Codling Moth Monitoring in Mating Disrupted Apple Orchards:
Development of Trap Thresholds and Prediction of Fruit Injury
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Justification and Background:

The primary insect pest of apples in Utah and the western U.S. is codling moth. Codling moth has historically required large amounts of chemical inputs to manage. In recent years, many Utah apple growers have switched to use of mating disruption—the release of a high concentration of the insect's female sex pheromone, codlemone, to disrupt normal mating behavior—supplemented with lower toxicity insecticides. When using mating disruption, monitoring adult codling moth density with insect traps throughout the season is essential to evaluating the success of the orchard's management program. More information is needed on new, commercially available codling moth lures designed for use in orchards with mating disruption.

The traditional lure used in orchards with mating disruption has been the 10x lure. The 10x lure releases ten times the rate of codlemone so as to be attractive to male moths within a background of pheromone from mating disruption dispensers. In recent years, a non-pheromone lure was developed based on a volatile chemical released from ripening pears. This pear ester has been nicknamed "DA" and is attractive to both male and female codling moths. The "DA" lure contains exclusively the pear ester. The "DA-Combo" lure contains both the pear ester and a high load of codlemone. For these lures to be adopted by Utah fruit growers, the efficacy of each lure under Utah environmental conditions and a trap threshold for treatment based on comparison of trap catch to fruit injury need to be determined.

The 2008 study was the third of three consecutive years of study on codling moth lures for use in mating disrupted orchards (10X and DA-Combo lures were tested in all three years, and DA was tested in two years only). Across the three years, lures were tested in 15 different orchards (26 study sites total, but some orchards were used for two and three years) and in seven cultivars of apple ('Braeburn', 'Cameo', 'Fuji', 'Gala', 'Golden Delicious', 'Jonathan', and 'Red Delicious').

Objectives:

1. To evaluate three types of lures for capture of codling moth adults in apple orchards treated with pheromone mating disruption under northern Utah conditions.
2. To develop trap thresholds based on predictions of fruit injury to determine when supplemental insecticide treatments are needed.

Methods:

Lures were tested in a total of 26 sites (15 different orchards) across three years (2006-08) in Utah County (in or near the towns of Genola, Payson, Santaquin, and West Mountain) of northern Utah. Studies were conducted in nine orchards in 2006, in 12 orchards in 2007, and in five orchards in 2008. Three types of codling moth lures were evaluated: 10X, DA, and DA-Combo (hereafter referred to as Combo).

Test lures were placed individually in large Delta traps. Each lure was replicated three times in a randomized block design. Traps were placed in orchards in early May within approximately one week of first capture of codling moth, or biofix. Mating disruption (MD) pheromone dispensers were applied by the growers either soon before or after study traps were deployed. Codling moths were counted, removed, and collected (from Combo and DA traps in 2007 and 2008 only) from traps approximately weekly through mid September. Because the 10X lure attracts only male moths there was no need to collect moths from these traps for sexing. Codling moths caught in Combo- and DA-baited traps were placed into vials with Histoclear™ to dissolve the adhesive. Trap positions were rotated systematically after each visit to avoid bias of trap position on moth catch. Lures were replaced according to manufacturer recommendations: every three weeks for 10X lures (red septa) and every six to eight weeks for DA and Combo lures (long-life, gray septa). The sticky trap liners were replaced as needed after they became filled with moths and/or debris.

Moths in vials were returned to the laboratory where the gender was determined based on the presence of claspers (males) or a heart-shaped oviposition pad (females) on the abdomen tip (Trece 2005). The abdomens of females were dissected to check for the presence of a spermatophore (sperm packet) (Trece 2005). If present, the number of spermatophores was counted to determine if the female had mated one or more times. If a spermatophore was absent, the female was recorded as unmated.

Following completion of the first and second generations of codling moth egg hatch (in early July and mid to late August, respectively), four replicate samples of 100 fruit each were visually inspected in each orchard for surface stings and larval entries. Fruit with deep stings and suspect larval entries were cut open to verify the type of injury. The percentage of fruit with stings and entries was determined.

To compare effectiveness of the three lures, the number of codling moths caught per week over time was compared with repeated measures analysis of variance, and the number of female and mated-female moths was compared between Combo- and DA-baited traps (Proc Mixed, SAS 2003). To determine if fruit injury could be predicted from trap captures for the different lures, fruit injury was regressed upon trap catch for each lure for each generation and for the season total (Proc Reg, SAS 2003).

Results and Discussion:

The growing seasons of 2006 and 2008 were similar in that codling moth biofix occurred in early May (May 2-6 in 2006 and May 5-8 in 2008) and two full and a partial third generations were completed (mean DD_{50} from biofix to September 15 was 2,531 and 2,397 for study sites in 2006 and 2008, respectively). The growing season of 2007 began earlier and was hotter than the other two years. Biofix was April 26-29 and nearly three full generations of codling moth were completed (mean DD_{50} was 2,822).

Monitoring codling moth populations

Across the 26 orchard sites studied during three years there were significantly more codling moths caught in Combo-baited than in DA- or 10X-baited traps (4.3 $\pm$ 0.5, 1.0 $\pm$ 0.2, and 0.8 $\pm$ 0.1 for Combo, 10X, and DA lures, respectively) ($F_{2,481} = 86.2$, $p < 0.0001$) (Figs. 1-3); however, all three lures tracked peaks and declines in codling moth populations. The main difference was that the magnitude of peaks was greater in Combo-baited traps.

In all three years there were multiple peaks in the first generation of moth emergence (Figs. 1-3). The presence of a distinct second, or "B" peak, was especially prominent in 2008 (Fig. 3). Split-peaks during the first generation of codling moth have been observed in Washington state and other locations (V. Jones, personal communication). New research results suggest that variation in emergence timing of first generation codling moth may be caused by a greater proportion of diapausing (i.e., overwintering) third generation larvae produced the previous year (V. Jones, personal communication). Prior to the 1990s, fewer degree-days were accumulated during a growing season as compared to the last 10-15 years, and only two generations of codling moth occurred in most years in northern Utah. The warming climate trend and increase in generations of codling moth may be the main factors in causing multiple peaks in emergence of the first generation.

Attraction of female moths

Combo and DA lures both attracted more male than female moths (Figs. 4 and 5). Significantly more male moths were caught in Combo- than DA-baited traps (57.4 $\pm$ 14.9 and 7.6 $\pm$ 1.8 moths per week for Combo and DA lures, respectively) ($F_{1,155} = 11.1$, $p = 0.002$), but the numbers of female and mated-female moths were similar between the two lure types (7.0 $\pm$ 2.4 and 5.3 $\pm$ 1.1 females per week, and 3.3 $\pm$ 1.2 and 2.9 $\pm$ 0.7 mated females per week, for Combo and DA lures, respectively) ($p > 0.05$) (Figs. 4A & B vs. Fig. 5A & B, and 6 A and B). Detection of mated females may help assess if MD is preventing mating and, thus, egg-laying. Dates when the most mated-females were caught aligned with peaks of moth flight. Females that had mated multiple times (indicated by asterisks in graphs) were detected primarily in the second and third generations (Figs. 4 and 5). Multiple-mated-females were detected with both Combo and DA lures, but in each 2007 and 2008, they were detected once more in Combo- than in DA-baited traps.

Prediction of fruit injury

Predictions of fruit injury from trap captures were analyzed using data from all sites and years. The best-fitting regression lines were found for Combo ($r^2 = 0.62$, $p < 0.0001$) and DA lures ($r^2 = 0.49$, p < 0.0001). The closer the r^2 value is to 1.0, the more accurate the prediction. The slopes of regression lines were 0.07 for the Combo lure and 0.23 for the DA lure. This implies that fruit injury (stings and larval entries combined) increased by approximately 0.1% for every moth caught in a Combo-baited trap, and by 0.2% for every moth caught in a DA-baited trap. The intercept (point where the regression line crosses the y-axis) was -0.20% for the Combo lure and 2.7% for the DA lure. This implies that 0% fruit injury didn't completely match-up with zero moth capture, but given that these are field-generated data, these small discrepancies in the intercept are reasonable.

Trap thresholds

Development of action thresholds to indicate when supplemental insecticide sprays are needed have been evaluated in the Pacific Northwest. Guidelines recommended for a high-load trap (10X lure) at a density of one trap per 2.5 acres is a cumulative catch of 4-10 moths (Brunner and Gut 1996). Knight et al. (2006) found that thresholds of 1-2 moths for DA traps and 2-4 moths for 10X traps reduced control failures while avoiding unnecessary spraying.

In this study in 2007 and 2008, most codling moth injury was due to stings rather than entries (Table 1). Fruit injury due to larval entries was common in 2006. Supplemental insecticides were applied to most of the orchards one or two times per season when growers determined that trap captures had exceeded their personal economic thresholds. Six of the study orchards had 5% or less total injury and in these orchards, mean cumulative moth capture per trap for the season did not exceed 9, 10, or 45-moths for DA, 10X, and Combo lures, respectively. Of the 15 sites that had 10% or less total injury, mean cumulative moth capture per trap for the season did not exceed 9, 20, or 65-moths for DA, 10X, and Combo lures, respectively.

Utilizing the predictive relationships determined for Combo [% fruit injury= -0.2 + 0.07(# of moths)] and DA lures [% fruit injury = 2.7 + 0.23(# of moths)], cumulative capture of 10 codling moths would result in 0.5 and 5.0% fruit injury, respectively. These predictions correspond closely with the above results for the DA lure, but fruit injury is under-predicted by the Combo lure regression model.

Conclusions:

All three lures reasonably tracked codling moth generations. Combo lures caught the most moths, and more males than females were attracted by all three lure types. The ability to predict fruit injury from trap catch was the best for Combo and DA lures. Trap capture by 10X lures was less consistent than the other two types, and this resulted in a weaker relationship between fruit injury and trap capture. Based on predictive models of fruit injury for Combo and DA lures, trap thresholds were developed. These thresholds are based on an approximate trap density of one trap per 2 to 3 acres and on weekly trap servicing (moths counted and removed).

Cumulative moth capture per trap to maintain the suggested fruit injury levels or less:
Combo lure
0.5% --- 10 moths
1.0% --- 20 moths
5.0% --- 100 moths
DA lure
0.5% --- 1 moth
1.0% ---2 moths
5.0% --- 10 moths

The above thresholds are based on total trap capture and do not consider the number of males and females caught. Further refinement of thresholds could consider moth gender and female mating status. DA and Combo lures have the advantage of attracting female moths and, thus, providing the orchard manager with information on female moth activity. However, the moths must be sexed and in order to determine mating status of females, the abdomen must be dissected and presence of spermatophore(s) determined. The gender of moths on sticky trap liners can be determined by a trained person with the aid of a 15-20X magnification hand lens. Determination of female mating status is more difficult and may require the aid of a microscope. Therefore the utility of female moth information is limited unless the pest manager learns to perform these techniques.

The red septa-10X lure is only effective for about three weeks compared to eight weeks for the gray septa-DA and Combo lures. The cost of the lures when purchased was $1.23, $3.81, and $4.08 each for 10X, DA, and Combo lures, respectively. Given that DA and Combo lures last 2.7 times longer than 10X lures, the comparative cost for 10X lures to last eight weeks is $3.32, so the cost savings is only $0.49 to $0.76 (less than $1 per trap for an eight week period).

In conclusion, use of Combo or DA lures is recommended for monitoring codling moth populations in mating disrupted orchards. Based on predictive models derived from three years of study in 26 orchard sites including seven apple cultivars in Utah County of northern Utah, trap thresholds for total cumulative moth capture per trap were developed. The DA-lure-model appears to align well with fruit injury data across all study orchards, whereas, the Combo-lure-model predicts less injury at higher moth densities than observed in some orchards. Further model validation and refinement is needed based on data from more orchards, years, and locations in northern Utah.

References:

Brunner, J. and L. Gut. 1996. Trap thresholds for codling moth management. Washington State University Cooperative Extension Areawide IPM Update. Vol. 1, No. 4. http://www.tfrec.wsu.edu/IPMnews/IPM501.html#Trap

Knight, A., R. Hilton, P. VanBuskirk, and D. Light. 2006. Using pear ester to monitor codling moth in sex pheromone treated orchards. Oregon State University Extension Publication EM 8904 (8 pp.). http://extension.oregonstate.edu/catalog/pdf/em/em8904.pdf.

SAS. 2003. Version 9.1.3. SAS Institute, Cary, NC.

Trece. 2005. Codling moth sexing: by microscope, hand lens, or naked eyes. Trece Inc., Adair, OK. http://www.trece.com/PDF/Codling_Moth_Sexing_Sheet.pdf.

Figure 1. 2006: Influence of trap lure type (10X and Combo) on weekly capture of codling moths in 9 mating-disrupted apple orchards in Utah County, UT.

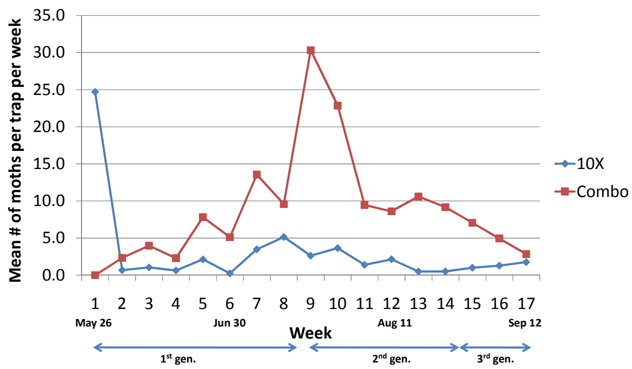


Figure 2. 2007: Influence of trap lure type (10X, Combo, and DA) on capture of codling moths in 12 mating-disrupted apple orchards in Utah County, UT.

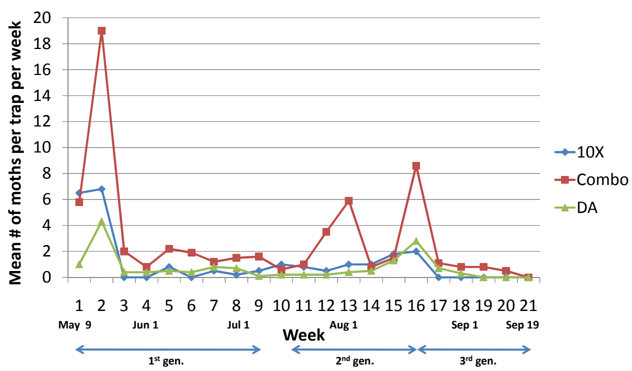


Figure 3. 2008: Influence of trap lure type (10X, Combo, and DA) on capture of codling moths in 5 mating-disrupted apple orchards in Utah County, UT.

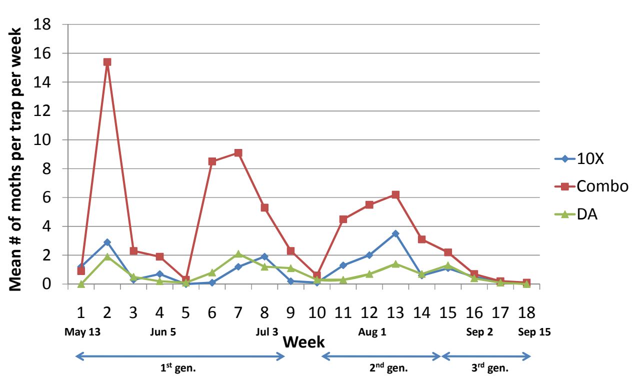
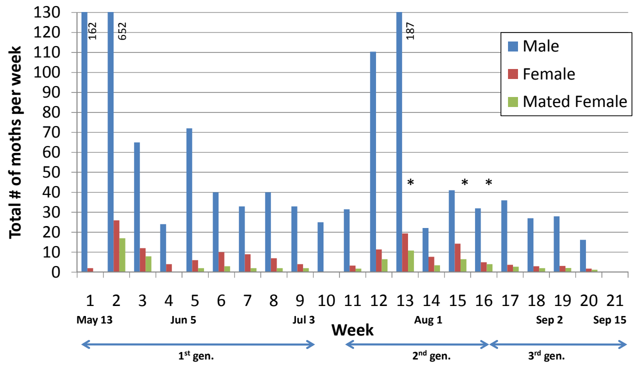
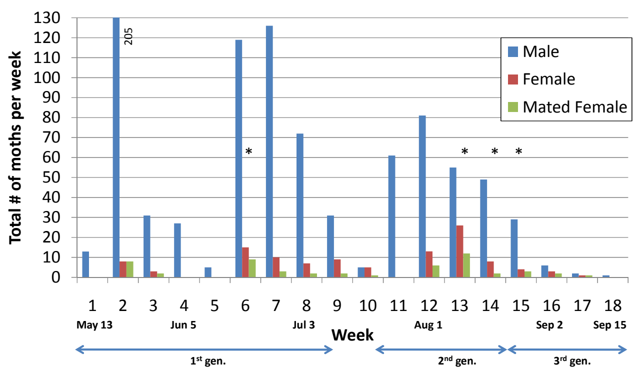


Figure 4A. 2007 Combo lure: Gender and mating status of codling moths.



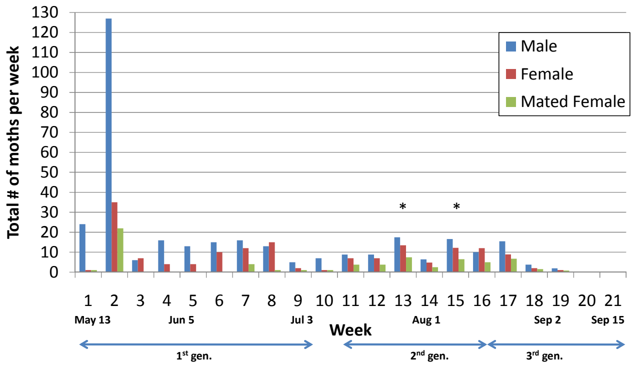
*Weeks with females mated more than once

Figure 4B. 2008 Combo lure: Gender and mating status of codling moths.



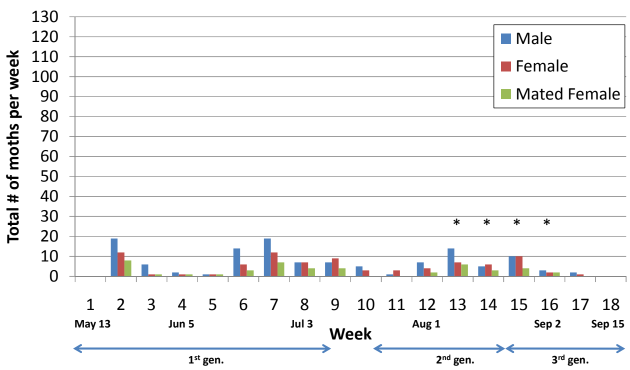
*Weeks with females mated more than once

Figure 5A. 2007 DA lure: Gender and mating status of codling moths.



*Weeks with females mated more than once

Figure 5B. 2008 DA lure: Gender and mating status of codling moths.



*Weeks with females mated more than once

Table 1. Relationship between codling moth trap capture for three lures types (10X, Combo, and DA) and mean fruit injury (stings and larval entries) in 26 apple orchard study sites in Utah County, UT in 2006-2008.

	Cumulative mean # of codling moths per trap												Mean % of fruit with codling moth injury						
	1st generation			2nd generation			3rd generation			Season total*			1st generation		2nd & 3rd generations		Season total		
Orchard	**10X**	**Combo**	**DA**	**10X**	**Combo**	**DA**	**10X**	**Combo**	**DA**	**10X**	**Combo**	**DA**	**Stings**	**Entries**	**Stings**	**Entries**	**Stings**	**Entries**	**Total**
2006																			
Braeburn	3.0	3.5	.	5.5	47.5	.	0.5	1.0	.	9.0	52.0	.	7.0	1.0	1.5	2.8	8.5	3.8	12.3
Fuji	1.0	5.0	.	2.0	84.0	.	0.0	5.5	.	3.0	94.5	.	7.3	1.5	2.0	1.0	9.3	2.5	11.8
Fuji2	1.0	16.0	.	1.5	19.5	.	0.0	8.5	.	2.5	44.0	.	1.8	0.5	0.5	1.0	2.3	1.5	3.8
Gala	0.5	5.5	.	3.0	12.5	.	0.0	0.0	.	3.5	18.0	.	0.0	0.0	0.8	1.3	0.8	1.3	2.0
Gala2	3.5	12.5	.	29.0	74.5	.	10.5	32.5	.	43.0	119.5	.	2.3	2.5	1.3	4.3	3.5	6.8	10.3
Golden Delicious	0.0	0.0	.	0.0	8.5	.	0.5	3.5	.	0.5	12.0	.	1.5	1.5	0.3	3.0	1.8	4.5	6.3
Jonathan	1.5	10.0	.	5.0	36.5	.	0.5	5.0	.	7.0	51.5	.	7.5	8.5	0.3	12.5	7.8	21.0	28.8
Jonathan2	15.5	27.0	.	67.5	143.0	.	31.0	106.5	.	114.0	276.5	.	2.5	5.8	3.0	21.5	5.5	27.3	32.8
Red Delicious	7.5	87.5	.	17.5	171.0	.	6.5	98.0	.	31.5	356.5	.	3.0	12.0	1.5	20.3	4.5	32.3	36.8
2007																			
Cameo	2.7	5.3	0.3	0.7	4.7	0.3	0.7	4.0	0.7	4.1	14.0	1.3	2.3	0.0	2.5	0.5	4.8	0.5	5.3
Fuji	4.7	9.7	1.7	0.3	9.3	1.7	0.3	3.3	1.3	5.3	22.3	4.7	8.3	0.0	1.3	0.0	9.5	0.0	9.5
Fuji2	1.3	4.3	1.3	0.0	3.3	1.7	0.7	2.3	1.0	2.0	9.9	4.0	9.0	0.0	1.5	0.0	10.5	0.0	10.5
Gala	4.7	9.7	1.0	0.3	4.7	0.3	0.3	5.3	0.3	5.3	19.7	1.6	4.5	0.0	1.8	0.3	6.3	0.3	6.5
Gala2	9.3	18.7	1.3	0.0	0.7	1.0	0.3	0.7	0.0	9.6	20.1	2.3	0.8	0.0	1.8	0.0	2.5	0.0	2.5
Gala3	21.7	123.7	23.0	21.7	71.3	12.0	41.3	20.0	68.3	84.7	263.3	55.0	14.3	0.5	3.0	0.5	17.3	1.0	18.3
Golden Delicious	2.3	3.7	2.7	0.3	2.3	2.3	0.0	0.7	1.3	2.6	6.7	6.3	5.5	0.0	1.3	0.0	6.8	0.0	6.8
Golden Delicious2	38.3	67.3	18.7	4.0	11.3	3.7	2.3	7.3	1.7	44.6	85.9	24.1	6.3	0.0	2.5	0.0	8.8	0.0	8.8
Jonathan	18.3	18.7	2.3	1.7	7.2	0.3	0.3	2.3	0.3	20.3	28.2	2.9	7.5	0.0	1.3	0.3	8.8	0.3	9.0
Red Delicious	27.3	50.7	16.0	0.0	2.7	0.0	0.0	1.0	0.3	27.3	54.4	16.3	11.3	0.0	1.5	0.3	12.8	0.3	13.0
Red Delicious2	8.3	21.7	9.7	1.0	15.7	6.7	2.0	26.7	8.7	11.3	64.1	25.1	5.3	0.0	3.0	0.3	8.3	0.3	8.5
Red Delicious3	10.7	47.3	18.0	1.3	31.7	4.7	7.7	49.7	7.7	19.7	128.7	30.4	4.3	0.0	0.8	0.0	5.0	0.0	5.0
2008																			
Fuji	1.3	75.0	13.0	1.3	23.7	5.0	2.0	6.7	3.3	20.0	105.3	21.3	4.5	0.0	1.3	0.3	5.8	0.3	6.1
Gala	3.0	31.0	6.3	0.3	7.3	1.0	0.0	0.7	1.3	3.3	39.0	8.7	3.3	0.3	1.0	0.0	4.3	0.3	4.6
Gala2	11.3	78.7	14.7	27.3	41.7	5.7	6.7	6.0	4.0	45.3	126.3	24.3	3.3	6.3	11.8	8.8	15.1	15.1	30.2
Jonathan	10.7	33.7	2.7	3.0	16.7	3.0	0.3	1.0	0.3	14.0	51.3	6.0	2.8	0.0	2.3	1.3	5.1	1.3	6.4
Red Delicious	0.7	15.0	2.7	0.3	10.3	2.3	0.0	1.3	0.0	1.0	26.7	5.0	2.5	0.0	1.5	0.0	4.0	0.0	4.0