Sterile Insect Technique (SIT) combined with Mating Disruption for Management of Codling Moth in Pear Orchards

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ABSTRACT

In 2025, a series of 20 weekly releases of sterile codling moths (CM) on the windward side of pear orchard blocks were used to examine the potential for use of sterile insect technique (SIT) to augment present pest management tactics (mating disruption (MD)) in mature California pear orchards. Six ~20-acre pear orchard blocks under MD were selected. Three blocks received mating disruption only. Three blocks received mating disruption and 800 mixed-sex CM/acre releases concentrated in the 5 acres of the windward side of the block. Release and control blocks will be switched in 2026. Overall, around 62% of the males were captured in pheromone traps on the edge of the orchard, compared to 38% in the center. The ratio of males captured in kairomone traps (not affected by MD) to pheromone traps was significantly lower for sterile CM than wild CM, suggesting that sterile CM were less impacted by mating disruption. In sterile release blocks, the percentage of wild females mated was lower compared to sterile females. These data are not consistent with a greatly reduced impact of mating disruption on the edges of pear orchards, but they indicate that mating disruption differentially affects sterile and wild CM and that fewer wild females were mated in plots where sterile codling moths were released. The impact of sterile release on CM infestation of pears as inferred from cut fruit sampling is also discussed.

INTRODUCTION

Early development of area-wide programs for control of the codling moth were centered in sterile insect technique (SIT) in British Columbia, Canada, instead of mating disruption, as in the Pacific western US states, because SIT seemed favorable to the more heterogenous terrain and mixture of urban and rural areas of British Columbia (Nelson et al. 2021). However mating disruption (MD) and sterile insect technique have successfully been used together to control codling moth (Horner et al. 2020, Judd and Garner 2005).

As pear orchards in California have become smaller and more widely dispersed, there have been concerns that mating disruption may be less effective for codling moth compared to previous decades. We therefore conducted a study in 2023 and 2024 examined recapture of released sterile codling moth and impact on pear infestation as determined by cut fruit sampling (Kron et al. 2024). That study generally found good recapture of sterile codling moth and trap overflowing but showed greater impact on mating of wild females when the treatment blocks were upwind in treatment blocks compared to downwind treatment blocks.

Given previous suggestions that mating disruption for codling moth was particularly weak on the upwind edge (Welter et al. 2005), we wished to estimate effectiveness of mating disruption on the edge vs. the interior of the orchard and compare edge plots with and without sterile release. We therefore used plots in six orchards–three with and three without sterile insect technique–to compare the impact of mating disruption on the edge and interior of the orchard and to examine the impact of SIT releases on the mating status of wild females. Crop damage at harvest was not assessed and is not directly reported, but codling moth damage is assessed via sampling of cut fruit (Zoller and Zoller 2001).

OBJECTIVES

- Determine if a pattern of greater pear damage from codling moth occurs in the upwind edge of pears under mating disruption
- Determine if SIT releases along the upwind edge of mating disruption orchards mitigate damage
- Determine if codling moth released on the edge of mating disruption blocks remain concentrated in these areas, or do they disperse throughout the block

PROCEDURES

Orchard sites Six ~20-acre pear orchard blocks under MD were selected. Three blocks received mating disruption only. Three blocks received mating disruption and 800 mixed-sex CM/acre releases concentrated in the 5 acres of the windward side of the block (Figure 1). Release and control blocks will be switched in 2026.

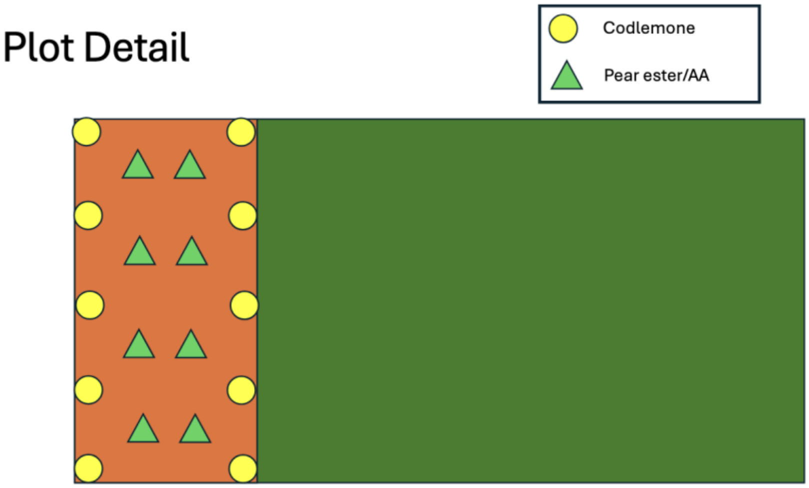


Figure 1. 20-acre plot detail. All trapping and sampling will occur in the orange area representing the windward edge of the orchard.

Monitoring Ten Codlemone traps and 8 pear ester/acetic acid traps per plot were deployed on April 4th and taken down on September 2nd. Orange wing traps (Suterra LLC, Bend OR, USA) were modified using bent wire spacers as described elsewhere (Kuenen et al. 2005, Burks et al. 2020). Eighteen traps were arranged as shown in Figure 1 in six orchards to compare distribution of sterile and wild moths between the upwind edges of the test orchards. Trap liners were changed weekly (if dirty or if they contain moths) for 20 weeks. Lures were changed according to manufacturer's guidelines. Traps containing moths were sent to the USDA-ARS for assessment of dye status and, for pear ester traps, for sex and spermatophore count of females.

Egg Monitoring Weekly egg searches of fruit clusters using the cut fruit technique were conducted (Zoller and Zoller 2001). Three cut fruits per trap location per orchard (3 fruit x 18 traps x 6 orchards) resulted in 324 cut fruit per week for 12 weeks.

Sterile moth releases Sterile codling moths (800 adults per acre) were released each Tuesday for 20 weeks, from 16 April to 26 August 2025. Insects were released manually in block 600 on April 22nd and blocks 400 and 600 on July 29th due to the drone crash/malfunction. Releases were shifted a day later due to holidays for the week of 27 May. Mixed-sex sterile codling moths were sourced from the Okanagan Kootenay Sterile Insect Release (OKSIR) Program (Kelowna, British Columbia, Canada). Adults were exposed to 150 Gy using a Cobalt Irradiator and imported into the United States by M3 Agriculture Technologies (Omak WA, USA). Codling moths from OKSIR are routinely fed a diet containing a lipophilic red dye (calco oil red) that is retained internally by adults and that permits distinguishing sterile released adults from wild codling moths. Moths were shipped from the US port of entry via parcel overnight express to Lakeport, CA, where they were picked up and released in fields the following day. Moths were kept at 2°C using pre-chilled refrigerant gel bags while in shipping, or temperature-controlled coolers while transported in vehicles to the field. Field release was conducted using the Hermes V.2 Unmanned Aircraft Systems (UAS)(Esch et al. 2021, Moses-Gonzales et al. 2021). Way points programmed into the UAS provided for release above each of the 9 monitoring points in the release plot.

Data analysis

Season totals of moths captured in pheromone and pear ester/acetic acid traps were determined for each of the categories examined (wild males, total wild females, and mated wild females, dyed males, total dyed females, and total mated females). Data were analyzed using R 4.4.1 (R Core Team 2024). To examine overall capture and trap overflowing, the hypothesis of equal captures in all orchard blocks was tested with a chi-square goodness of fit test, and the hypothesis of a trap overflowing ratio different from 1:1 was tested separately for each treatment block with an exact binomial test. To test the effects of edge vs. interior position on male capture, a chi-square 2 x 2 contingency test was used to examine the hypothesis of no difference in this ratio between wild and sterile moths. After no significant difference was found in these ratios, a pooled sterile and wild males were used with an exact binomial test to examine the hypothesis of equal captures between edge and interior traps. To compare the ratio of wild males in pear ester/acetic acid to pheromone traps between SIT and control block, and also the ratio of sterile and vs wild males in pear ester/acetic acid vs. pheromone traps in SIT blocks only, generalized linear models (GLMs) were used with binomial and quasibinomial distribution, respectively, and log odds were used to compare effect size. To compare mating rates of wild females between sterile release and comparison orchard blocks, and to compare the mating rate between wild and sterile females generalized linear mixed models (GLMM) with a binomial distribution was used.

CM egg numbers on cut fruit were compared in the SIT and Control blocks as well as with their presence in 2023 and 2024 tests (Kron et al. 2025). Paired t-tests were used to examine differences between SIT and Control areas in the three years of sterile insect release. Eggs were also divided between those found in the first-generation oviposition period vs the second-generation period. The probability between each year's mean difference between the two generations were compared by paired t-tests for the three years 2023-2025.

RESULTS

For all traps (pheromone and pear-ester/acetic acid), there were significant differences in wild adults captured between the blocks (chi-squared = 383.86, df = 5, p < 0.001). (Table 1). For each of the three SIT blocks, the trap overflooding ratio was > 1:1 (Table 1).

Table 1. Total captures of sterile and wild codling moth (both sexes, all traps) by orchard block

Block	Sterile	Wild	Over-flooding[a]
1	103	23	4.5***
2		16	-
3		134	-
4	110	66	1.7*
5		162	-
6	638	252	2.5***

[a] Ratio different from 1:1, exact binomial test. *P < 0.05, ***P< 0.001

Comparison of males captured in pheromone traps in the edge versus the interior revealed a variable ratio and low numbers for both wild and sterile males (Table 2). Comparison of sums of edge vs interior traps between wild and sterile moths revealed no significant difference in the ratios (chi-squared = 0.18, df = 1, p = 0.67), so pooled data were used for an overall comparison. Among all males captured (sterile and wild) in pheromone traps in the edge versus the interior, the proportion captured on the edge was 0.62. This was significantly different from 0.5 (P = 0.003). Block 6 is not included in this analysis because both rows of pheromone traps were on opposite edges of this orchard.

Table 2. Total captures of sterile and wild codling moth males in pheromone trap on the edge vs the interior of the orchard blocks.

Block	Source	Edge Traps	Interior Traps	Edge/Interior
1	Wild	4	2	2
2	Wild	2	3	0.7
3	Wild	15	7	2.1
4	Wild	2	5	0.4
5	Wild	37	22	1.7
1	Sterile	23	8	2.9
4	Sterile	13	11	1.2

Comparison between wild males captured in all pear ester/acetic acid traps vs. all pheromone traps (Table 3) revealed a significant variation in the ratio of males (Paired Wilcoxon signed-rank test, V = 21, P = 0.036), but in all cases over 1:1. The odds of capture in pear ester-acetic acid rather than pheromone traps differed significantly between SIT and comparison plots (GLM, binomial distribution, Deviance = 26.13, df = 1,4; P = 0.005). In SIT plots wild male had a 73% greater chance of being captured in a pear ester-acetic acid rather than a pheromone trap (95% CI = 18%,156%).

Table 3. Wild males captured in pear ester/acetic acid traps compared to wild males in pheromone traps

Block	Sterile Release?	Wild Males in PE/AA	Wild Males in Pheromone	MD Ratio
1	Yes	9	6	1.5
2	No	8	5	1.6
3	No	91	22	4.1
4	Yes	46	7	6.6
5	No	67	59	1.1
6	Yes	156	50	3.1

Examination of only the SIT blocks allowed a direct comparison of the ratio of males in pear ester/acetic acid vs. pheromone traps between the released sterile males and wild males (Table 4) Few wild males were captured in orchard block 1, and the ratios of males captured in pear ester/acetic acid traps vs pheromone traps were similar between sterile and wild males for that block. In blocks 4 and 6, however, this ratio was notably lower in sterile vs wild males. Indeed, in block 6, more sterile males were captured in pheromone traps than in pear ester/acetic acid traps. Overall, the difference in ratios of males in pear ester/acetic acid vs. pheromone was not quite significant (GLM with quasibinomial distribution, Deviance = 6.62, df = 2, 3; p = 0.06).

Table 4. Comparison of sterile and wild males captured in pear ester/acetic acid traps compared to pheromone traps in SIT sites

Block	Sterile	Pear Ester/Acetic Acid	Pheromone	MD Ratio
1	Yes	55	31	1.77
1	No	9	6	1.5
4	Yes	58	24	2.42
4	No	46	7	6.57
6	Yes	223	296	0.75
6	No	156	50	3.12

There was also a not-quite significant trend of fewer wild females mated in SIT sites than in comparison sites (Wilcoxon rank sum test, W = 9, p = 0.08). (Table 5).

Table 5. Comparison of mating in wild females in SIT and comparison blocks

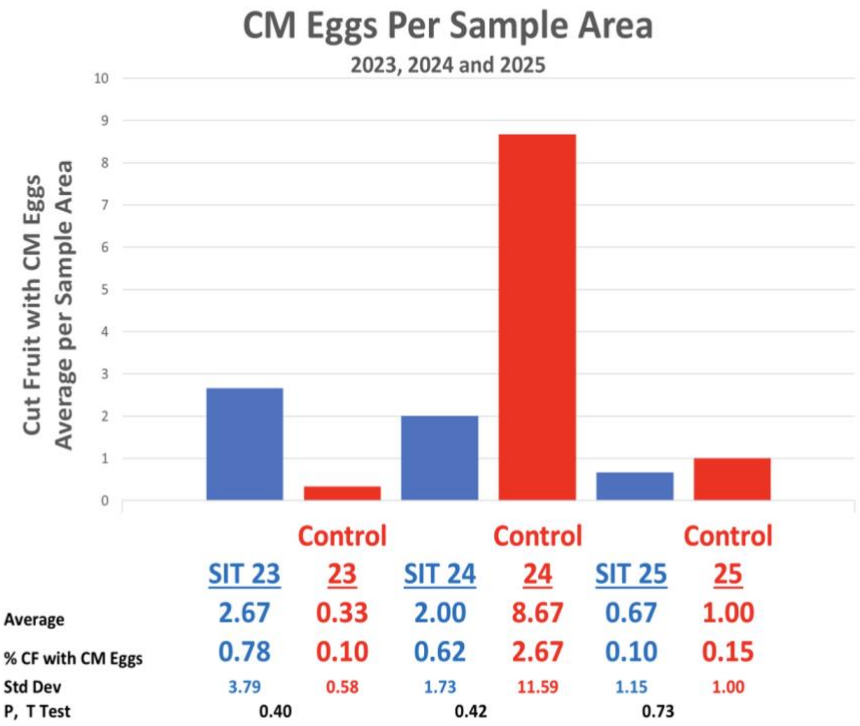
Block	Sterile release?	Wild Females	Mated Wild Females	Percent Mated
1	Yes	8	2	25
2	No	3	1	33
3	No	21	7	33
4	Yes	13	0	0
5	No	37	10	27
6	Yes	53	10	19

When the comparison was between sterile and wild females and limited to SIT treatment blocks, there was a significant trend of higher mating rates in sterile than in wild females (GLMM, binomial distribution, chi-square = 4.09, df = 1, 2; p = 0.04) (Table 6).

Table 6. Comparison of mating in sterile females in SIT and comparison blocks

Block	Sterile?	Total Females	Mated Females	Percent Mated
1	Yes	17	5	29
1	No	8	2	25
4	Yes	28	5	18
4	No	13	0	0
6	Yes	119	36	30
6	No	53	10	19

In the 2025 year of study, the % of mean CM eggs per cut fruit sample was generally lower than the previous two years 2023-2024 (Kron et al. 2024). In 2024-2025 there were more eggs in the Control areas than in the SIT areas. The probability of error was higher in 2025, however, because of the low egg numbers (Figure 2).



	SIT 23	Control 23	SIT 24	Control 24	SIT 25	Control 25
Average	2.67	0.33	2.00	8.67	0.67	1.00
% CF with CM Eggs	0.78	0.10	0.62	2.67	0.10	0.15
Std Dev	3.79	0.58	1.73	11.59	1.15	1.00
P, T Test	0.40		0.42		0.73	

Figure 2. Average number of codling moth eggs per sample area.

In comparison, the 2nd and 1st generation difference in egg numbers showed higher numbers in the 2nd generation Control than in the SIT areas in 2023-2024, but lower Control numbers than SIT in 2025. The probability of t-test error was much higher in 2025 because of these low numbers (Figure 3).

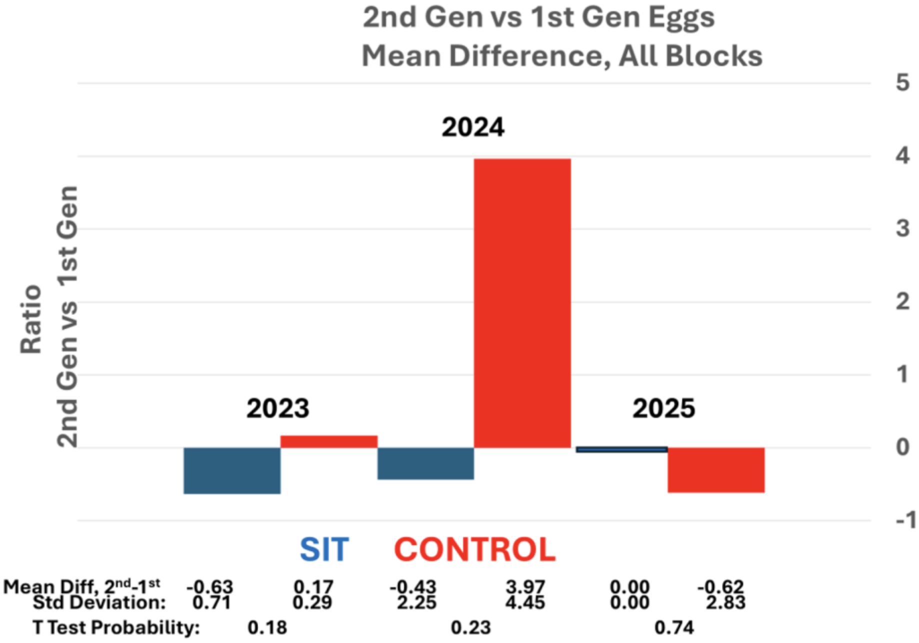
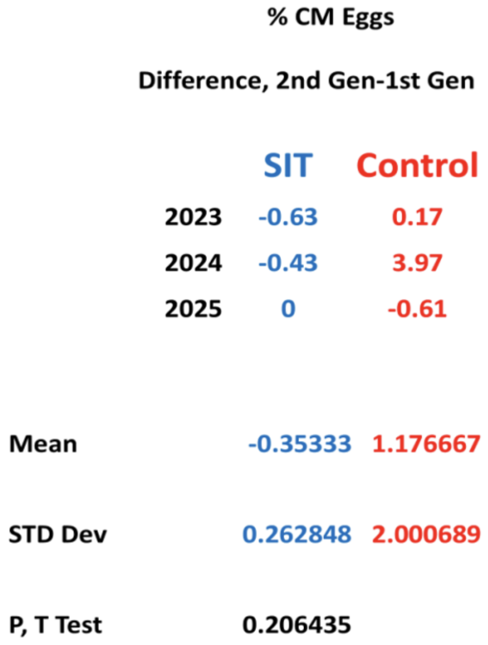


Figure 3. Second generation versus 1st generation codling moth eggs mean difference.

However, a comparison of the mean difference between 2nd generation and 1st generation egg counts for the three years still yields a t-test probability of error near 20%, similar to 2023 and 2024 (Table 7).

Table 7. T-test probability of error for mean difference between 2nd generation and 1st generation egg counts.



% CM Eggs

Difference, 2nd Gen-1st Gen

	SIT	Control
2023	-0.63	0.17
2024	-0.43	3.97
2025	0	-0.61
Mean	-0.35333	1.176667
STD Dev	0.262848	2.000689
P, T Test	0.206435	

DISCUSSION

There was significant overflooding of wild with sterile CM males in all release blocks, consistent with results in the predecessor study (Kron et al. 2024). Based on this study, we hypothesized that more males would be captured in pheromone traps on the edge of the orchard compared to interior positions. There were indeed significantly more males captured in pheromone traps on the edge, but this difference–60:40-is modest. There are still a notable number of wild males captured in the interior pheromone traps (Table 2).

Comparisons between wild codling moths between SIT and comparison orchard plots, and between sterile and wild CM within SIT plots, suggested an impact of the release of sterile moths on the wild population in the SIT plots. In males, this was indicated by fewer wild males being captured in pheromone traps relative to pear ester/acetic acid traps in SIT plots (Table 3), and fewer wild than sterile males in pheromone traps relative to pear ester/acetic acid traps when comparing within SIT plots (Table 4). These data suggest that the sterile moths released into the orchard oriented to the pheromone monitoring traps more effectively than the wild males, i.e., that the sterile males were less affected by mating disruption compared to the wild males.

There were likewise significant impacts on mating reflected by both a nearly significant trend to lower mating of wild females in SIT compared to comparison blocks, and lower mating of wild females compared to sterile females in comparisons within SIT blocks. Taken together, these observations are consistent with a hypothesis that SIT is augmenting mating disruption because both SIT males and females are less affected by the mating disruption treatment and outcompete their wild counterparts.

CM egg presence on cut fruit is suggested to be diminished in the 2nd generation compared with the 1st generation in SIT blocks vs Control blocks, although not less than a 20% probability of error.

In summary, the current data does not provide strong support to the hypothesis of greatly reduced effectiveness of mating disruption on the upwind edge of pear orchards. It does, however, suggest that the sterile CM release in SIT orchards were less impacted by mating disruption than their wild counterparts, and that sterile release therefore augmented mating disruption. This trial should be conducted for a second field season to test these effects more thoroughly.

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