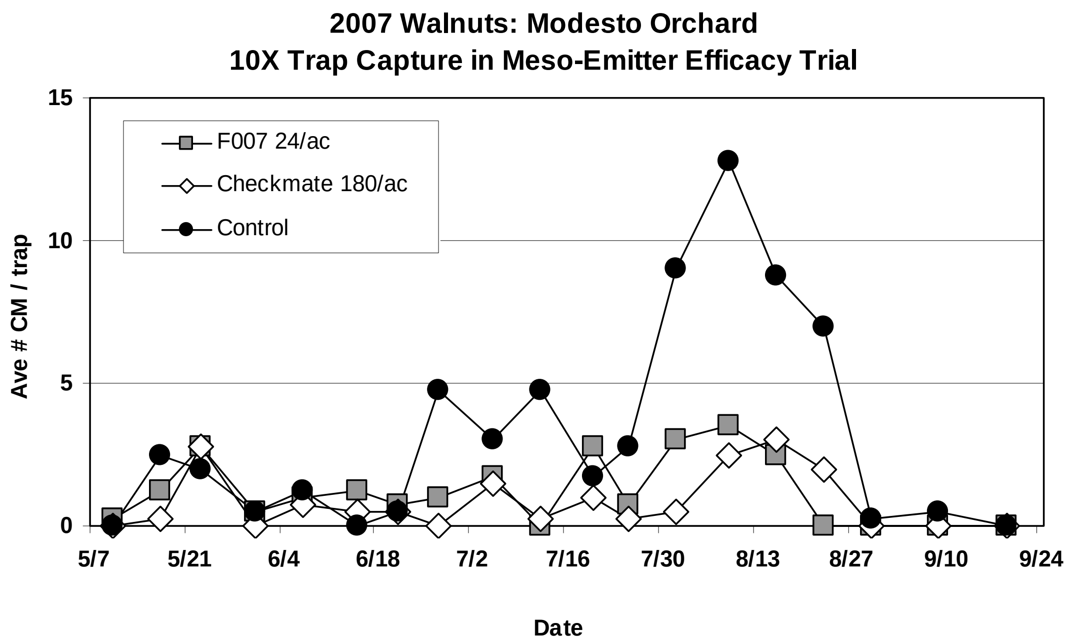

Fig. 11. Codling moth flight patterns shown by 10x traps in the Modesto orchard plots of the standardized meso-emitter trial. Data are shown for the Suterra F007 treatment, a standard pheromone treatment (Checkmate) and the grower control.

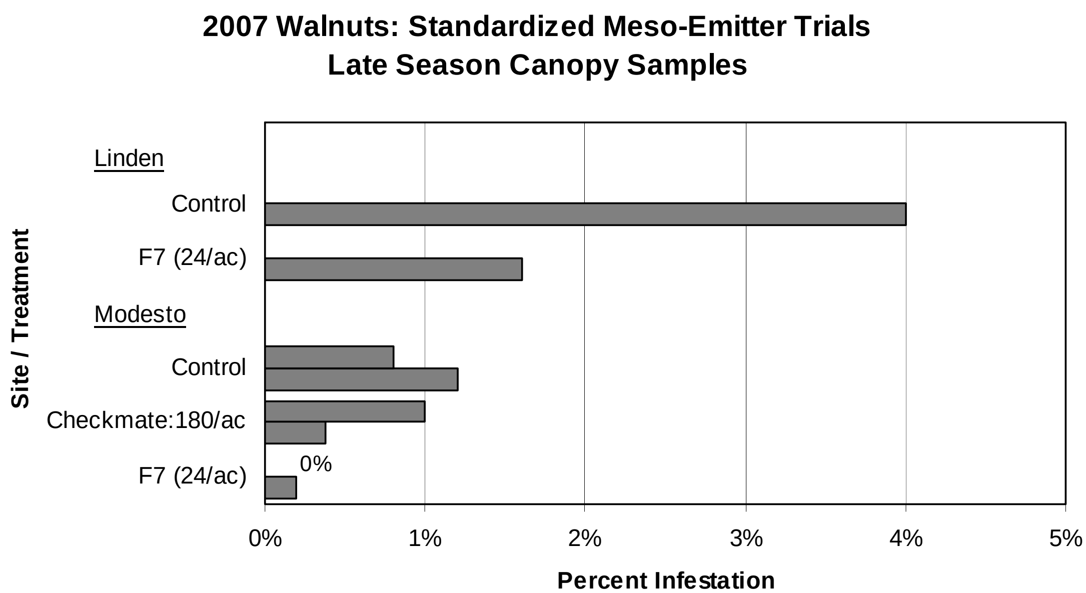

Fig. 12. Percent codling moth damage in late season walnut canopy samples made in the standardized meso-emitter plots compare damage in experimental plots vs a standard pheromone treatment (Checkmate CM-XL 1000) an the grower controls.

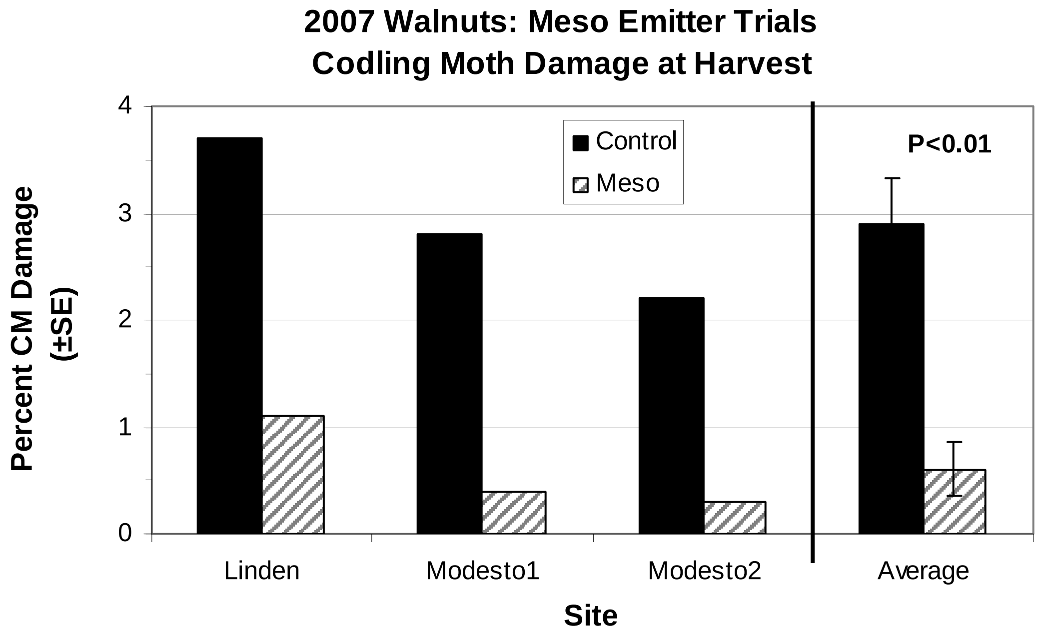

Fig. 13. Percent codling moth damage at harvest in standardized meso-emitter plots in walnuts.

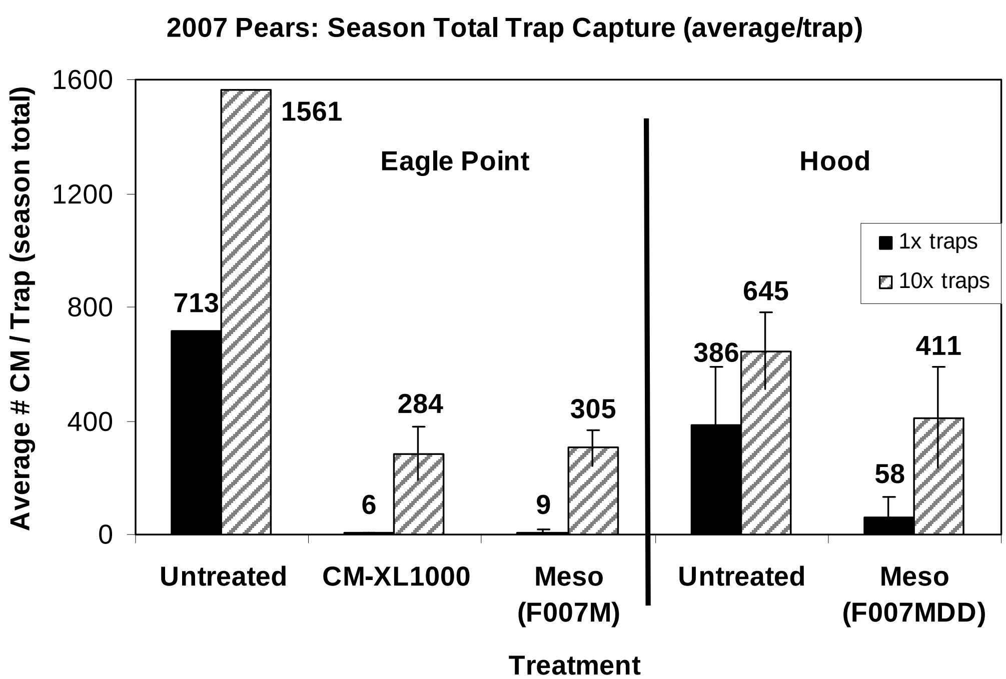

Fig. 14. Average season total codling moth counts for 1x and 10x baited traps in standardized meso-emitter trials conducted in two pear orchards.

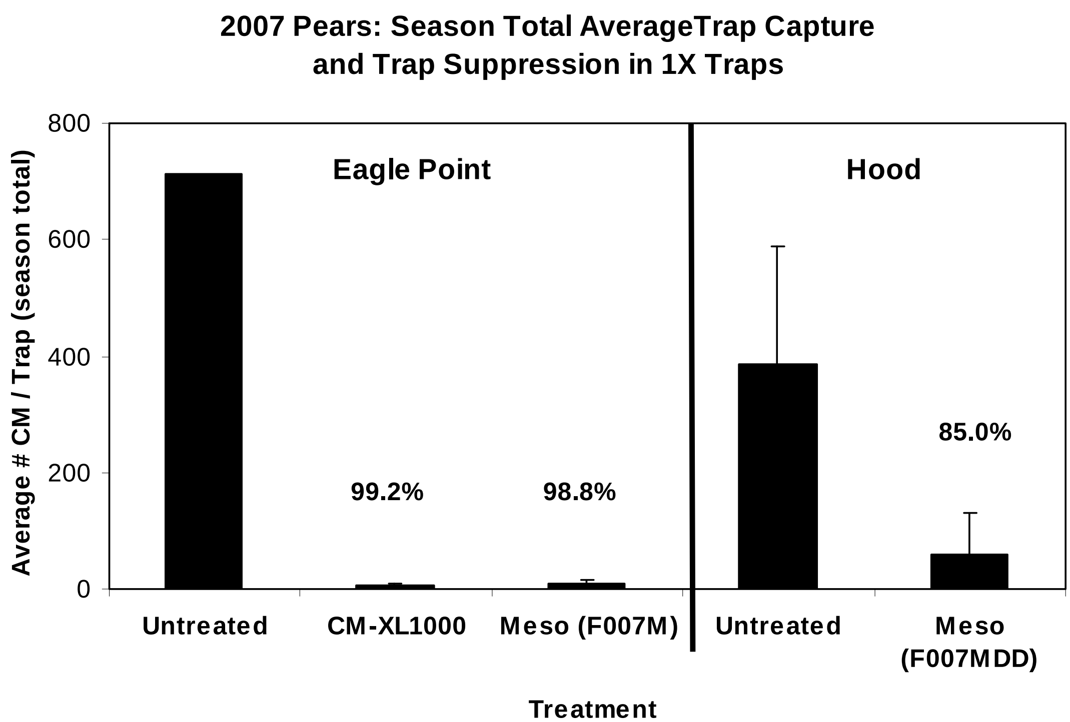

Fig. 15. Average season total codling moth counts in 1x baited traps and degree of trap suppression in meso-emitter treated pear plots.

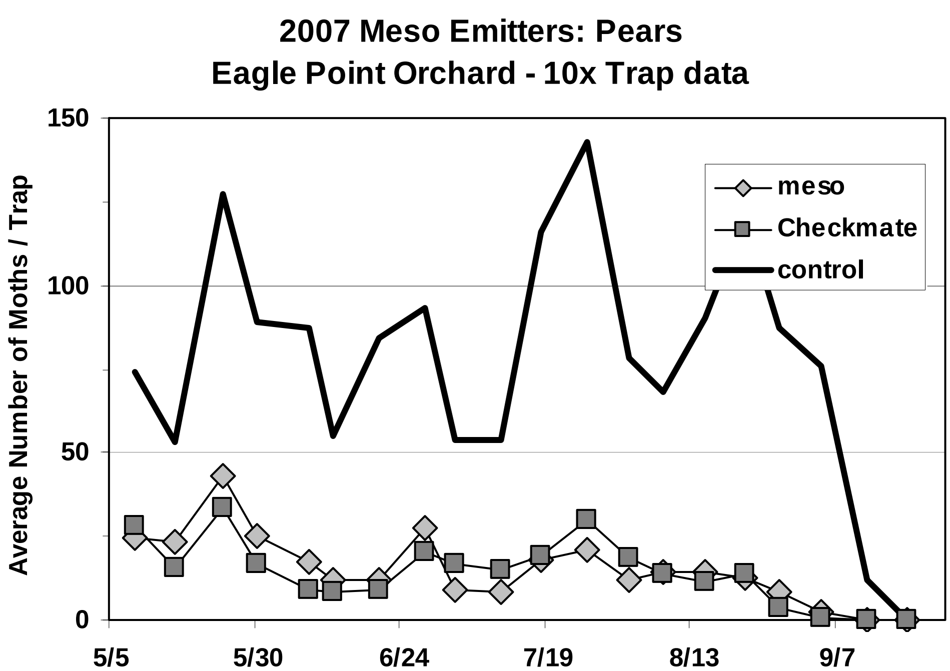

Fig. 16. Codling moth flight patterns shown by 10x traps in control and pheromone treated plots in the Eagle Point pear orchard.

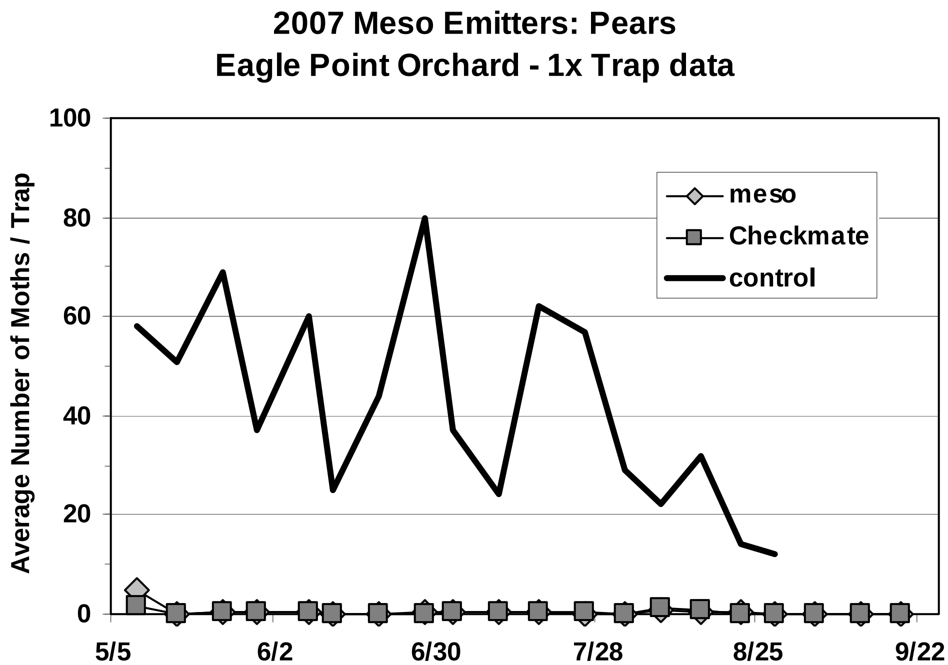

Fig. 17. Flight pattern shown in 1x baited trap in the untreated control and season-long suppression of 1x traps in two pheromone treatments in the Eagle Point orchard.

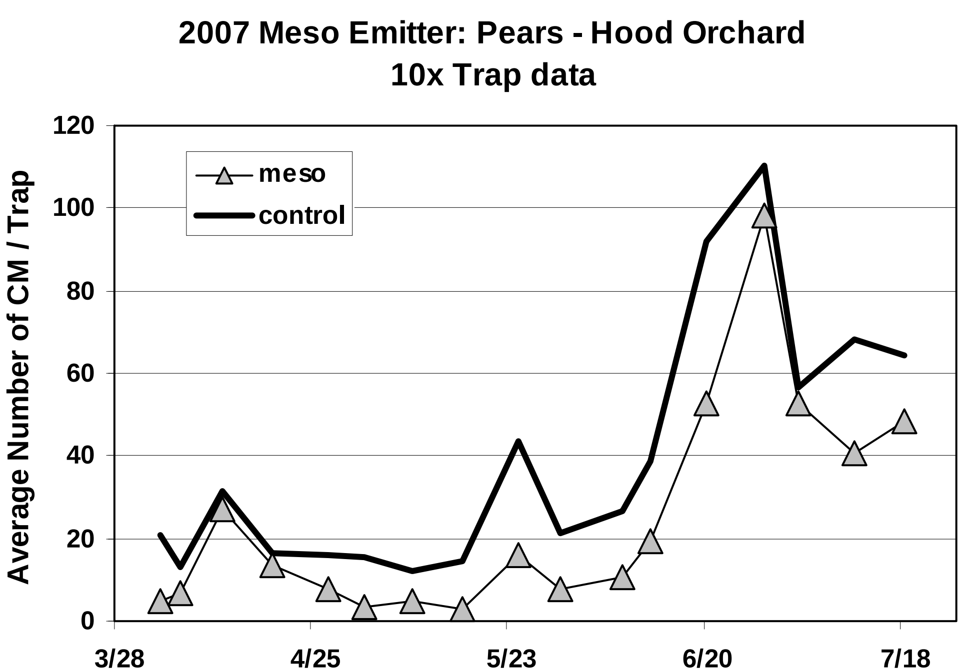

Fig. 18. Codling moth flight patterns shown by 10x traps in control and pheromone treated plots in the Hood pear orchard.

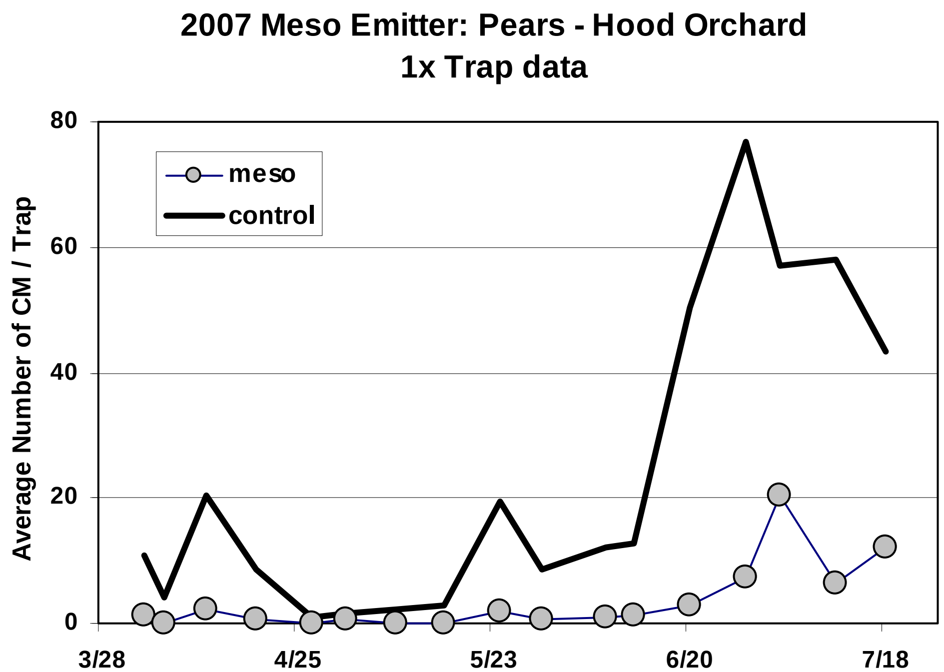

Fig.19. Average trap catch and flight pattern shown by 1x baited trap in the untreated controls and standardized meso-emitter treatments in the Hood pear orchard.

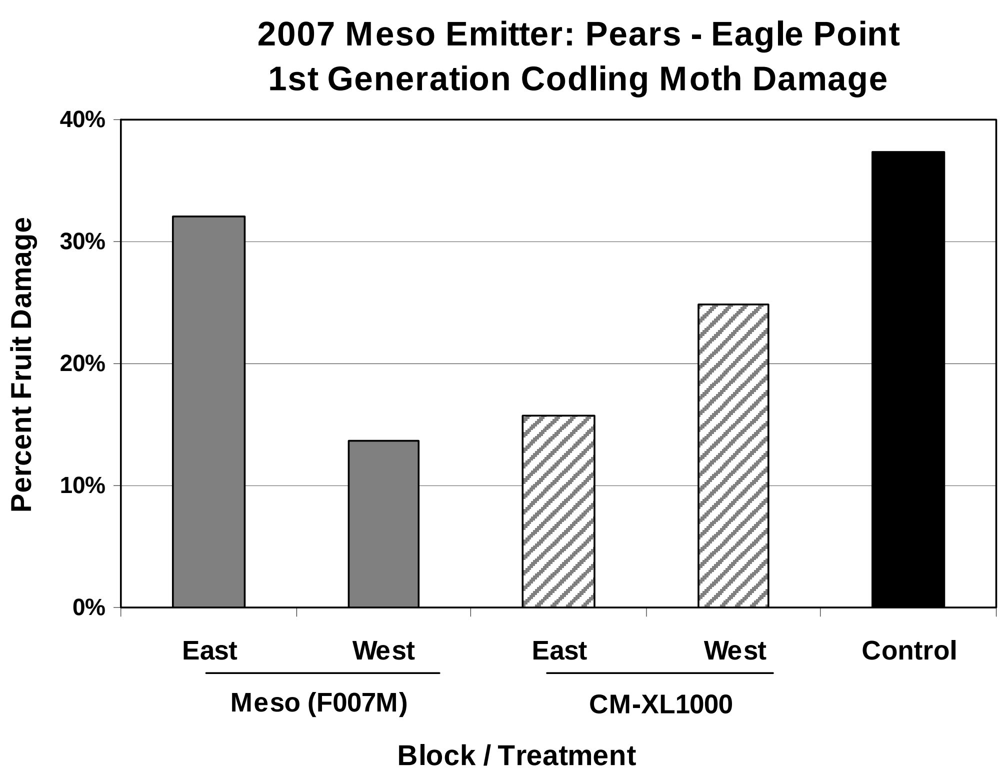

Fig. 20. First generation codling moth damage in all treatment blocks of the Eagle Point pear orchard.

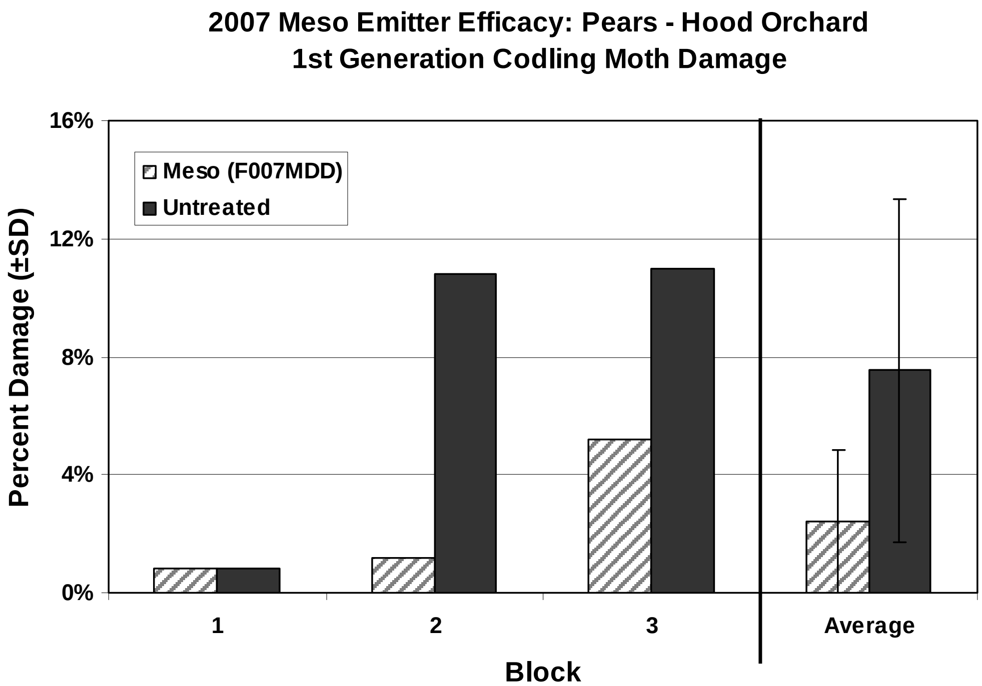

Fig. 21. First generation codling moth damage in all treatment blocks of the Hood pear orchard.

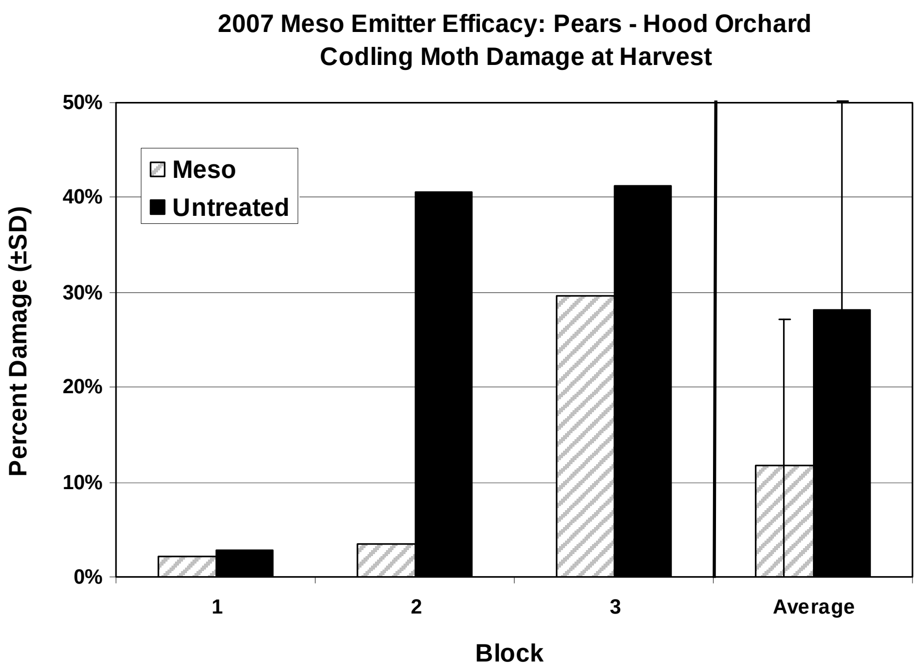

Fig. 22. Total codling moth damage at harvest timing in pheromone-treated and control blocks for the standardized meso-emitter trial conducted at the Hood pear orchard.

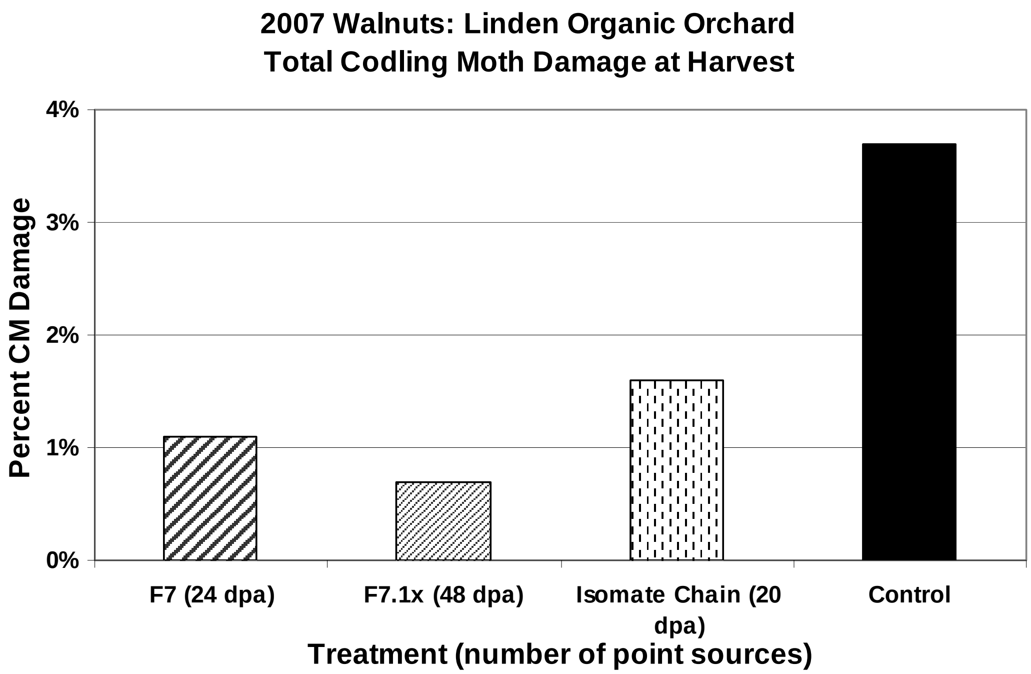

Fig. 23. Total codling moth damage at harvest in samples from three meso-emitter treated plots and an untreated control in the Linden organic orchard.

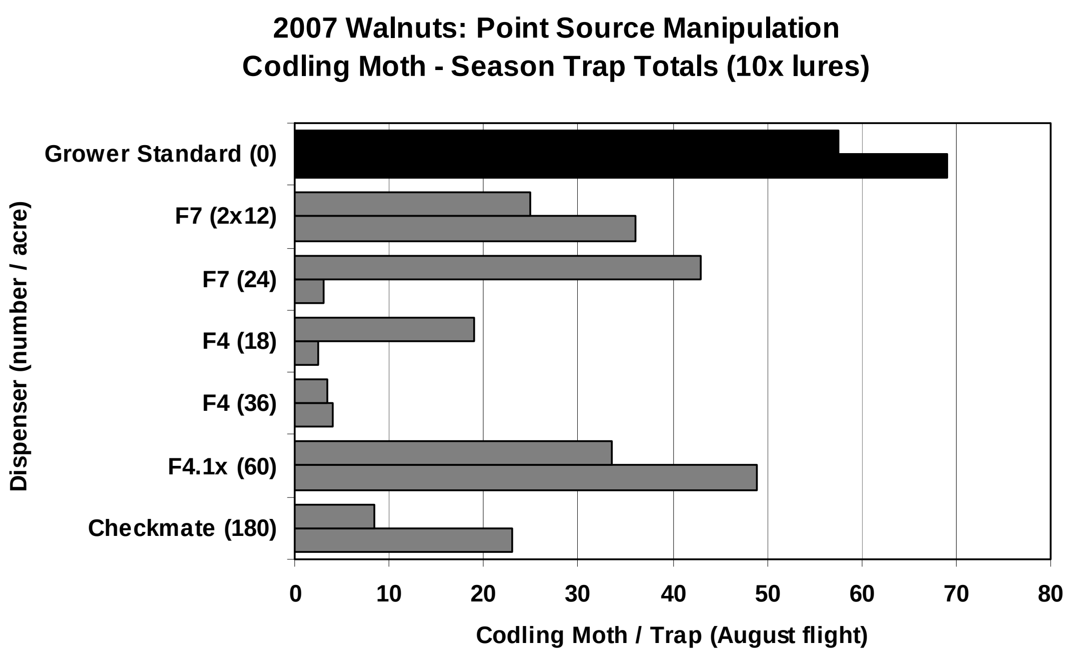

Fig. 24. Average total number off codling moths captured in 10x-baited traps placed in the point source trial.

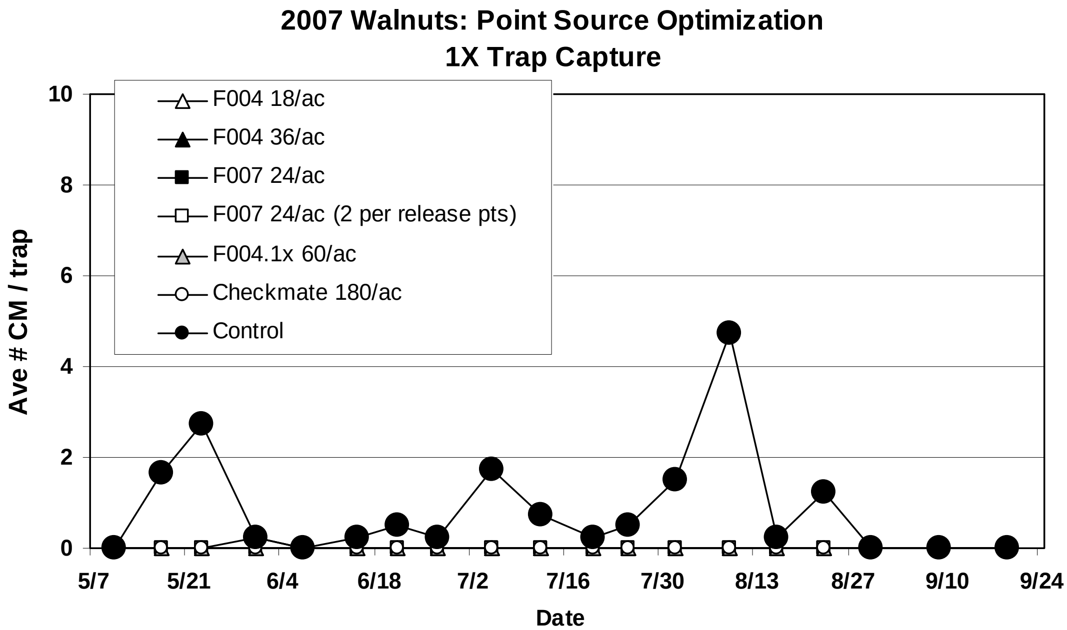

Fig. 25. Suppression of 1x-baited traps in pheromone treated plots vs the grower standard controls of the Modesto walnut orchard.

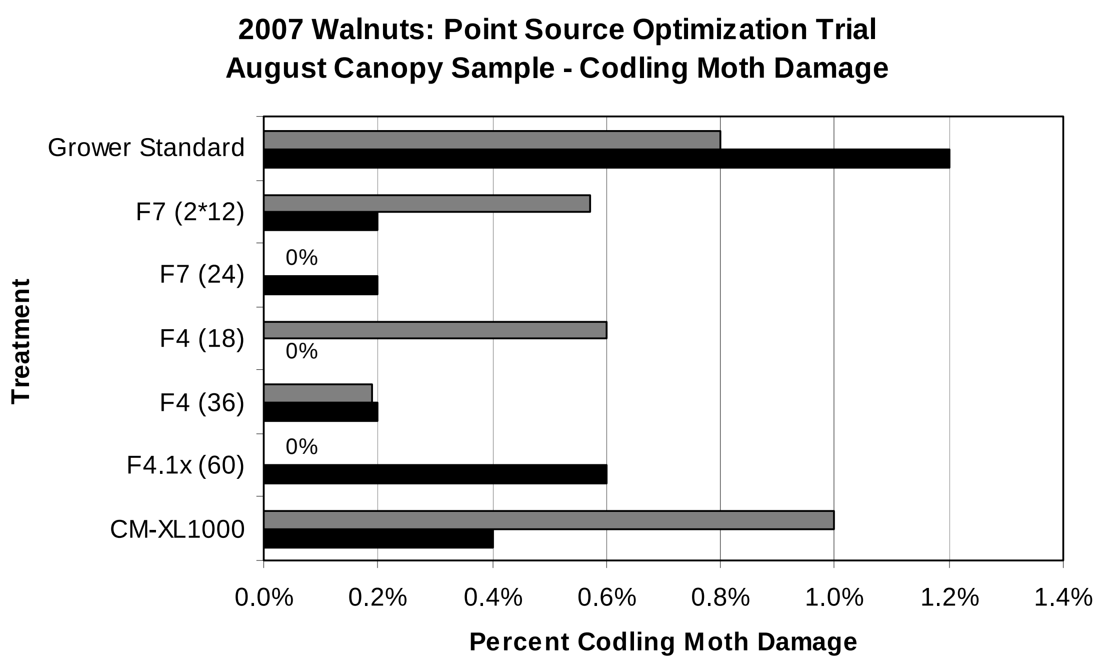

Fig. 26. Percent codling moth damage observed in the August canopy sample for the point source optimization trial.

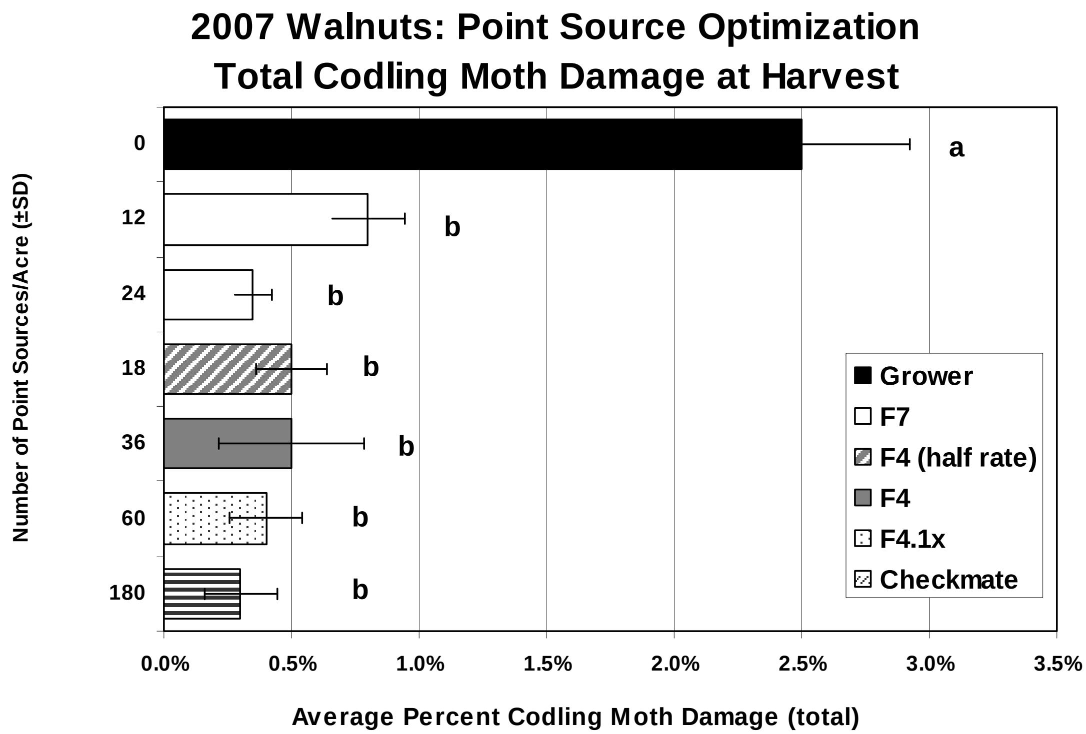

Fig. 27. Percent nut damage at harvest attributed to codling moth in the point source optimization trial and Modesto orchard blocks of the standardized meso-emitter trial (data for 0, 24 and 180 point sources).

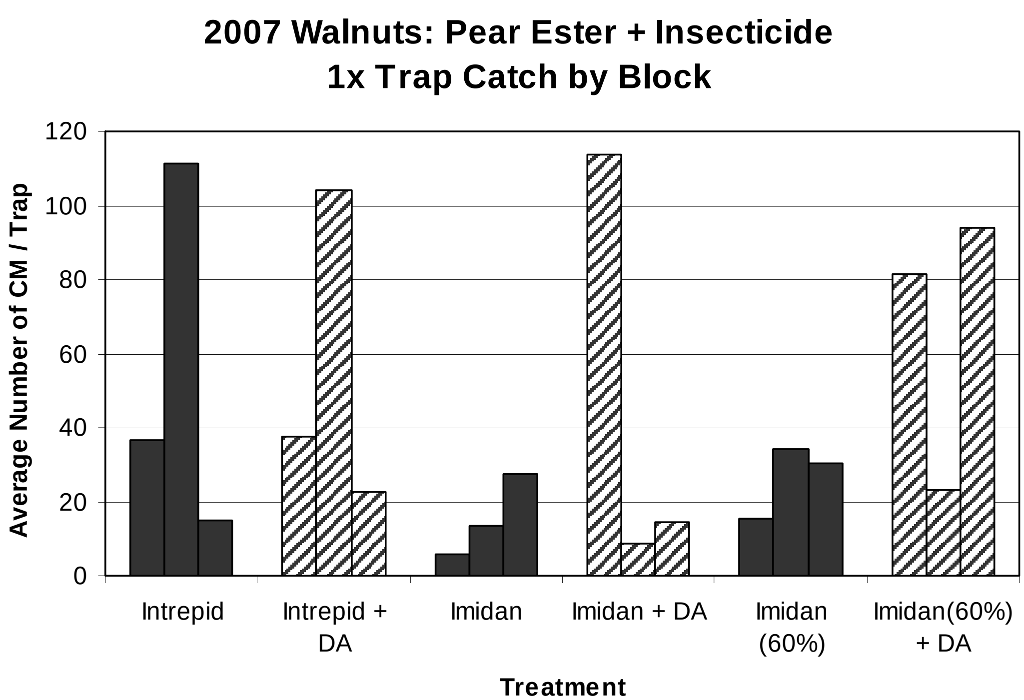

Fig. 28. Season total 1x trap capture for each block of each treatment showing variability across the orchard.

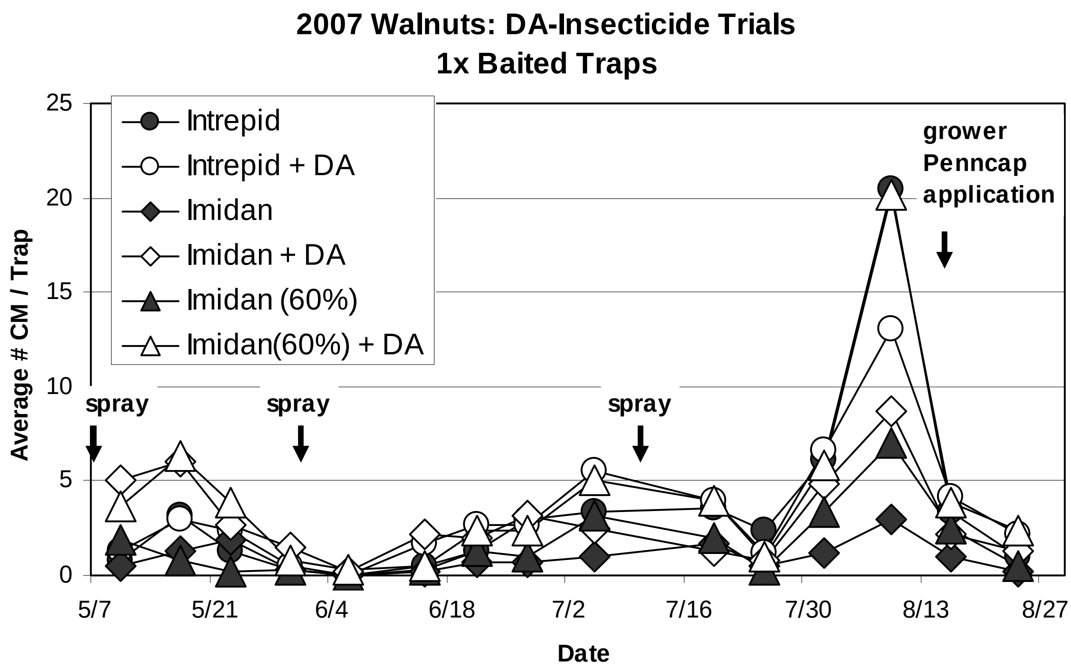

Fig. 29. Flight curves for all treatments and timing of experimental spray applications and the grower preharvest Penncap-M application.

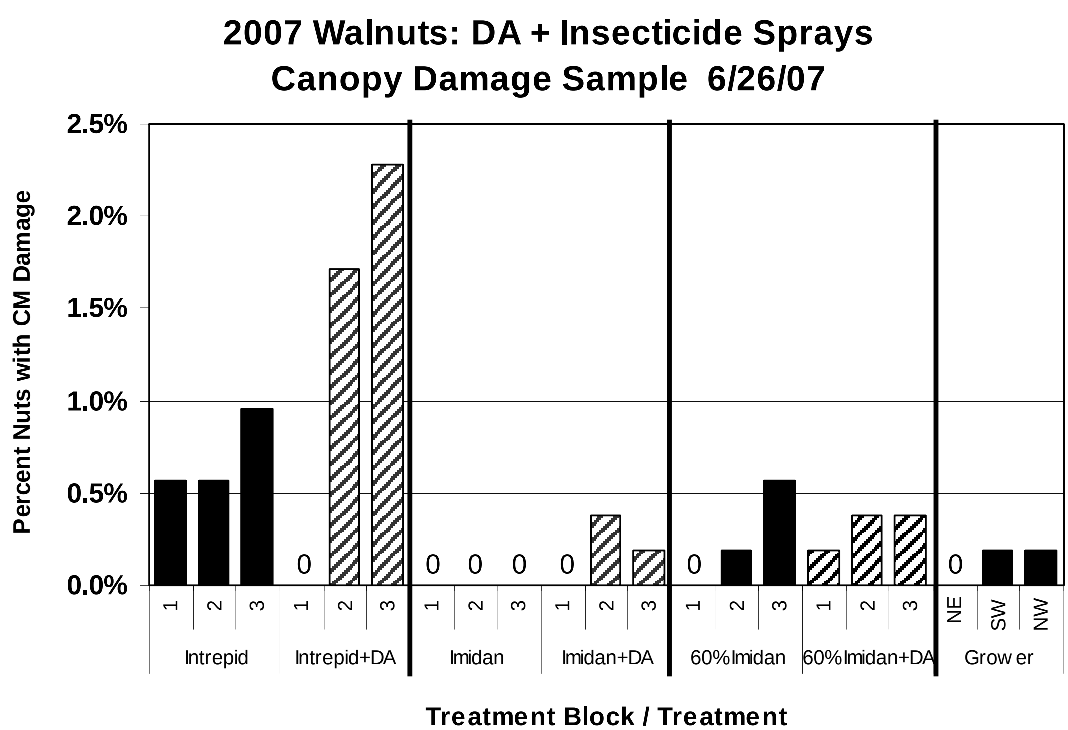

Fig. 30. Percent codling moth damage observed in the June canopy sample for the DA-MEC spray supplement trial.

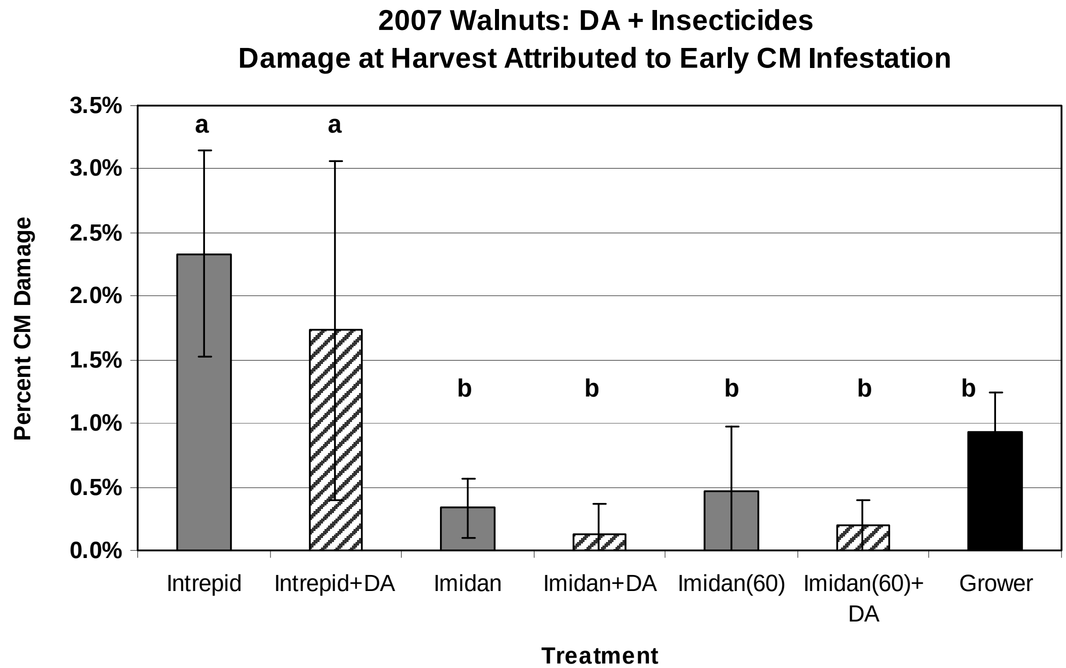

Fig. 31. Average percent codling moth damage observed in the treatments of the DA-MEC spray supplement trial. Damage shown resulted from codling moth activity during the active period of the spray trial.

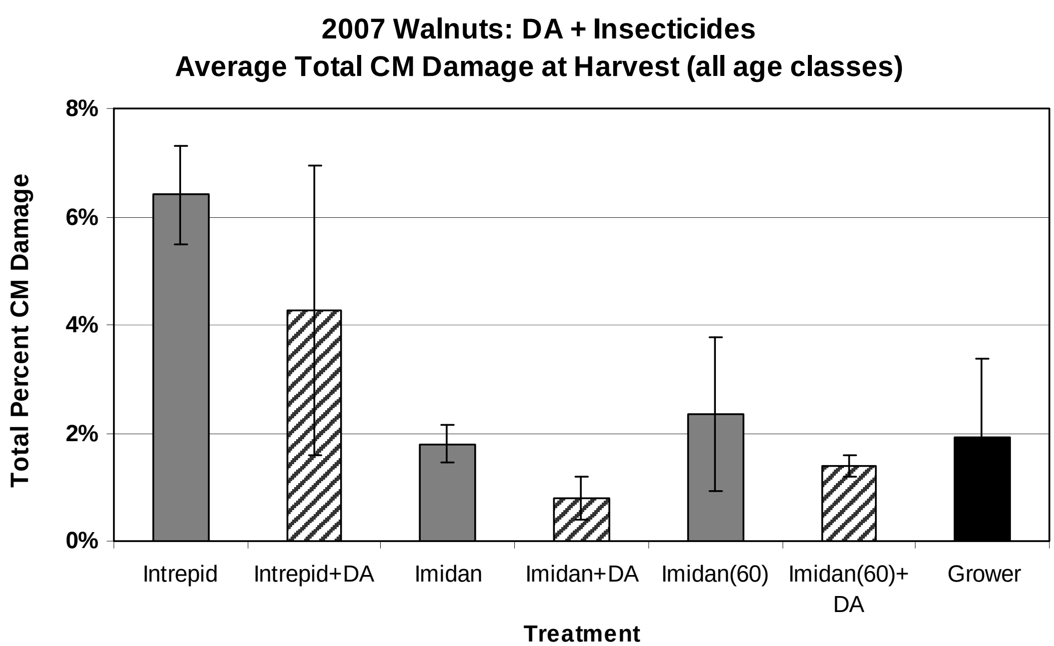

Fig. 32. Average total codling moth damage in the DA-MEC spray supplement trial. Total damage includes infestation from a late season codling moth flight that occurred after experimental applications would have had any impact.

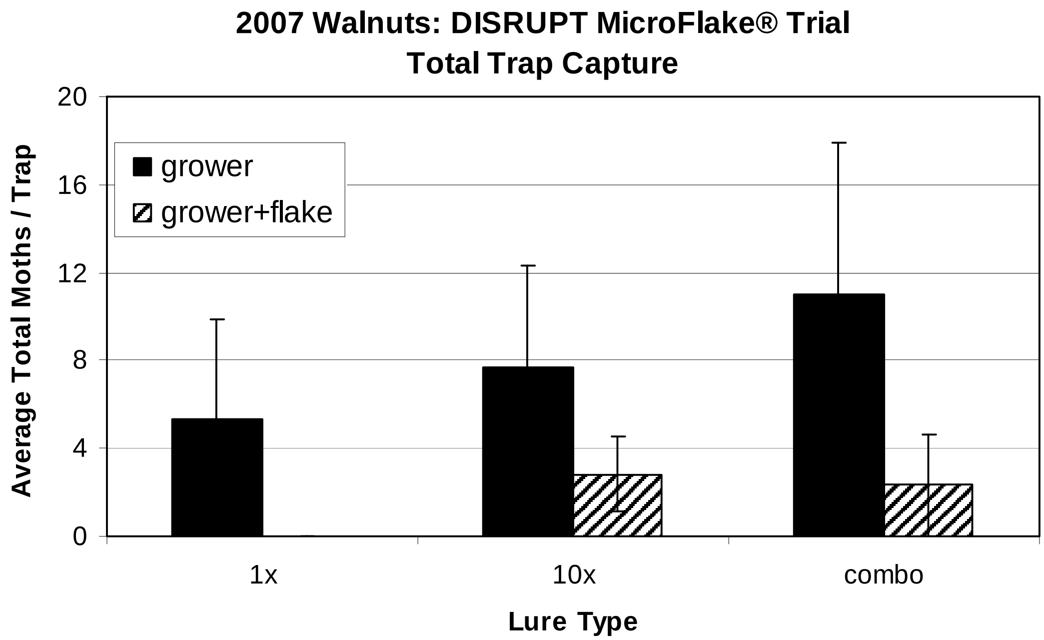

Fig. 33. Average season total trap capture in grower standard and Hercon Disrupt MicroFlake trials of the Stockton orchard.

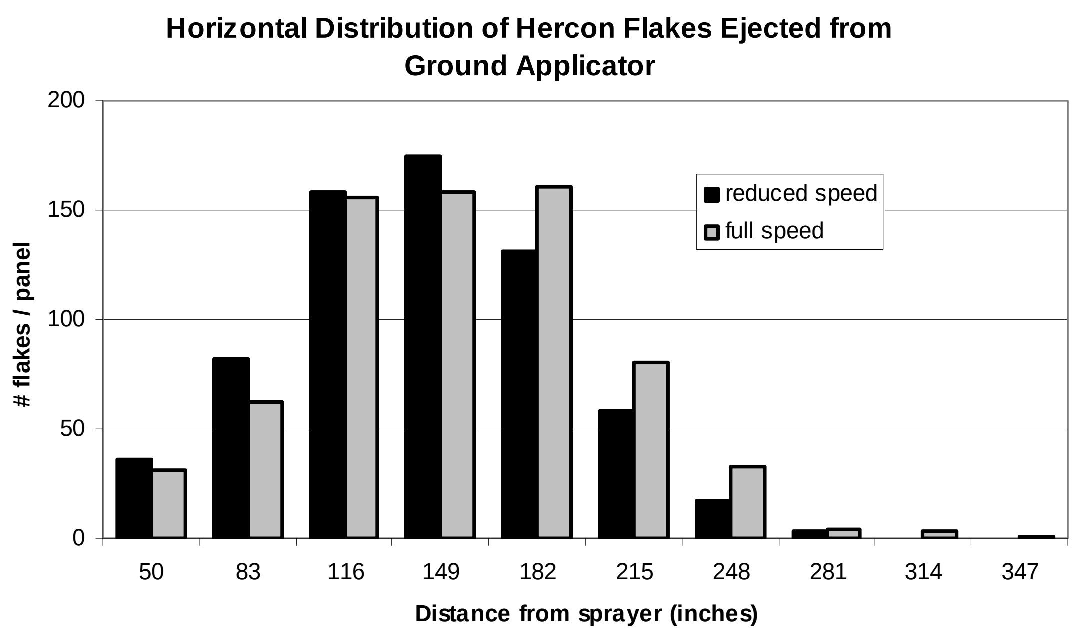

Fig. 34. Average number of flakes landing on panels following application at full or reduced blower speeds. Panels were placed on the ground in line with the blower and the distance indicated was measured from cannon nozzle to the center of the panel.

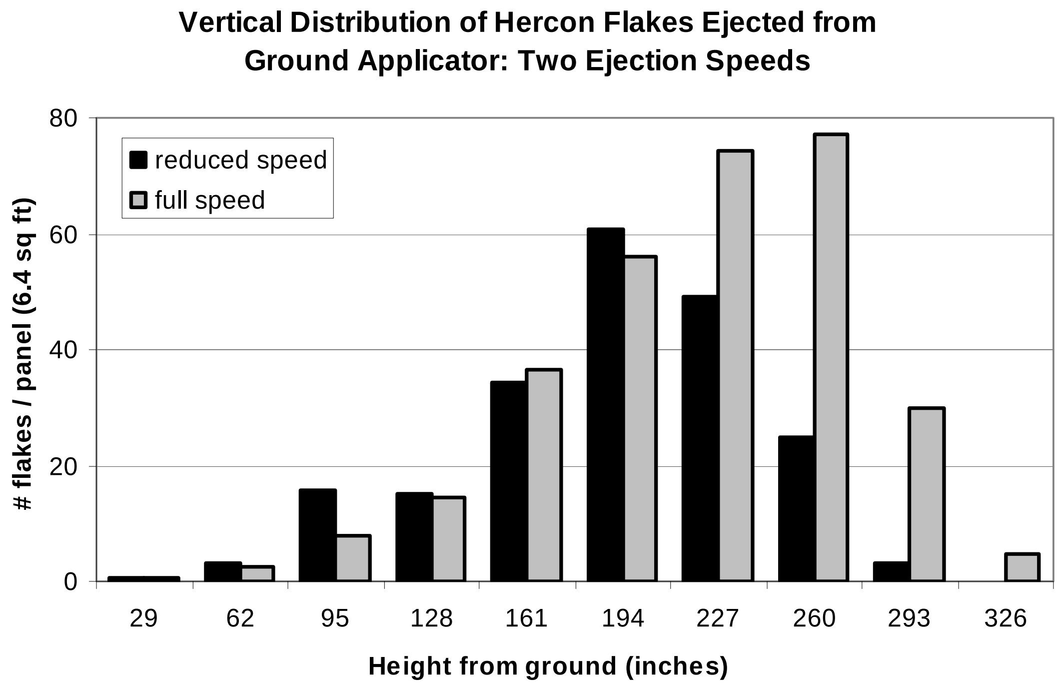

Fig. 35. Average number of flakes counted on panels following application at full or reduced blower speeds. Panels were hung from between two walnut trees and the distance indicated is the height from ground to center of each panel.

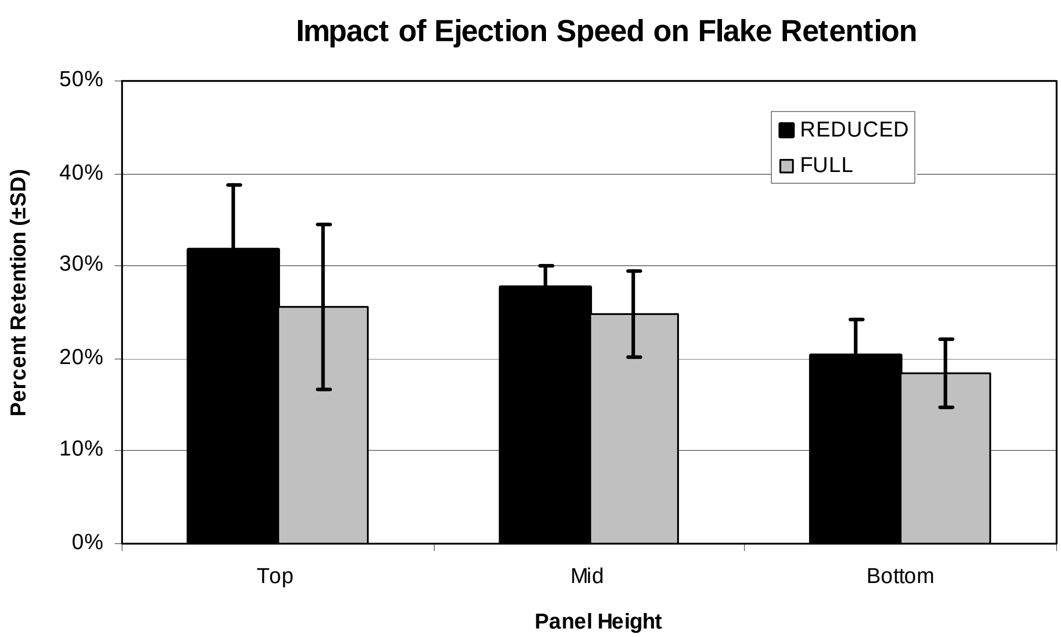

Fig. 36. Effect of ejection speed on the retention of flakes on a vertical surface placed at three heights. DISRUPT MicroFlakes were applied by the Micro-Tac applicator at full and reduced ejection speeds.