DEVELOPMENT AND OPTIMIZATION OF "MESO-PHEROMONE" EMITTERS FOR CODLING MOTH MANAGEMENT IN WALNUTS AND PEARS

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ABSTRACT

The development of meso-emitters as alternative pheromone dispensing devices continued to be the primary focus on our research in 2008 in both pears and walnuts. Using replicated 5-acre plots, two different types of meso emitters were evaluated in field trials which entailed 54 plots for a total of slightly more than 250 acres. A modified membrane dispenser that released ca. 20 times the normal rate of the Checkmate dispenser was developed in collaboration with Suterra. Similarly, an uncut chain often Isomate CTT twin tube dispensers was developed and tested in collaboration with Pacific Biocontrol. Both dispensers are deployed at much reduced rates per acre: 18 Suterra meso emitters per acre and 20 Isomate CTT chains per acre. The total amount of pheromone per acre is roughly equivalent to traditional pheromone programs, but the number of dispensers is reduced by ca. 90%. In pears, the two pheromone dispensers were compared against a standard pheromone mating disruption program using 200 CTT dispensers per acre. While the total number of moths caught in 1X or10X pheromone lures was higher in the meso emitter plots, these differences were not statistically significant. The total number of moths caught for the season on average per pheromone trap ranged from <10 to more than 600 moths across the orchards. Despite this range in pressure, all plots delivered very low codling moth damage at less than 0.3% in all test plots. All plots within an orchard received identical insecticide treatments based on the counts or damage levels in the standard pheromone mating disruption plots and determined by the grower or affiliated PCA. In walnuts, similar patterns were observed with higher trap captures in the meso-emitter treated plots, but these differences were not statistically significant. Despite high total captures in some plots, all plots did not develop codling moth damage beyond 1.2% at harvest. The lack of significant damage in the conventional walnut plots treated with only insecticides undermines our ability to conclude codling moth control by the alternative pheromone dispensers. Overall, codling moth damage was considerably less in all of our plots in 2008 compared to 2007.

INTRODUCTION

The adoption of pheromone mating disruption continues to increase as the primary control strategy for codling moth in pears and apples, while it is starting to emerge as one tactic for control of codling moth in walnuts. However, increasing concerns about labor availability and rising costs have stimulated the development of alternative pheromone dispensers that are less labor intensive in their application. Similarly, problems with tall canopies, e.g. mature walnut trees, have forced the use of hydraulic lifts to place the pheromone dispensers into the upper one third of the tree canopy. The results from both walnut and pear trials have been pooled in this report since codling moth is a key pest in common to both crop systems. While significant differences exist between the crops, these differences allow for different types of trials to be conducted across a wider range of circumstances. By pooling the data across the 2 systems, a larger set of conditions can be shown that vary in pressure, background management systems, economic constraints, and susceptibility to attack by codling moth.

Typical pheromone mating disruption programs will have 180-200 dispensers per acre, using dispensers with lower emission rates, e.g. 1-3 mg per day. Research was started ca. 4 years ago to explore the possibility of developing pheromone dispensers that have release rates of ca. 20 mg per day which would allow the total amount of pheromone released into an acre of orchard to be kept constant, while reducing the number of dispensers to ca. 20 dispensers per acre. Dispensers with higher release rates are called meso emitters since their release rates lie between traditional hand-applied dispensers and the aerosol puffers. Because of the reduced number of dispensers per acre, the speed of application and total application cost could be reduced proportionately. Similarly, the need for a relatively large labor pool for a short time frame would be reduced. Finally, and perhaps most importantly for walnut growers, fewer dispensers per acre will hopefully allow pheromone mating disruption to be logistically feasible despite the taller tree canopies.

In addition to the number of dispensers per acre, research was initiated to look at the potential to reduce the total amount of pheromone deployed per acre if dispensers using higher release rates per acre were used. Given that the pheromone itself is a substantial portion of the cost of the program, the hope is that the total program cost could also be reduced for the grower.

Finally, pheromone mating disruption programs have continued to require supplemental insecticides to arrest increasing populations of codling moth, which can disrupt the balance between natural enemies and their prey in some situations. One alternative strategy may be the use of attract and kill programs that utilizes an alternative chemical, e.g. a host plant volatile like the pear ester, to attract adult codling moths to specific point sources that contain very low doses of an insecticide. The difficulty with this approach has been to find attractants and the appropriate dose that will cause the moth to approach the lure and then touch the lure and the associated insecticide. The dilemma arises from the fact that if lure doses are too low, then the moth will not be able to locate the lure. Conversely, if the lure is too high, then the moth will approach to a certain distance, but then be repelled as the concentration increases as the moth gets closer to the lure. Typically, the moth will turn away from the lure before contact is made. Therefore, considerable effort was put into refining the wind tunnel and our protocols at UC Berkeley for evaluating single lures under controlled conditions. The hope is that the appropriate rate and attractant can be identified for shaping the development of alternative odor dispensing technologies such as the Hercon flake which can have a specific emission rate.

PROCEDURES

Objectives:

1. Field efficacy trials of meso-emitter treatment strategies in multiple orchards under varying codling moth pressures at application rates of 18 to 20 dispensers per acre. (pears and walnuts)
   a. Suterra emitters applied at 18 dispensers per acre using “best” meso-emitter treatment option from 2007
   b. Isomate “chain” product applied at 20 dispensers per acre (added program)

2. Preliminary evaluation of the effect of total pheromone emissions per acre at a fixed number of dispensing units per acre (18 units per acre) (walnuts)
3. Field aging study of Suterra experimental emitters
4. Development of flake containing either a pheromone or plant volatile that will produce an attraction and contact by codling under field conditions. (walnuts)

Two types of meso-emitters were evaluated in 2008: 1) a modified membrane dispenser developed by Suterra and referred to in this report as the "Meso" emitter and 2) a series of 10 uncut Isomate CTT twin-tube dispensers that are formed into a loop and referred to a the "chain" for this report. Each of these dispensers was evaluated in pear and walnut orchards as shown in Table 1. In pears, the programs were compared against a standard pheromone mating disruption program of 200 Isomate CTT twin tube dispensers. All plots within an orchard received the same insecticide treatment programs. All orchards, except the Lykins orchards were under a standard pheromone mating disruption for the entire orchard except for our plots. The Lykins orchard continued to rely on a more traditional insecticide program such that the pheromone standard program consisting of a 5 acre plot with 200 Isomate CTT hand applied dispenser per acre was applied by our project at the same time as the meso and chain emitters. A total of 19 plots were used in the pear trials that were spread across 5 orchards. The contrast of interest was the relative success of the plots treated with only 18-20 meso emitters per acre compared to plots treated with 200 Isomate CTT dispensers. If the number of point sources per acre is as critical as some data has suggested, then the meso emitter plots would be expected to have much higher rates of damage.

The walnut trials were similar with the primary difference being that walnut orchards did not have standard pheromone mating disruption program using 200 CTT dispensers per acre. All plots received the same insecticide treatments. Thus, the contrast of interest is between the conventional insecticide only plots and the plots with insecticide plus pheromone. Any additional suppression of codling moth would be attributed to the addition of the meso or chain emitters. Similarly, the 2 treatments could be compared directly for differences. A total of 11 walnut plots were compared.

A third experiment was conducted in walnuts to evaluate the potential for reducing the total amount of pheromone per acre. Four different types of meso membrane dispensers that varied in their release rates per dispensers were established at 20 dispensers per acre. These combinations allowed us to evaluate a range of total emission rates per acre on codling moth control. Unfortunately, the novelty of the manufacturing process at such high load rates per dispenser had prevented the preliminary evaluation of these dispensers under field conditions. Unexpected breaks in the seals resulted in openings in the dispensers that allowed either the pheromone containing pad to slip from the dispensers or altered the unit's release rate. Thus, release rates per acre presented later in the report are only estimates based release rate trials with Suterra in 2007, except for G040. Actual total release rates are presumed to be lower than expected, but the degree is unknown.

Table 1. Summary of 2008 pheromone trials.

	Crop	Site	Treatment Plots: Meso	Chain	Pheromone Std (CTT)	Conventional Grower Std
Efficacy Trials	Pears	Aldrich	1	1	1	
		Carmany	1	1	2	
		Ceccarelli	1	1	2	
		Chan	2		2	
		Lykins	1	1	1	1
	Walnuts	Berg	1	1		1
		Brandstad	1	1		1
		Lumina	1			1
		Vaccarezza	1	1		1
	Total number of plots = **30**		**10**	**7**	**8**	**5**
Rate Trials	Walnuts	Berg	8		2	2
		Deerfield	4		1	1
		Garcia	4		1	1
	Total number of plots = **24**		**16**		**4**	**4**

Field efficacy trials of standardized meso-emitter for codling moth control. The Suterra meso-emitter indicating best season-long emission characteristics from field aging studies conducted in 2007 was selected for standardized efficacy trials in pears and walnuts. Residual analysis of field aged dispensers (Suterra LLC, Bend, OR 97702) in 2007 suggested one unit performed with a more consistent release rate through the entire season. The release rate of the G037 dispenser (same as 007 from 2007) on a per acre basis appeared to match or exceed that of a standard Checkmate application and thus was selected for standardized trials across commodities. A second reduced point source strategy mechanism was incorporated with the Isomate "chain" - a variation of the Isomate CTT dispenser (Pacific Biocontrol Corporation, Vancouver, WA) in which ten twin tube units remain linked together in a long line.

The Suterra G037 units were deployed at rates of 18 dispensers per acre, whereas the Isomate "chain" was deployed at 20 units per acre in all trials. Deployment was made in a uniform grid pattern through 5-acre treatment plots. All emitters were placed in the upper third of the tree canopy in pears. Placement in walnuts was made as high as possible (mid to upper canopy) from pruning towers and with the use of an extension pole. Codling moth flight activity was monitored through the season with a set of four large plastic delta traps (Suterra) placed within each five acre treatment and corresponding control plot. Traps were baited with 1X or 10X (two traps) Biolures (Suterra) or Pherocon® CM-DA COMBO™ lures (Trécé, Inc., Adair, OK 74330). Traps baited with 1x lures were hung low, and those with 10x or combo lures were placed high in the canopy. Traps were read each week and lures changed on the recommended schedule. Damage assessments were made at two time points for each cropping system. In pears, inspection of 1000 fruit per treatment and control plot was conducted after 1st generation (1000dd) and at harvest. In walnuts, canopy samples were conducted in all sites mid August by inspecting 600 nuts per treatment plot, and harvest samples of 1000 nuts were collected immediately after shaking from each treatment plot. The final nut sample was cracked out in the lab and visible damage or worms were identified as codling moth or navel orangeworm.

All plots within an orchard received the same insecticide treatments such that potential differences between plots could be attributed to the differences in the pheromone programs. Insecticide applications rates and dates of application are shown in Table 2 (pears) and Table 3 (walnuts). The number of applications varied from no applications (Garcia) to applications targeting multiple peak flights (Berg). Plots in the Berg ranch were used in 2008 successfully despite the insecticide treatments because of the susceptibility of the cultivars and the large tree canopies.

Table 2. Pear sites and grower standard treatment programs for codling moth.

Site	Grower Standard Treatments
Ceccarelli	Isomate CTT 200dsp/ac Delegate 7 oz/ac 5/2/08 Imidan 7 lbs/ac 5/28/08
Carmany	Isomate CTT 200dsp/ac Delegate 7 oz/ac 5/14/08 Guthion 3 lbs/ac 5/30/08
Chan	Isomate CTT 200dsp/ac Delegate 7 oz/ac 5/6/08 Assail 3.4 oz/ac, 5/27/08 Warrior 5.12 oz/ac, 5/27/08 Oil 1 gal/ac 5/27/08 Altacor 4.5 oz/ac 6/25/08
Lykins	Delegate 7 oz/ac 5/6/08 Guthion 3 lb/ac 5/29/08 Guthion 3 lb/ac 6/18/08 Altacor 4 oz/ac 7/3/08
Aldrich Organic	Isomate CTT 200dsp/ac Omni oil 4 gal/ac 4/18, 4/28 Cyd-X + Omni 5/6, 5/13, 5/20, 5/27,6/3 Entrust + Omni 6/10, 6/24

Pear efficacy trials. Efficacy trials were conducted in replicated plots located in five Bartlett pear orchards in the Sacramento River delta region. The grower program for codling moth control was Isomate CTT applied at 200 dispensers per acre in four sites with one of these being an organic orchard. The grower standard in a fifth orchard followed an insecticide control program with no pheromone. We applied a five acre Isomate CTT treatment to the conventional insecticide orchard in order to have a standard pheromone comparison in this site. All sites received supplemental insecticide treatments in 2008.

Six plots of the Suterra G037 meso emitter were deployed across the five orchards, while four plots of the Isomate chain were deployed. Five acre grower standards (CTT) were monitored in all sites while two standards were included in three of these orchards due to reported potential CM population gradients across our plots. Suterra G037 applications were completed March 26-27, 2008 and the Isomate chain applications were completed April 2-3, 2008. First generation codling moth damage assessments were conducted June 13-17. Harvest samples were completed July 9-11.

Table 3. Walnut sites and 2008 grower standard treatment programs for codling moth.

Trial	Site / Variety	Grower Standard Treatments
Efficacy Trial	Berg – 6 / Ashey	Asana 16 oz/ac, May-08 Warhawk 5 oz/ac, May-08 Lorsban 4 pts/ac, 6/26/08 Penncap-M 7 pts/ac 8/8/08
	Brandstad /Payne	Warrior 3.6 oz/ac 5/29/08 *Lorsban + Nu-Lure 2 qts/ac 8/8/08**
	Lumina / Serr	Imidan 5 lb./ac, 6/2/08 *Asana + Nu-Lure 12/8 oz/ac 7/21/08*
	Vaccarezza / Nuggett	Assail 5.3 oz/ac, Aug-08
Emission Rate Trial	Berg – 3 / Ashley (2 replicates)	Asana 16 oz/ac, May-08 Warhawk 5 oz/ac, May-08 Lorsban 4 pts/ac, 6/26/08 Govern 7 pts/ac 8/8/08
	Deerfield / Vina	Imidan 4.8 lb/ac 5/23/08 Surround 25 lb/ac 6/2/08 Warrior 3.5 oz/ac 6/30/08 Surround 25 lb/ac 7/5/08 *Asana 12.8 oz/ac 7/16/08*
	Garcia / Serr	No insecticide sprays

**Walnut husk fly treatment with effects on codling moth populations dependent on timing relative to flights.*

Walnut efficacy trials. Efficacy trials for the Suterra G037 emitter were conducted in replicated five acre plots across four mature walnut orchards. Additionally, five acre Isomate chain treatments were placed into three of these orchards. Varieties represented included Ashley, Serr, Payne and Nugget. All standard grower programs were conventional insecticide-based and ranged from zero to three applications based on grower defined needs (Table 3). Applications that were targeting husk fly are shown in italics given that they may also provide some codling moth control depending on the timing relative to the flights. Trap and damage evaluations were conducted in a five acre grower standard at each orchard. Pheromone applications were made April 10, and April 18 -23. Canopy samples for codling moth damage were conducted August

13-19 with the use of pruning towers by inspecting 25 nuts from each of 24 trees in each treatment and grower standard plot for a total of 600 nuts per plot. Harvest samples of 1000 nuts were collected from each site between the shaker and harvester action on the grower's schedule. Collections were made from the central region of each plot (from within a perimeter defined by the trap placement).

Effect of total pheromone emissions per acre at a fixed number of dispensing units. Field trials conducted in 2007 that varied the number of pheromone dispensers per acre while holding the total pheromone load within a certain range suggested effective control could be achieved with deployment rates of 18 point sources per acre. Our strategy in 2008 studies was to use a deployment rate of 18 dispensers per acre and vary total emissions per acre through the use of dispensers with different emission rates. Initial estimates of emission rates were based on residual pheromone analysis of field aged dispensers from 2007 (Table 4). Replicated plot trials using 5-acre plots were established for this study that compared the impact of four experimental dispensers from Suterra. Comparison was made with a standard Checkmate XL1000 application and the grower standard. A conventional spray program was the grower standard at each site. All plots received the same insecticide treatments such that differences if differences were observed between treatments, the difference would be attributed to the additional pheromone component. This approach was used successfully in 2007 to evaluate the impact of the number of pheromone release points per acre. The trial was replicated four times across three orchard sites in Riverbank (two replicates), Oakdale, and Winters. The five-acre treatment plots were each monitored with a set of four traps as described above in the efficacy trials. Canopy and harvest samples were conducted as described earlier.

Dispenser aging trial. Field aging studies of dispensers were again conducted by placing 40 dispensers of each type in orchard canopy (pear orchard in the Sacramento delta) and collecting 8 dispensers from each type at days 0, 28, 68, 97, and 138. Residual analysis of the dispensers is being conducted by Suterra. Emission rates will be calculated from these data when analysis is completed.

Table 4. Estimated season average emission rates of experimental dispensers.

Treatment	# dispensers / acre	Estimated release rate mg/day/acre*
G037	18	297
G038	18	256
G039	18	188
G040	18	276
Checkmate CM-XL1000	200	247
Grower standard	0	0

* Rates estimated from 2007 field aging studies. Indicated release rates were an average release rate encompassing days 15 through 169 and disregarded the initial "blow-off" emissions

immediately following application. Rate for the G040 dispenser, which was a hybrid between G037 and G038, was calculated as an average between the two tested dispensers. These emission rates represent the highest emission rates that might have been expected per acre in these plots given unforeseen difficulties with sealing the margins of the dispensers. The higher loading rates per dispenser resulted in technical difficulties in sealing the margins during manufacturing. As such, some of the units either had splits along the margins which would alter the emission rates dramatically or had the pad containing the pheromone slip from the entire unit. The failure rate of the units also varied by type with the "standard" meso treatment (G037) having the lowest failure rate and the G039 having the highest. Thus, the range of differences between treatments was even greater than anticipated.

Wind Tunnel. Wind tunnels provide insight regarding the behavior of the codling moth with the unique ability to observe both positive and negative results including individual preference and choice that is impossible to observe in large scale field experiments. To explore these questions several preliminary experiments are being conducted in an attempt to further understand the potential of pheromone mating disruption through individual choice and how best to optimize desired responses in lab settings. Previous efforts to utilize our wind tunnel to understand individual moth responses were hindered by inconsistent performance and high variability between individual runs or moths. Therefore, 2008 focused on identifying the variables that were contributing to this variation.

RESULTS AND DISCUSSION

Application of meso-emitters in field plots.

Pears. Application of the G037 Suterra dispenser to the upper third of the tree canopy was direct and rapidly completed with use of a pole applicator. The G037 meso-emitter was manufactured with an attached clip, much like a standard Suterra CM XL1000. Application to a five acre experimental plot could be completed in 50 minutes by a single person. The experimental Isomate chain dispenser required preparation prior to application. A continuous line of CTT dispensers had to be cut to 10-dispenser "chain" lengths and manipulated to create a loop from which to hang the chain. Application of this dispenser is most easily made prior to leafout as the loop has to be dropped over a branch and leaf development makes a secure placement more difficult and time consuming. Because of product availability we conducted the chain applications the first week of April by which time canopy development did negatively impact the time required for placement. While chain applications took 20-50% longer at this timing than the G037 had taken, a more rapid application should be possible with an earlier deployment.

Walnuts. Application of all pheromone dispensers was made as high into the tree canopy as possible given the tree size, and pruning tower lift attained in each orchard. Thus, placement ranged from mid to upper canopy. All Suterra meso-emitters were manufactured with an attached clip, thus, eliminating any pre-application preparation. Time required for deployment of Suterra emitters at 18 units per acre rate averaged 90 to 100 minutes (range: 80 to 130 minutes) to complete a 5-acre plot. The time range varied due to several factors including experience, tree size and spacing, and pruning tower speed and mobility. As noted earlier, the Isomate chain application was slower, because canopy development at our deployment dates (mid-April) was significant in some sites and made secure placement much more difficult.

Field efficacy trials of standardized meso-emitter for codling moth control.

Trap data are presented in 3 forms with a complete record of all total trap captures for all plots shown, total trap captures for all treatments, and by seasonal flights for specific orchards or treatments to illustrate specific patterns or issues.

Pear trap data. The seasonal flights using all three lure types are shown as an average for orchards with intermediate levels of pressure (Fig 1-3), for the Lykins conventional orchard (Fig 4-6), and the organic Aldrich orchard (Fig 7-9). Seasonal totals are shown for all plots by treatment for the combination lures (Fig. 10), the 10x lures (Fig 11), and the 1x lures (Fig 12) as well as the averages for all three treatments (Table 5). Clearly, a range of pressures were found across the orchards if counts from the combination lures are examined (Fig 10). The combination lures in both walnuts and pears provided the greatest trap captures and hence greatest resolution for discerning flights. The flight curves for the combination lures for the Aldrich ranch (Fig 7), the Lykins ranch (Fig 4) and the three ranches with intermediate populations (Fig 1-3) show multiple peaks throughout the season.

The combination lures and 10X lures are expected to catch moths throughout the season whereas the 1x lure placed low in the tree canopies is not expected to capture codling moth in pheromone treated areas. The organic Aldrich ranch had totals exceeding 600 moths for the season (Fig. 10), whereas the Ceccarelli ranch had very low population levels of less than <25 moths for the season. The Lykins ranch, which was the only orchard still not under pheromone mating disruption, had the second highest trap counts with >300 moths in the meso membrane plots (Fig. 10). One feature that emerges is that not all plots even within the same orchard had equal pressures as indicated by the counts in the combination lures. For example, the range in counts between the plots in the Aldrich ranch varied from ca. 150 moths in the CTT plots to ca. 600 moths in the meso membrane and meso chain plots (Fig 10). This variation between plots made statistical discrimination between treatments much more difficult despite larger differences (Table 5).

Table 5. Seasonal total trap captures of codling moth in 3 management treatments in traps baited with 3 lure types.

		Lures		
Pears	**Treatment**	**1X**	**10X**	**Combo**
	Isomate CTT	0.6 A	44.7 A	81.4 ± A
	Isomate Chain	4.5 A	87.1 A	233.5 ± A
	Suterra Meso	5.3 A	101.5 A	195.5 ± A
Walnuts		**1X**	**10X**	**Combo**
	Grower	17.0 A	93.0 A	150.5 A
	Isomate Chain	0.8 A	7.3 A	73.7 A
	Suterra Meso	0.0 A	8.6 A	40.3 A

One outcome regardless of the lure type is that fewer moths were caught in general in the Isomate CTT plots. However, these differences were not consistent across orchards and the pattern is largely driven by the Aldrich counts which are quite a bit higher than the other orchards. For examples, in the Lykins ranch with the second highest counts, the pattern does not hold as strongly for the combination lures for the 10X lures. The 1X lures in the meso membrane plots did have higher counts.

Another pattern that did emerge with potentially troubling implications was the higher counts in the 1x lures in all orchards that had the pheromone as their standard program. The CTT plots never caught moths in the 1X lures, whereas the meso treatments (membrane and chain) caught from 0 – 15 moths over the season. While these differences did not produce any meaningful infestation by codling moth at harvest (see Table 5), they do suggest that the programs are as effective at completely suppressing the lures. What is less clear is how to interpret these results relative to program risk. The objective of the program is not to suppress trap, but to suppress damage. The ultimate question asked is "Do the reduced labor costs and advantages of more rapid placement outweigh the potential loss of complete trap shutdown, especially within the context of programs that use a combination on insecticide and pheromones to suppress codling moth"? Similarly, a question about efficacy remains until the plots are scaled up in size from 5 acres to larger blocks.

Pear damage suppression. First generation damage surveys conducted mid June across all 18 treatment and grower standard plots (Isomate CTT) revealed a single damaged pear in the 18,000 pears inspected. Codling moth damage estimates at harvest were low across all sites and did not differ with averages of 0.1%, 0.07%, and 0.06% for meso, chain, and standard CTT treatments respectively (Fig. 13; P>0.05, NS). Nine sites revealed no codling moth damage and no site exceeded 0.2% damage except for 0.3% observed in the grower CTT plot in the organic site. These trials did not reveal treatment differences with the different dispenser technologies. However, all growers included insecticide applications in their 2008 treatment programs, which could have masked the pheromone treatment differences. Strong persistent winds in the delta region throughout spring were a challenge to any pheromone program and supplemental insecticide applications were a prudent grower strategy. In essence, the question of interest was "If under the combination programs of insecticide and pheromone which are currently being using by growers, did the reduction in the number of pheromone dispensers per acre result in increased programs?" In 2008, the answer was no, but the damage levels were so low as to make the treatment effects potentially less meaningful. However, the positive results do suggest that large treatment plots and testing could be undertaken next year as the products move towards commercial deployment.

Walnut trap data. Typical flight curves are shown for one orchard using all three lure types (Branstad, Fig. 14-16), whereas the seasonal totals for all lure types are shown all treatments and orchards in Fig. 17-19. The highest counts were recorded in the grower standard for all lure types (Table 5, Figure 17), but these differences were often driven by strong differences in one plot (for the combination lures – Berg 6, Figure 17) or for the 10 X lures Branstad (Figure 18). These differences were not statistically significant given the variation (P<0.05). No pattern was also observed between the two treatments using the meso-membrane or meso-chain pheromone dispensers.

Walnut damage suppression. Canopy samples conducted in mid-August revealed damage ranging from 0% to 1.3% damage across all treatment plots (Figure 20). No significant differences were observed in damage between the supplemental pheromone treatments of the meso and chain applications and the grower standard which averaged 0.45%, 0.59% and 0.56%, respectively.

Nut samples collected at harvest indicated codling moth damage ranging from 0% to 0.7% and averaged 0.23%, 0.28%, and 0.37% for the supplemental meso and chain treatments and grower standard, respectively (Figure 21). While the supplemental pheromone treatments averaged slightly less damage than the standard insecticide programs alone, differences were not significant (P>0.05). Note that a fifth orchard (Deerfield) was included in this data analysis. While this site was originally established in the trial to test the effects of different levels of pheromone emissions per acre, miscommunication at harvest resulted in samples being available only from the grower standard and G037 sites. As a result, we opted to include these harvest data in this comparison.

***Effect of total pheromone emissions per acre at a fixed number of dispensing units*.**

Walnut trap data. The seasonal flights of codling using all three lure types in all treatments are shown in Fig. 22-24. Similarly, seasonal totals for all treatments, orchards, and averages are shown for the combination lures (Fig. 25), 10X lures (Fig. 26), and for the 1X lures (Fig. 27). All plots caught similar number of moths using the combination lures with no statistical differences between the treatments (P>0.05, Tukey's HSD test). For the 10x lures, no differences existed between the treatments, but the grower standard was significantly different from all treatments but G038 (P < 0.05, Tukey's HSD test). A similar pattern was observed for the 1x lures with excellent trap suppression observed in comparison to the non pheromone permeated grower standard. No statistically significant differences occurred between treatments, but all treatments differed from the grower standard (Tukey's HSD test, P<0.05). No pattern was observed between the projected rate of emission and trap counts. The pattern of higher trap counts in the meso treatments compared to a standard pheromone program, the Checkmate XL 1000 plots, did not repeat in this study.

No trends were observed between the total rates of emission per acre and the total seasonal counts in the combination lures, whereas the 10x lures were suppressed equally in all pheromone plots in comparison to the conventional plots. Traps baited with the 1x lures were suppressed throughout the entire growing season for all treatments in comparison to the grower standard. The strong suppression of the 1x lures was somewhat surprising given that total emission rates were even lower than initially projected due to the problems with seam splitting.

Walnut damage suppression. August canopy samples of plots treated with different rates of pheromone emissions were compared with the grower standard (Fig. 28). Codling moth damage ranged from 0% to 1.0% with no consistent pattern across treatments. The CM XL1000 supplemental application averaged only 0.1% damage across the four replicates while the grower standard and lowest rate pheromone supplements averaged approximately 0.4% damage. In the data analysis, a significant block effect was observed with the Deerfield site indicating a significantly reduced infestation. However, overall pheromone treatment differences were not significant (P=0.31). The target low emission rates of the G039 and G038 meso-emitters provided an additional challenge in these trials as the units themselves were compromised and had frequent failures of the membrane seal with subsequent loss of the pheromone. Unit failure of the G039 emitter was estimated as about 33% and of the G038 emitter at about 48%.

Nut samples at harvest were collected from all treatment plots in three replicated sites (Fig. 29). As noted earlier, we were able to collect from only two treatments from the fourth replicate, thus, that site is not included in this harvest data. The different treatments indicated average damage ranging from 0.25% to 0.7% with no significant treatment effect observed (P=>0.05). The highest observed damage observed was 1.2% in the G039 treatment of the Garcia replicate. This orchard had no insecticide treatments in 2008. The G039 treatment had the dual issue of planned lowest emission rate as well as the unintended unit failure which further reduced the pheromone load in the treatment site. However, the G039 treatment still did not indicate a significant treatment effect.

Dispenser aging trial. Residual analysis of the field aged dispensers is scheduled to be completed by Suterra at the end of January 2009. At that time we will look at the emission characteristics of all dispenser variants at each time point and refine our strategy to select the dispenser characteristics that will provide the best options for 2009 trials.

Wind Tunnel Protocols. The wind tunnel measures ca. 3.50 m from the air intake to the fan downwind of the experimental chamber. The experimental chamber measures 86 cm wide x 86 cm high x 243 cm long and is constructed of glass. The wind tunnel is a low speed open pull system attached to the building's exhaust. Air is pulled into the tunnel and filtered through a pleated industrial filter and activated carbon to remove the air of odors and contaminates. Temperature is between 21 – 23° C. Wind speed is maintained between 28-32 cm s^{-1}, manipulated via a speed-controlled fan located downwind from the experimental chamber. Three bulbs provide white light measuring 20 lux from inside the experimental chamber. The light is diffused by a cloth draped between the bulbs and the wind tunnel and additional coverings placed on the glass top of the wind tunnel to prevent points of light. A protocol for cleanliness was developed and maintained throughout experiments. 95% ethanol is used to clean the wind tunnel and metal platforms in the experimental chamber between trials and/or pheromone treatments.

The procedure to best handle insects prior to experiments has evolved during the course of the year. Initially 48-30 h old virgin males were taken to the experimental room 30 min before the dark phase. Males were kept in one ounce cups containing an artificial diet from which they were reared and placed in a fume hood supplied with carbon filtered air within the wind tunnel room. Initially the cups from which they emerged were the cages males were released from during the trials. After evaluation a release cage that could be opened externally from the experimental chamber was created to prevent disturbance in an attempt to reduce erratic behavior. Currently glass cylinders 25mm in diameter 15 cm long are used, and insects are stored in the wind tunnel room within these tubes 1 h prior to experiments. These cylinders allow for a faster trial process, better positive response of males from having more room, while still maintaining the initial goals of cleanliness. Mating status of males is no longer seen as a variable for initial preparatory studies. Adults are placed upon emerging into a large humid chamber and aged to 72-48 h prior to experiments, allowing them the opportunity to use their wings and satisfy their needs for space which facilitated positive behavioral response. Septas are made 24 h prior to use and stored in a freezer while not in use. They are hung over a platform ~2.1 m upwind of the male release platform. Males were given 3 min to respond or were eliminated from the trial. Behavior is scored as: activation, take off, oriented flight, flying 1/2 way up the tunnel, flying within 10 cm of the lure, touching the lure and fanning behavior at the lure.

By the end of the summer with the help of Jennifer King, Monica Lee, and a new post-doctoral researcher in our lab, Daniel Casado, the rate of successful orientation by a male to our optimal odor source ranges from 70-80%, which is one of the highest success rates reported in the literature. Pheromone based experiments were conducted on both red and grey septa, exhibiting different matrix properties and thus release characteristics. We examined different pheromone doses and how the role of initial starting distance from the point source influences follow-through behavior from orientation and early flight to touching the point source. The results were compared across two colonies originating in different crops and from different geographic regions. Several experiments involving both the pear ester and the apple volatile were initiated in an attempt to develop quantitative results of the percentage of males and females that exhibit positive responses. These experiments will be repeated and refined by Dr. Casado over the winter using our newer protocols.

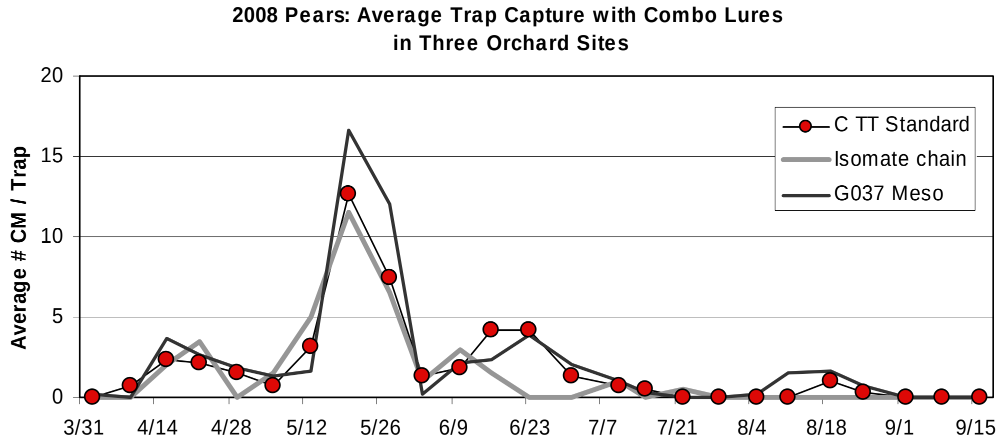

Figure 1. Average seasonal flights of codling moth in 3 pear orchards with intermediate levels of pressure using combination lures in 3 pheromone treatments.

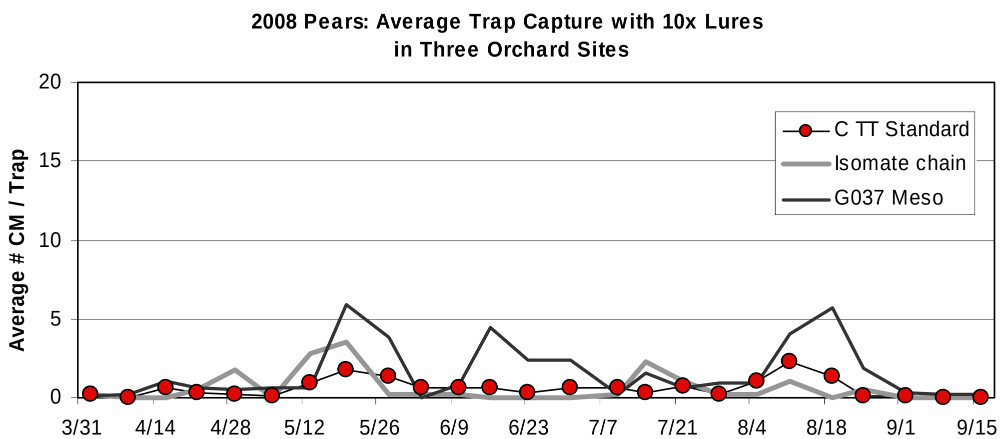

Figure 2. Average seasonal flights of codling moth in 3 pear orchards with intermediate levels of pressure using 10x lures in 3 pheromone treatments.

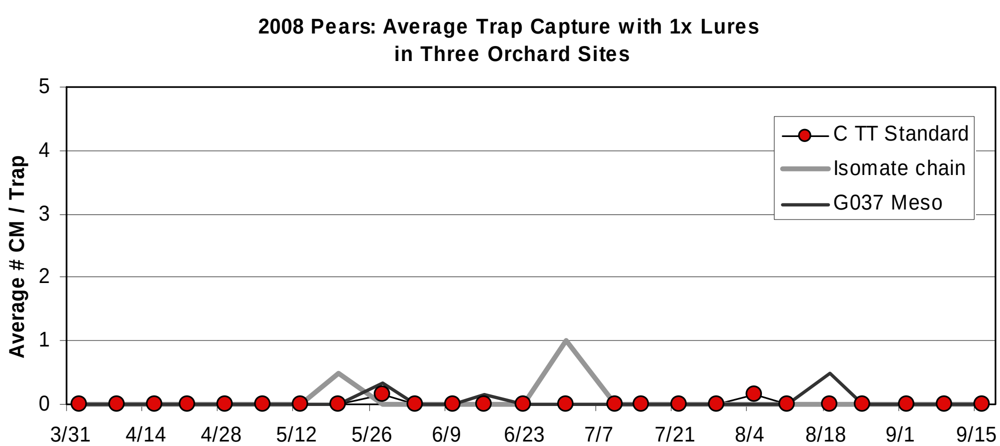

Figure 3. Average seasonal flights of codling moth in 3 pear orchards with intermediate levels of pressure using 1x lures in 3 pheromone treatments.

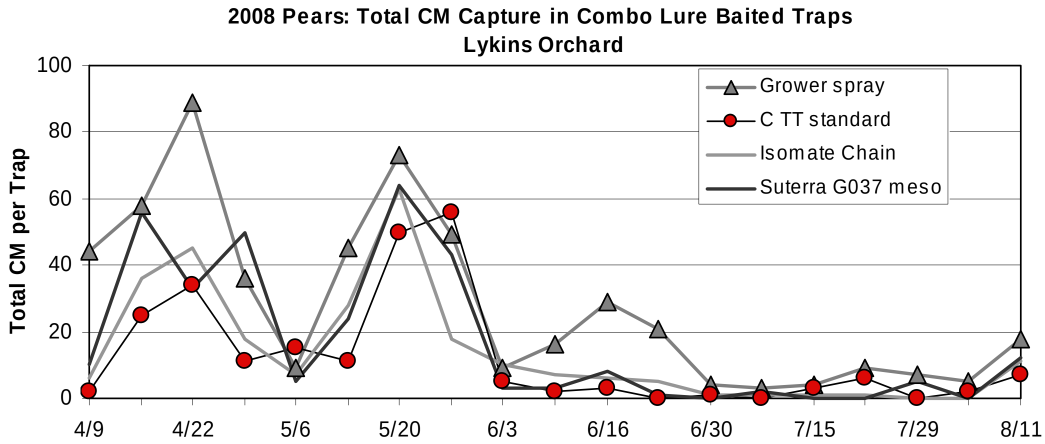

Figure 4. Seasonal flights of codling moth in a conventional pear orchard using combination lures in 3 pheromone treatments.

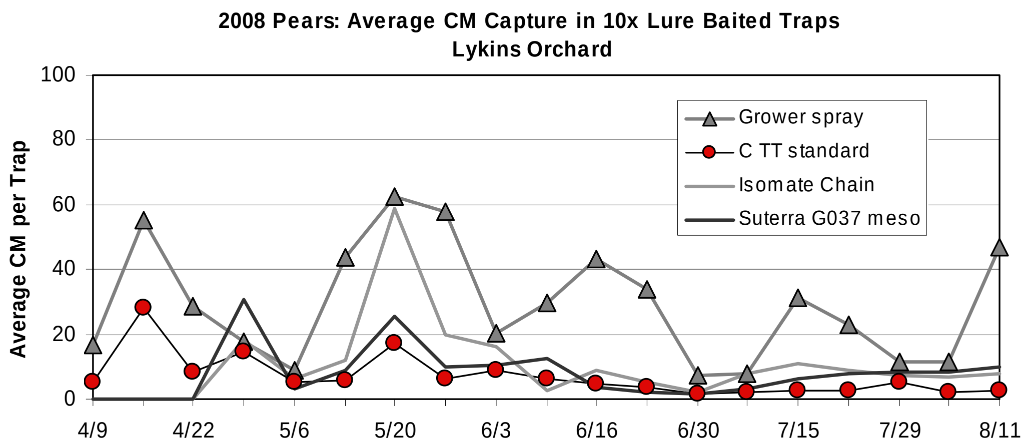

Figure 5. Seasonal flights of codling moth in a conventional pear orchard using 10x pheromone lures in 3 pheromone treatments.

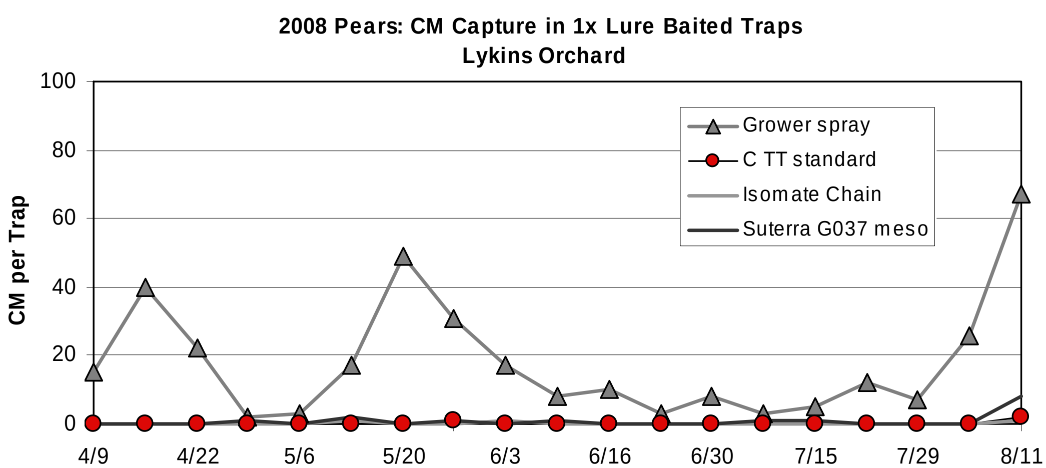

Figure 6. Seasonal flights of codling moth in a conventional pear orchard using 1x pheromone lures in 3 pheromone treatments.

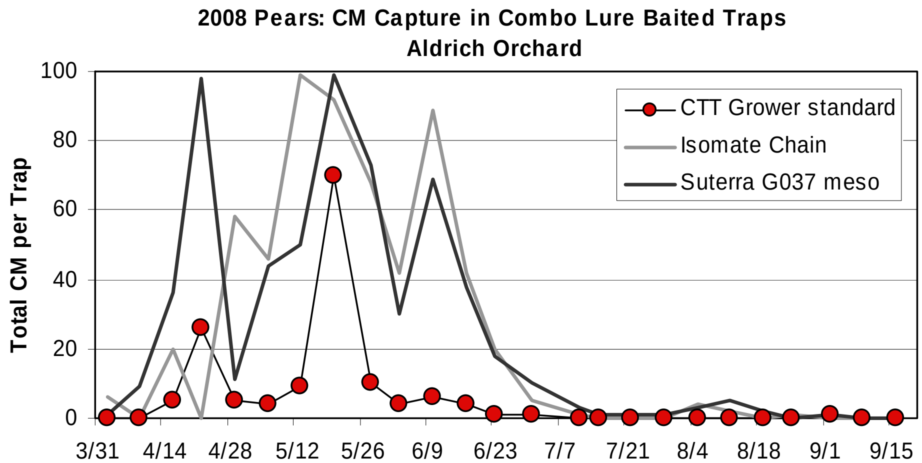

Figure 7. Seasonal flights of codling moth in an organic pear orchard using combination lures in 3 pheromone treatments.

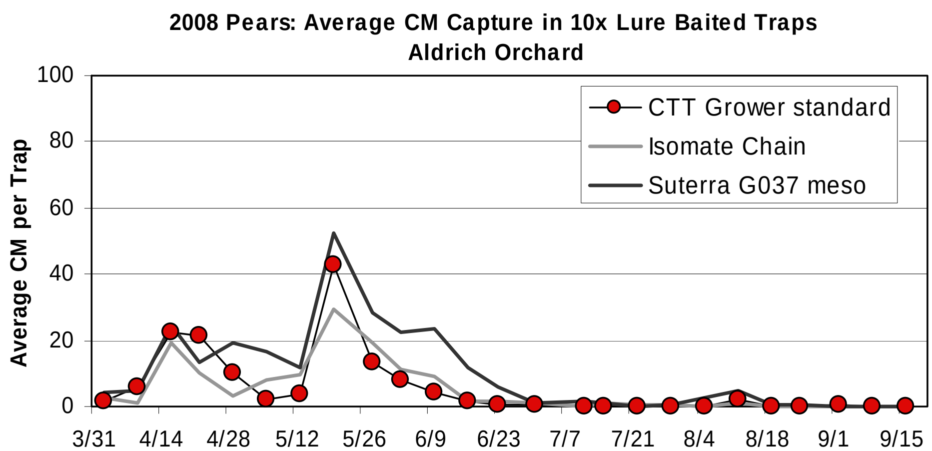

Figure 8. Seasonal flights of codling moth in an organic pear orchard using 10x pheromone lures in 3 pheromone treatments.

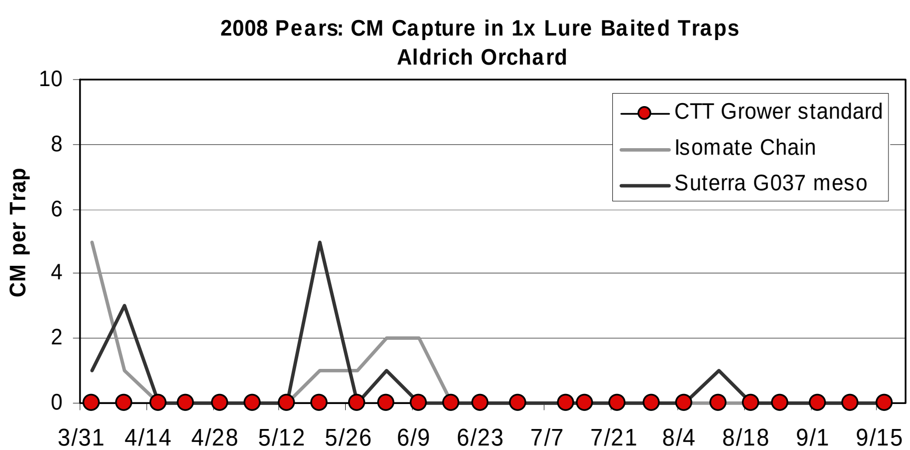

Figure 9. Seasonal flights of codling moth in an organic pear orchard using 1x pheromone lures in 3 pheromone treatments.

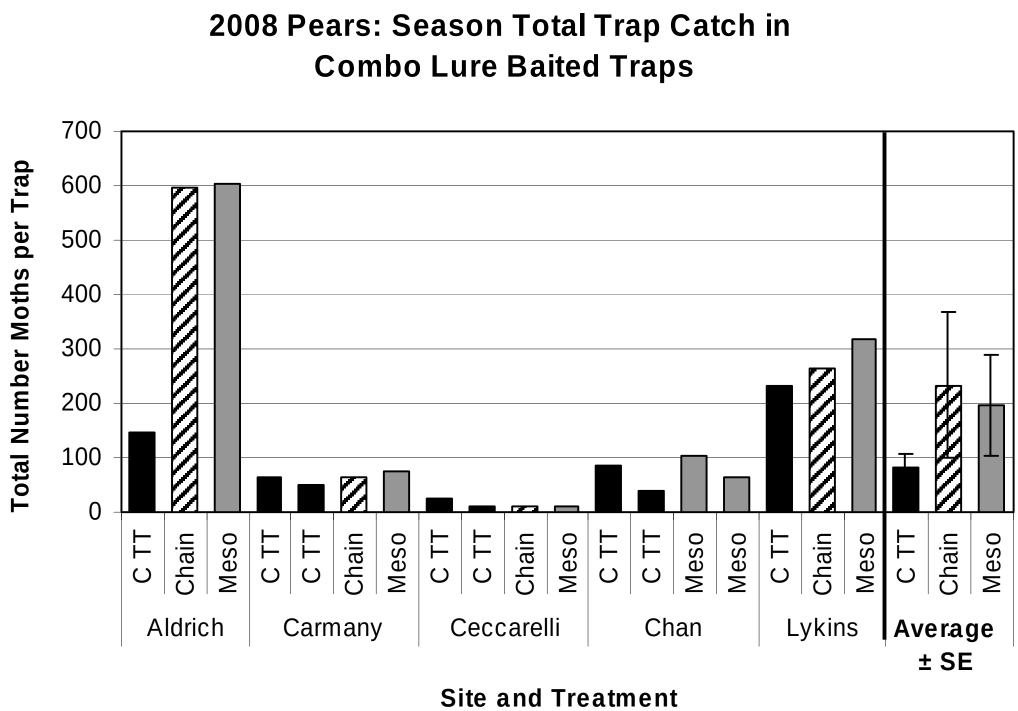

Figure 10. Seasonal total counts for codling moth in 3 pheromone treatments using combination lures.

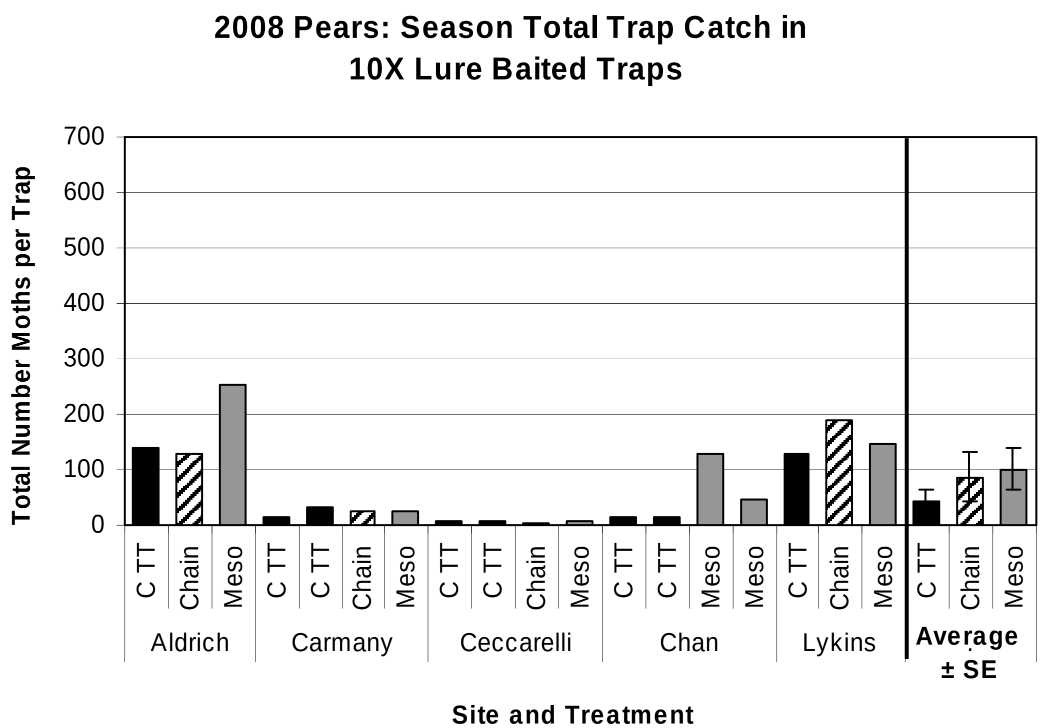

Figure 11. Seasonal total counts for codling moth in 3 pheromone treatments using 10x pheromone lures.

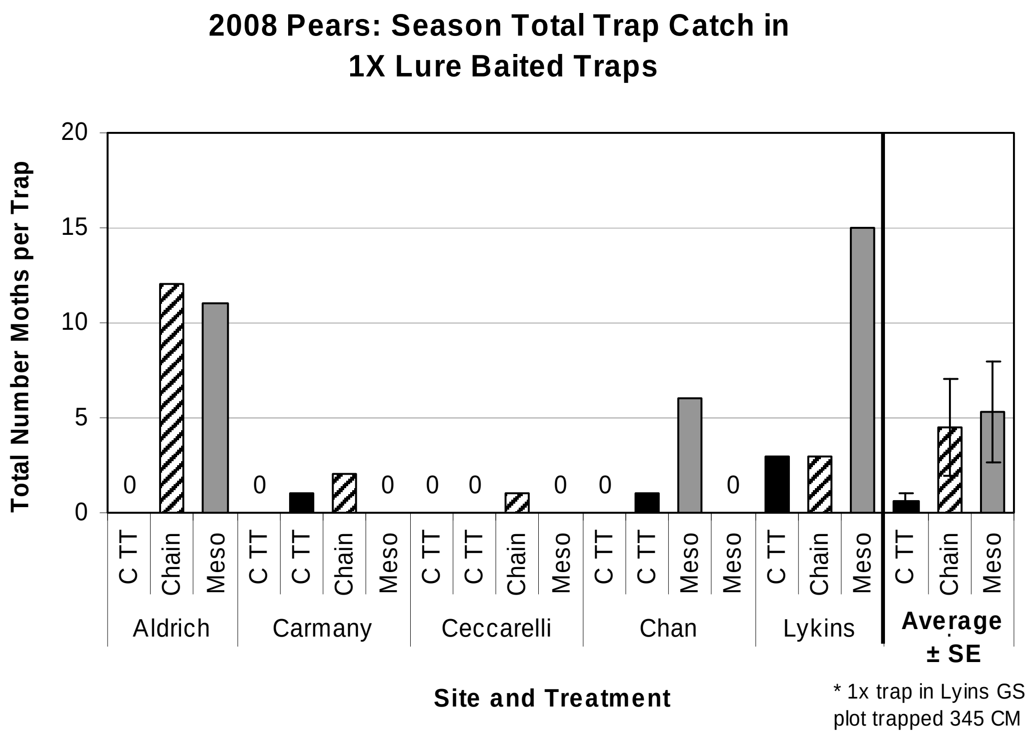

Figure 12. Seasonal total counts for codling moth in 3 pheromone treatments using 1x pheromone lures.

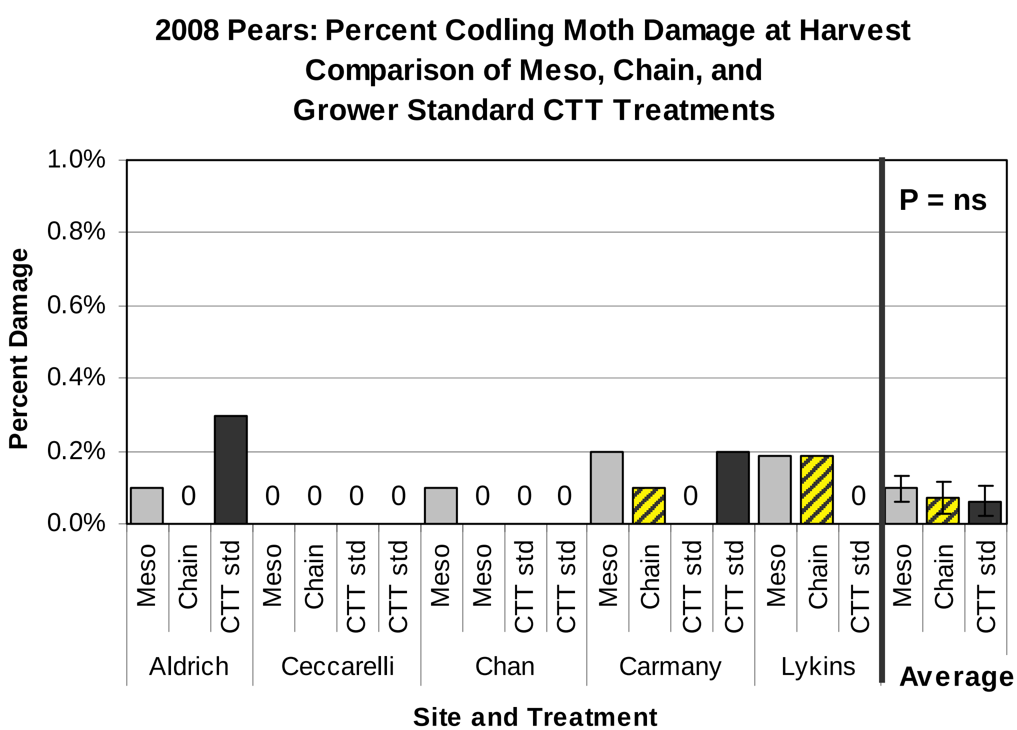

Figure 13. Codling moth damage at harvest in 3 pheromone treatments in pears.

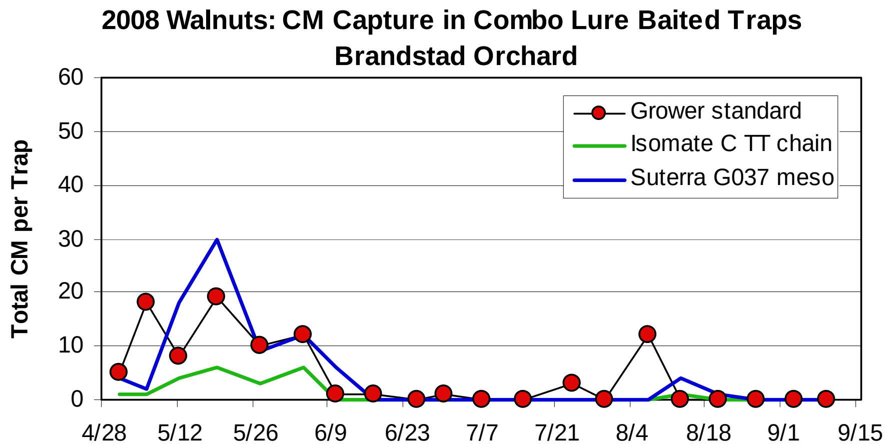

Figure 14. Seasonal flights of codling moth in a conventional walnut orchard using combination lures in 3 pheromone treatments.

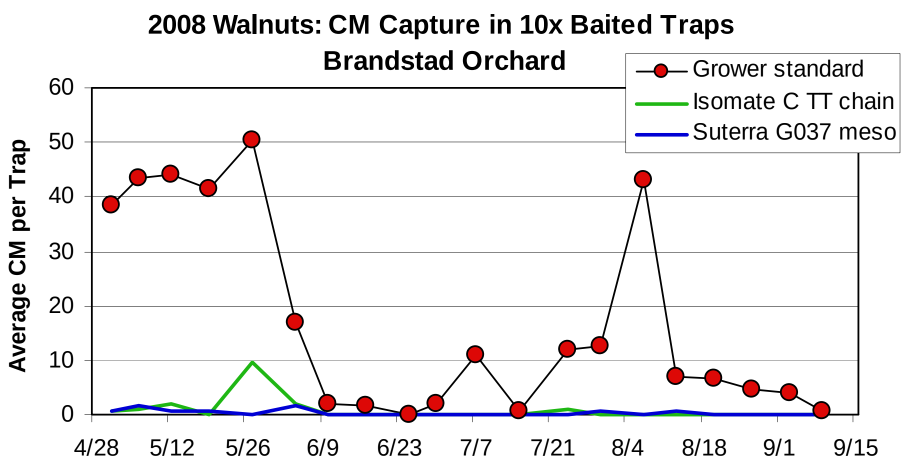

Figure 15. Seasonal flights of codling moth in a conventional walnut orchard using 10x pheromone lures in 3 pheromone treatments.

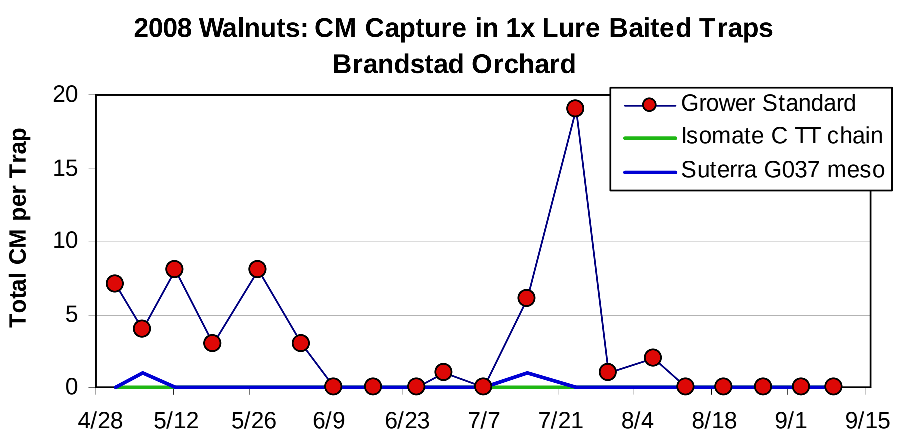

Figure 16. Seasonal flights of codling moth in a conventional walnut orchard using 1x pheromone lures in 3 pheromone treatments.

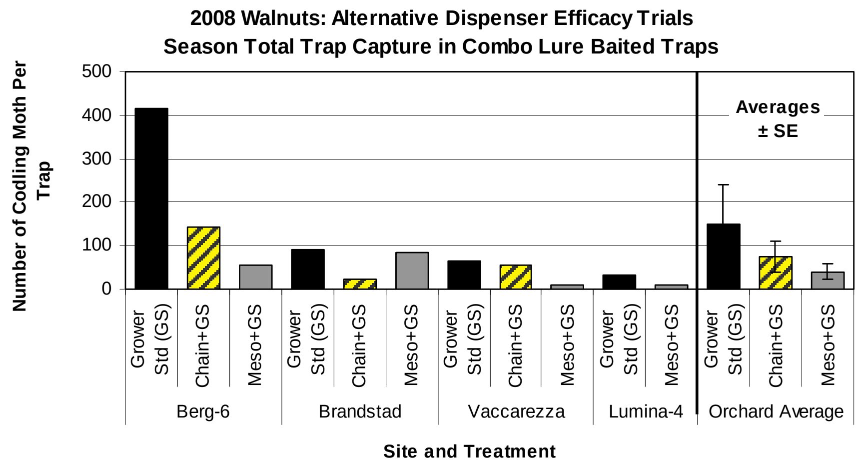

Figure 17. Seasonal total counts for codling moth in 3 pheromone treatments in walnuts using combination lures.

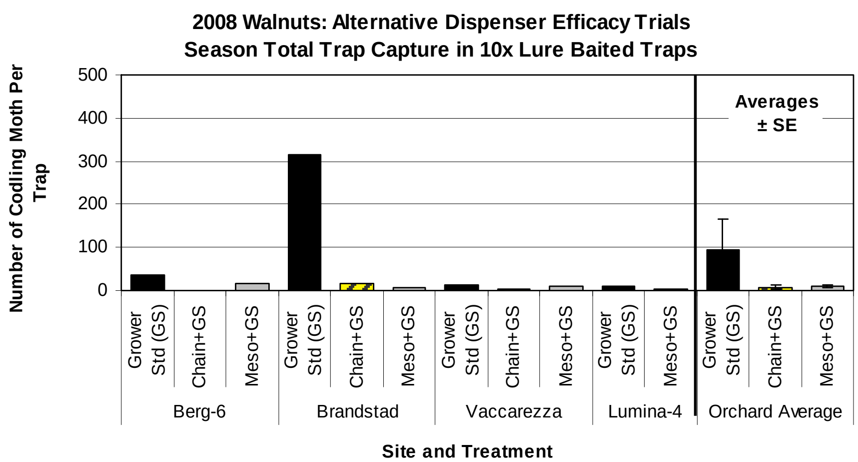

Figure 18. Seasonal total counts for codling moth in 3 pheromone treatments in walnuts using 10x pheromone lures.

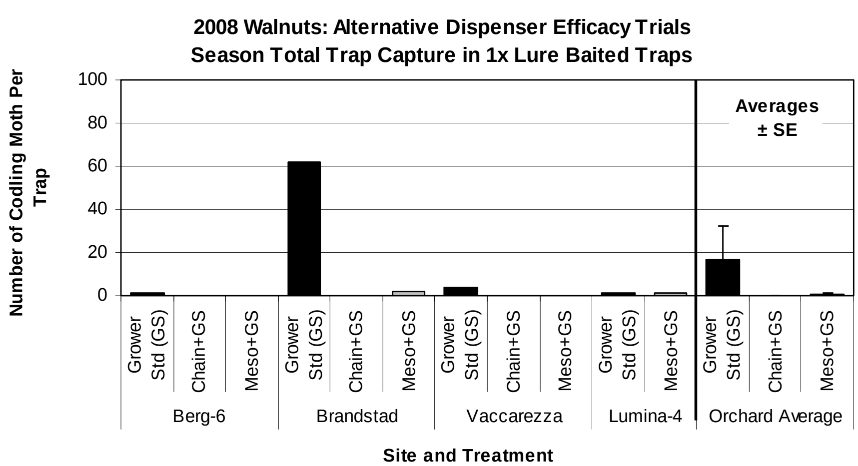

Figure 19. Seasonal total counts for codling moth in 3 pheromone treatments in walnuts using 1x pheromone lures.

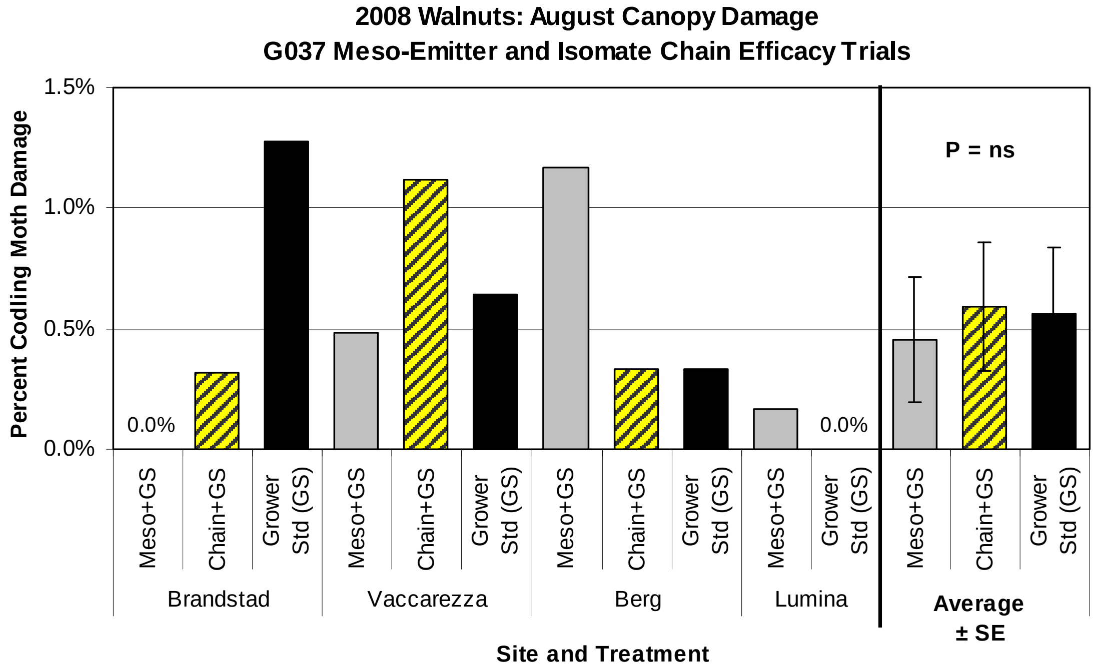

Figure 20. Codling moth damage from canopy samples in August, 2008 within 3 pheromone treatments in walnuts.

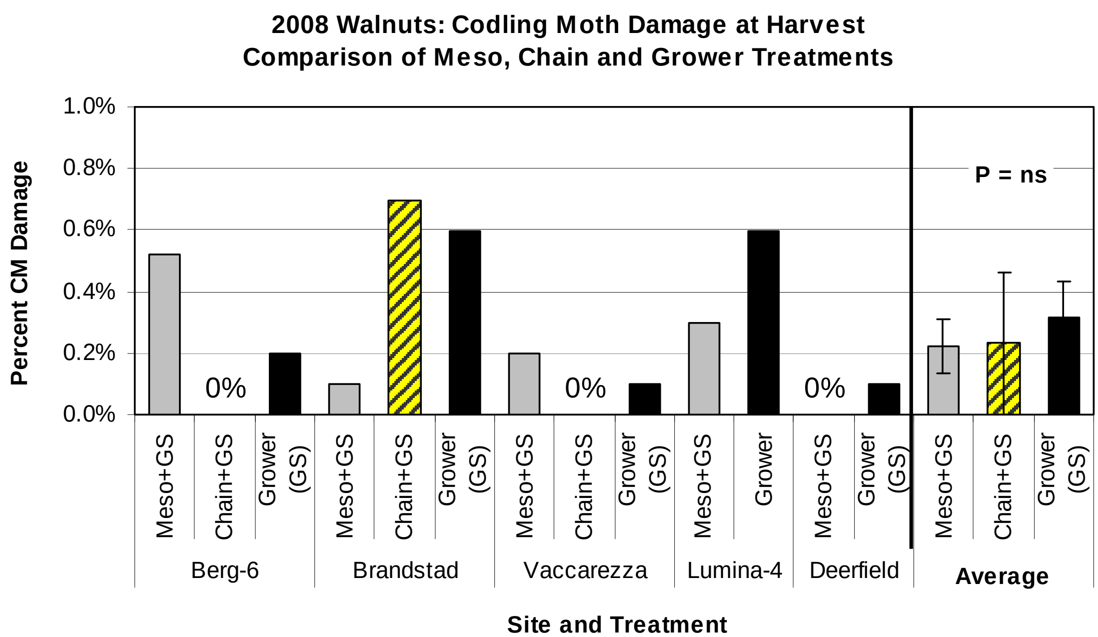

Figure 21. Codling moth damage at harvest within 3 pheromone treatments in walnuts.

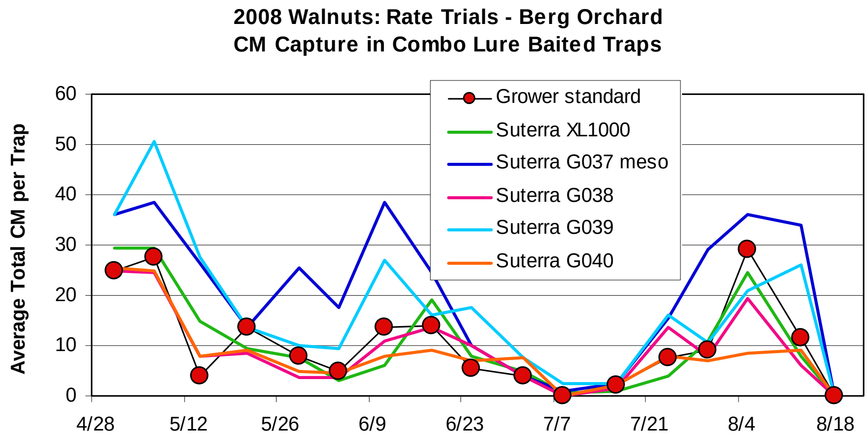

Figure 22. Seasonal flights of codling moth in a conventional walnut orchard using combination lures in plots treated with different levels of pheromones per acre.

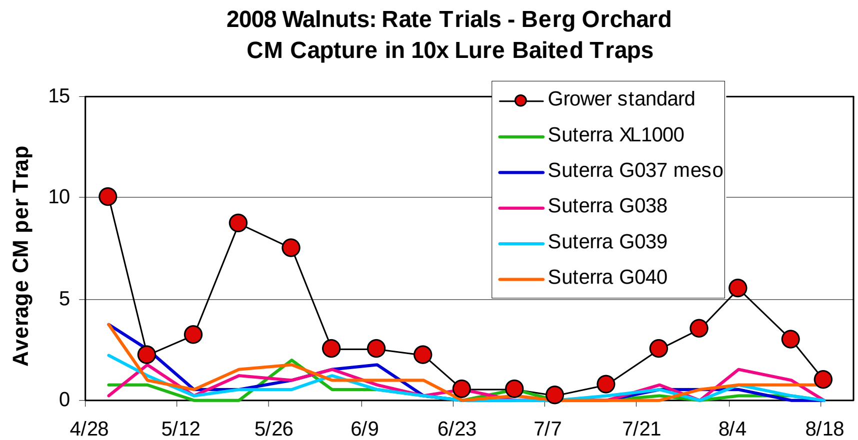

Figure 23. Seasonal flights of codling moth in a conventional walnut orchard using 10x lures in plots treated with different levels of pheromones per acre.

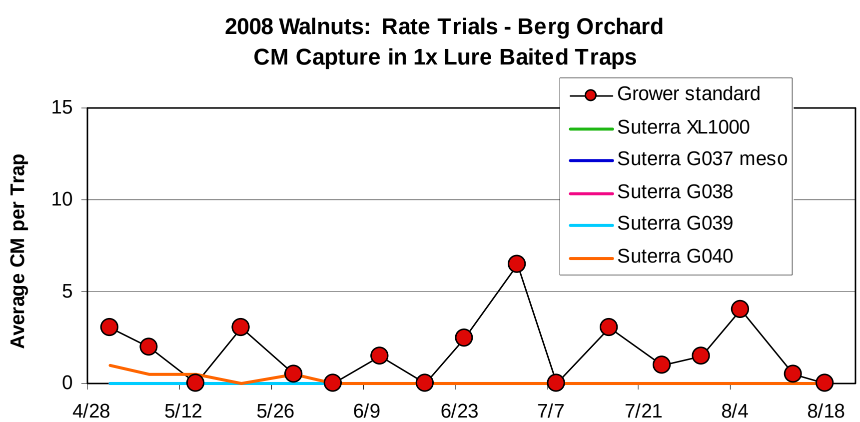

Figure 24. Seasonal flights of codling moth in a conventional walnut orchard using 1x lures in plots treated with different levels of pheromones per acre.

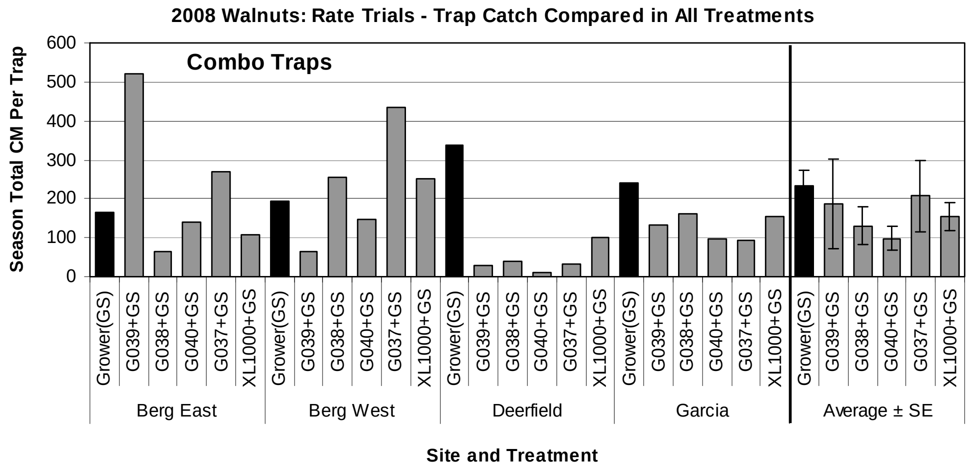

Figure 25. Seasonal total counts for codling moth in plots treated with different levels of pheromone per acre in walnuts using combination lures.

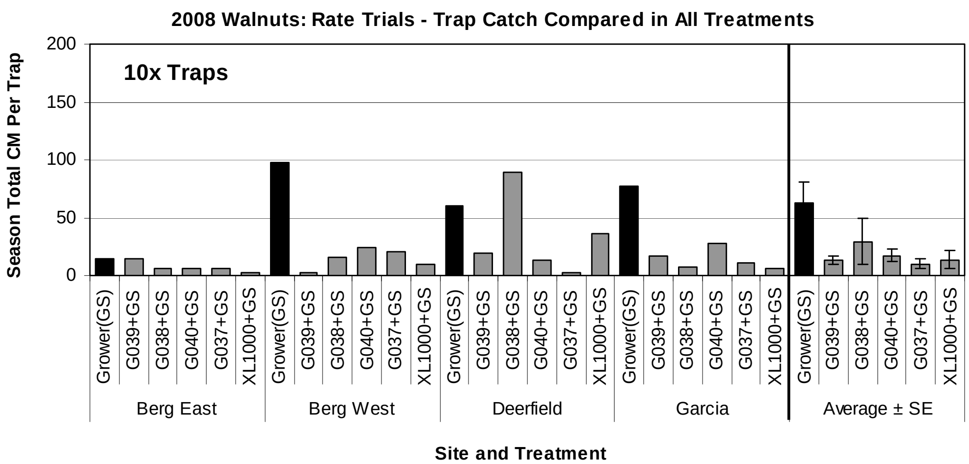

Figure 26. Seasonal total counts for codling moth in plots treated with different levels of pheromone per acre in walnuts using 10x lures.

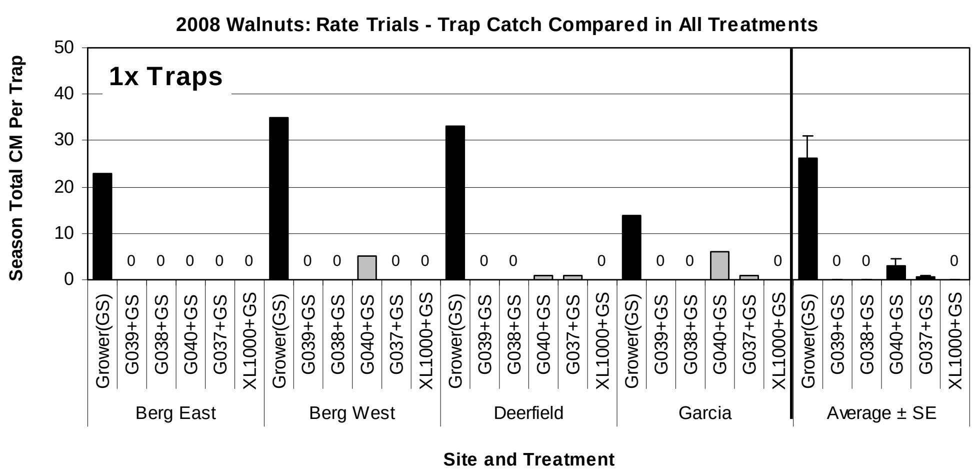

Figure 27. Seasonal total counts for codling moth in plots treated with different levels of pheromone per acre in walnuts using 1x lures.

Figure 28. Codling moth damage in canopy samples in August, 2008 in plots treated with different levels of pheromone per acre in walnuts.

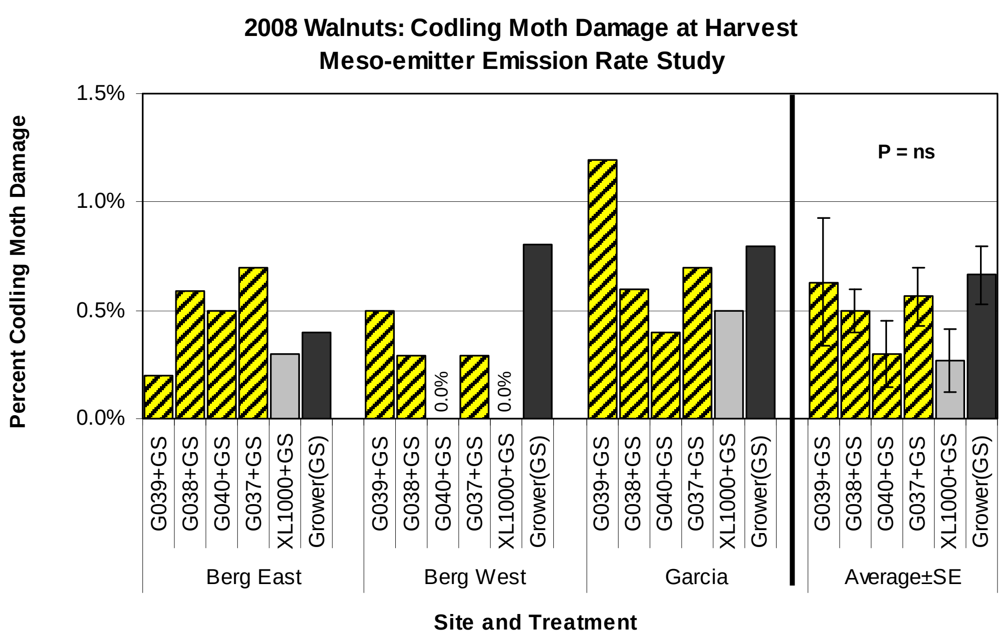

Figure 29. Codling moth damage at harvest in plots treated with different levels of pheromone per acre in walnuts.