Project Title: Quantifying codling moth capture, lure plume reach, and trap area

Report Type: Final Project Report

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Project Duration: 3 Year

Total Project Request for Year 1 Funding: $207,430
Total Project Request for Year 2 Funding: $188,216
Total Project Request for Year 3 Funding: $195,530

Other related/associated funding sources:
Funding Duration:
Amount: **$**
Agency Name:
Notes: *After Western SARE preproposal was invited to submit a full-proposal for cost off-sets, it was rejected in 2023 for the ca. $345,000 request.*
WTFRC Collaborative Costs: none

Budget 1
Primary PI: RT Curtiss
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Item	2022	2023	2024
Salaries[1]	$96,601.00	$86,901.00	$90,377.00
Benefits[2]	$41,301.00	$36,776.00	$38,247.00
Wages[3]	$12,000.00	$12,480.00	$12,979.00
Benefits[4]	$1,173.00	$1,220.00	$1,269.00
Equipment[5]			
Supplies[6]	$46,855.00	$41,339.00	$43,158.00
Travel[7]	$9,500.00	$9,500.00	$9,500.00
Miscellaneous[8]			
Plot Fees[9]			
Total	$207,430.00	$188,216.00	$195,530.00

Footnotes: [1]Salaries for project technician (1@ 1 FTE), and Postdoc (yr1 1@ 0.9175 FTE, yr2,3 1@ 0.6618 FTE); [2]Benefits for technician @ 41.32%, Postdoc @45.54%; [3]Wages for time slip ($15/hr in yr 1, $15.50/hr in yr2, and $16/hr in yr 3) for 20 weeks/summer; [4]benefits for time slip employees (9.8%); [6]Supplies: computer, printer/software; lab/office supplies, electronics; video camera/accessories, sterile moths (400 dishes/week yr1, 300/wk yr2,3), traps and sticky bottoms, lures. [7]Travel to plots, motor pool rental, fuel, per diem, other related travel.

ORIGINAL PROJECT OBJECTIVES:

1. Research: Compare codling moth lures in commercial apple orchards with mating disruption.
    a) Analyze codling moth capture in traps with 5 commonly used lures under 3 mating disruption regimes (mark-release-recapture study: 15 treatments with 18 replications each).
    b) Determine the number of traps needed per acre when using each lure for accurate monitoring under the three types of mating disruption (from recapture data analysis).
    c) Estimate codling moth population density based on moth capture data in a monitoring trap baited with each (lure) x (mating disruption) type (from recapture data analysis).

2. Extension: Produce practical guidelines for field application of these findings by growers.
    a) Create a decision matrix table of each combination of lure x mating disruption.
    b) Communicate findings to the industry via extension presentations at field days, grower meetings, and updated webpage with project-related factsheets added to the Tree Fruit Extension website.

SIGNIFICANT FINDINGS

Objective 1 – 2022-2024 key findings

- 297 total releases in 2022-2024 resulted in variable capture by lure and mating disruption (MD) type
- Early spring capture was almost always poor with all lures
- Each year, and all years combined, passive mating disruption (hand applied reservoir dispensers) suppressed capture for 4 out of 5 lures
- Each year, and all years combined, the CMDA+AA lure had the most consistent capture across the three MD schemes
- Sufficient replication across all years was achieved to accurately estimate traps/acre and population densities

Objective 2

- PI Curtiss has presented findings at 4 grower meetings in 2022, 3 in 2023, and at 6 in 2024. At two recent extension events where these findings were presented, 98% of attendees reported that they will adopt these findings and alter their management. Extension will continue beyond the end of this project.
- The decision matrix table is presented herein, but it will be modified for publication and readability in print materials in 2025.
- The project webpage, and project-related fact sheets are in development as of the writing of this report but will be completed in early 2025.

METHODS

<u>OBJECTIVE 1: Compare codling moth lures in commercial apple orchards with mating disruption</u>

This study involved three years of replicated codling moth field releases under 15 treatment combinations. The field component of the study was completed by the end of the third field season and then through data analysis we determined mean capture, number of traps needed per acre, and estimated codling moth population density per treatment.

Plots: Experiments were conducted in commercial apple orchards in geographically diverse locations across Washington State during the summers of 2022, 2023, and 2024. Orchards contained a variety of apple cultivars, rootstocks, irrigation schemes, and tree training systems on 8-10-acre plots. All orchards were treated with codling moth pheromone mating disruption using: 1) actively dispensing aerosol emitters (i.e., ISOMATE® CM Mist Plus (Vancouver, WA)) at 0.5-1/acre, 2) passively dispensing reservoir dispensers (i.e., ISOMATE® CM Flex, and Scentry NoMate® CM Spiral (Billings, MT)) at recommended rates, or 3) no mating disruption. Conventional chemical controls were applied as needed by farmers.

Experimental design and moth releases: The experiment released externally marked sterile codling moths (75 cups/week for 20 weeks/year) for on-farm evaluation of codling moth lures. The cost for moths increased every year, but we were able to keep other costs down to compensate for the differences. Sterile, mixed-sex codling moth adults were obtained from the Okanagan-Kootenay Sterile Insect Release (OKSIR) facility in Osoyoos, British Columbia, Canada. Upon eclosion, moths at the OKSIR facility were immediately placed in petri dishes at an approximate ratio of 1:1 males:females (ca. 800 moths/petri dish) and treated in a Cobalt-60 irradiator. The dishes of irradiated moths were then packed into battery-powered coolers (2.8 Cu. Ft. Portable Fridge/Freezer: Edgestar co. Austin, Texas) held at approximately 2-5 °C (36-41 °F) and shipped to Washington State. Moths arrived before noon the same day they were packed allowing for immediate release into field plots. Because moths were transported as mixed-sex batches in chill coma directly from the shipper to field sites for immediate release, the sexes could not be separated prior to release.

Immediately upon arrival at field sites, moths were dispensed into 540-ml polystyrene cups (Fabri-Kal Corp. Kalamazoo, MI) in batches corresponding to the number being released at each distance, but never more than 4,000/cup. Moths for each release distance were uniquely colored using ca. 1.25 ml/800 moths with Dayglo florescent pigments (ECO11 Aurora Pink®, ECO15 Blaze Orange™, ECO18 Signal Green™, ECO19 Horizon Blue™) (DayGlo Color, Cleveland, OH), allowed to warm to ambient temperature, and then released at pre-marked locations at distances of 20, 40, 60, and 80 m (66, 131, 197, 262 ft) and from the central pheromone-baited trap location. Moths were gently tossed by hand from the containers of colored moths ca. 1-2 m (3-6 ft) into the canopy of pre-marked trees (Figure 1).

Figure 1. Toriani Kent, Project Technician, releasing pink moths into the orchard canopy (R. Courtney, Good Fruit Grower Magazine)

The experiment employed a cardinal-direction mark-release-recapture design with a single central trap following protocols from Curtiss (2021) (Figure 2). Release locations were marked with flagging tape in the four cardinal directions from the single trap at distances of 20, 40, 60, and 80 m (66, 131, 197, 262 ft) . In each replicate, approximately equal numbers of females and males were released, and the number of moths was increased with increasing distance. Each of the four 20 m (66 ft) release points received ~400 sterile males/~400 sterile females, the four 40 m (131 ft) release points each received ~800 sterile males/~800 sterile females, the four 60 m (197 ft) release sites each received ~1600 sterile males/~1600 sterile females, and each of the four 80 m (262 ft) release sites received ~3200 sterile males/~3200 sterile females.

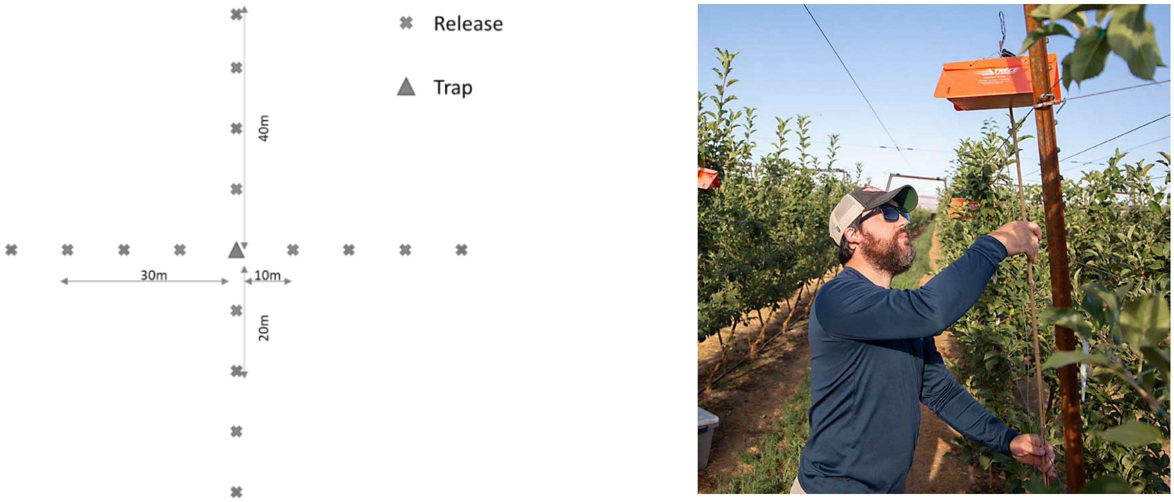

Figure 2. Cardinal-direction mark-release-recapture with a single central trap experimental layout. RT Curtiss is shown hanging a trap in the orchard canopy (R. Courtney, Good Fruit Grower Magazine).

Sampling: The uniquely colored pre-marked moths released at each distance were recaptured at the central trap location. Recaptures of sterile male and female marked moths were quantified using Orange Pherocon VI delta traps (Trécé Inc., Adair, OK) baited with a PHEROCON® CM-DA COMBO™ Lure + AA Lure (Trécé, Inc.) designed to attract both male and female codling moths. The 2-part lure was held above the replaceable sticky liner with a pin through the top of the trap. To maximize catch, traps were placed within the top 1/3 of pre-marked trees. Lures were changed every six weeks. Traps were monitored for 14 days following release. Trap sticky liners were removed and replaced if moths were present when traps were checked weekly and were subsequently examined in the laboratory using UV illumination (400-405 nm, 12 UV LED bulb flashlight, BioQuip Products, Rancho Domingo, CA) to determine the color and sex of marked moths. Each treatment will be replicated 18 times over the course of the three-year study (6 replications of each treatment/year) due to limitations in weekly availability of moths and test sites. One full replication of all treatments spanned a nine-week period because only 300 dishes of moths were available weekly for this experiment and each individual release requires 60 dishes (Figure 3).

		Lure 1	Lure 2	Lure 3	Lure 4	Lure 5
Block 1	Passive MD	Wk 1,4,7,10,13,16	Wk 3,6,9,12,15,18	Wk 3,6,9,12,15,18	Wk 2,5,8,11,14,17	Wk 1,4,7,10,13,16
Block 2	Active MD	Wk 2,5,8,11,14,17	Wk 1,4,7,10,13,16	Wk 2,5,8,11,14,17	Wk 1,4,7,10,13,16	Wk 2,5,8,11,14,17
Block 3	No MD	Wk 3,6,9,12,15,18	Wk 2,5,8,11,14,17	Wk 1,4,7,10,13,16	Wk 3,6,9,12,15,18	Wk 3,6,9,12,15,18

Figure 3. Example experimental layout and timeline.

Data analysis: Analysis of mark-release-recapture experiments provided estimates of codling moth dispersive distance, plume reach of lures, and trapping area related to males and females independently. To ensure that only reliable and robust data are used for analysis, only replications with at least two recaptured moths from each release distance were used; typically, 10-40% of replications were not acceptable (Curtiss et al., in prep). Males and females were analyzed separately. Data analysis will be plotted following the quantitative methods of Miller et al. (2015) to provide: 1) an untransformed graph of the released moths over distance from trap, 2) plot of 1/proportion of released moths recaptured over distance of release from central trap (MAG plot), and 3) (annulus area)*(proportion of codling moths recaptured)/distance of release from central trap (Miller plot). The untransformed plot confirms that release distances are selected appropriately when a concave line with an asymptotic approach to zero catch is observed. The slope of the MAG plot, linear over close release distances, is used to determine plume reach of monitoring trap lures using the standard curve of Miller et al. (2015), Fig. 4.12. The maximum dispersive distance for 95% of the responding population is estimated by a second-order polynomial fitted to the Miller plot data with the point at which the line crosses the x-axis estimating the maximum distance 95% of the population can disperse (Adams et al., 2017). The average proportion caught out of all insects in the full trapping area (Tfer) for these experiments will be calculated by dividing the mean of the proportion caught at a specific distance (spTfer) × annulus area by the mean annulus area [mean (spTfer × annulus area)/mean annulus area] (Eq. 5.2, Miller et al., 2015), and will be used to estimate population density per trapping area. Areas of trapping annuli will be calculated as per Miller et al. (2015).

Anticipated results and potential pitfalls: One-third of the total planned replications of each treatment were planned in each year, so major analysis was not planned to occur until the end of the third field season. However, due to some moth supply issues in 2023, eight releases planned for that year did not occur. In 2024, we tried to make up some of the lost releases and conducted five more than originally planned. Over the three years we only missed three planned replications, and they were all due to OKSIR supply issues. We anticipated data would suggest the need for higher trapping densities for orchards under the more efficacious lure types and mating disruption.

Some replications did not have adequate capture for meaningful analysis, and were not included in the analysis.

OBJECTIVE 2: Produce practical guidelines for field application of these findings by growers

Products: The important products of this study are 1) recommendations on the minimum number of traps needed per area to accurately monitor codling moth in apple orchards treated with any of the mating disruption and lure combinations tested, and 2) interpretation of moth capture in those monitoring traps, i.e., what is the density of moths within the trap area if a single moth is captured in a monitoring trap. To deliver useful information to the industry at the end of this project, we have created a decision matrix table displaying lure types and mating disruption technologies and corresponding pest density estimates. From these data, IPM thresholds can be clarified to account for estimated pest densities, and management decisions can be more informed and save money and effort.

Dissemination: Our progress on this project will continue to be shared based on requests from the industry (i.e., distributor and packing house meetings) and at extension events (field days, fruit schools, workshops, etc.) beyond the end of WTFRC funding.

RESULTS AND DISCUSSION

OBJECTIVE 1: Compare codling moth lures in commercial apple orchards with mating disruption

Sterile codling moth releases were conducted in 45 commercial orchards each year from 2022–2024. Orchards were divided into three geographically distinct blocks corresponding to latitudes and longitudes 46-47°N and 119–121°W (Royal city region), 47–48°N and 119–121°W (Quincy Region), and 48–49°N and 119–121°W (Okanogan Region). Fifteen orchards were in each geographic block, with five blocks for each treatment: no mating disruption, passive mating disruption, and active mating disruption. All releases were performed when scheduled, unless moth supply issues interfered.

There were 100 total releases performed over 20 weeks of the summer 2022, and due to moth supply issues only 92 releases were performed in 2023, 105 releases were conducted in 2024. Each orchard (lure × mating disruption combination) received at least three releases, resulting in 17-22 acceptable replications of each combination across the three geographic blocks and the three years of releases. There were no statistical differences in combined male+female moth capture due to geography. However, some trends emerged. Capture in the early spring and late fall is poor across all lures, indicating that growers may not be receiving accurate wild moth population data when populations are low and weather conditions are not favorable for flight. Passive mating disruption appears to suppress trap-finding more than active mating disruption, indicating that active mating disruption may be deployed at too low densities to fully suppress mating in our plots. The CMDA+AA lure had the most consistent capture across the three mating disruption schemes and provided the overall highest combined capture.

Preliminary population density estimates based on the 2022-2024 replications also show some trends. All lures can be used in all mating disruption schemes to detect codling moths. However, the CMDA+AA and Megalure 4k lures both appear to detect codling moth at the lowest population levels across management schemes. The CML2, 10x, and CMDA lures had more variable capture, but appear less able to detect codling moths until populations are high when mating disruption is present.

The results presented in this final report are from three seasons and include the combined male+female recapture data, but there are some important considerations arising for farmers. First, the lure used in monitoring programs needs to be carefully matched with the mating disruption program. Second, codling moth capture-based decision making on apple farms is more accurate with the results of this study demonstrating a better understanding of the interactions between the lures and mating disruption types. Last, spray decision-making based on monitoring traps may be inaccurate in the early spring when accuracy is critical because codling moth responses to traps are poor due to variable and unfavorable weather conditions. A parallel study from the Curtiss Lab found that temperature impacts moth capture significantly, with low temperatures suppressing capture and high temperatures increasing capture more than expected.

Now completed, this project provides accurate treatment guidance for industry decision makers. Accuracy in spray decisions can lead to cost savings by preventing unnecessary sprays, and/or inducing a spray to prevent crop losses. The cost savings, and/or gains will contribute to the long-term sustainability of farming apples in Washington. The continued investment of the WTFRC-ACP in study will provide the industry with more precise codling moth predictions upon which to base spray decisions.

<u>OBJECTIVE 2: Produce practical guidelines for field application of these findings by growers</u>

PI RT Curtiss has presented preliminary project findings at four grower meetings in 2022, three in 2023, and six in fall 2024. At least 450 growers and decision-makers were present collectively at these meetings. The decision matrix table is presented in table 1. As of the writing of this report (Dec 23, 2024), the project webpage and project-related fact sheets are still in development. Project fact sheets will be completed by early 2025.

In addition to project-specific activities, we applied for a Western SARE grant ($347,287) to expand the research aspects of the project in 2023-2024 and add an extension-focused year (2025) to disseminate our findings. Our preproposal was accepted, and we were invited to write a full proposal that was ultimately rejected. The Western SARE proposed project would have allowed us to expand the scope of this project, cover unanticipated cost increases, and fund additional personnel. Unexpected cost increases are primarily for sterile moths which increased considerably since our original quote in summer 2021 (quoted at $24/unit in 2021, cost $30/unit in 2022, increased to $38/unit in 2023) when this project was in preparation. The increased costs of sterile moths caused us to not have sufficient funds for hiring hourly staff. Despite the lack of staff, we were able to complete all the releases for which we received moths, but we had to postpone work on the project fact sheets and attend fewer grower meetings in 2023 and 2024.

REFERENCES:

Adams, C.A.; Schenker, J.H.; McGhee, P.S.; Gut, L.J.; Brunner, J.F.; and Miller, J.R. 2017. Maximizing Information Yield from Pheromone-Baited Monitoring Traps: Estimating Plume Reach, Trapping Radius, and Absolute Density of *Cydia pomonella* (Lepidoptera: Tortricidae) in Michigan Apple. Journal of Economic Entomology 110 (2): 305-318.

Curtiss R.T. 2021. Factors influencing sterile codling moth (*Cydia pomonella* L.) recapture, dispersion, and effectiveness as a control tactic in apple orchard systems. PhD. Dissertation, Michigan State University Press, East Lansing, MI.

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Miller, J.R.; Adams, C.G.; Weston, P.A.; and Schenker, J.H. 2015. Trapping of Small Organisms Moving Randomly: Principles and Application to Pest Monitoring and Management. Springer Briefs in Ecology. pp 114.

		LURE TYPE				
		CML2	CM 10x	CMDA	CMDA+AA	Megalure 4k
MATING DISRUPTION TYPE	Passive	Recapture: 0.335% n=22 Dispersive Distance: 91m Population Est.: 514/ha Trap area: 2.60 ha # Traps / 4.05 ha: 1.56	Recapture: 0.315% n=19 Dispersive Distance: 85m Population Est.: 863/ha Trap area: 2.27 ha # Traps / 4.05 ha: 1.78	Recapture: 0.287% n=20 Dispersive Distance: 91m Population Est.: 986/ha Trap area: 2.60 ha # Traps / 4.05 ha: 1.56	Recapture: 0.352% n=20 Dispersive Distance: 86m Population Est.: 595/ha Trap area: 2.32 ha # Traps / 4.05 ha: 1.74	Recapture: 0.258% n=18 Dispersive Distance: 88m Population Est.: 1133/ha Trap area: 2.43 ha # Traps / 4.05 ha: 1.66
	Active	Recapture: 0.341% n=22 Dispersive Distance: 90m Population Est.: 599/ha Trap area: 2.54 ha # Traps /4.05 ha: 1.59	Recapture: 0.514% n=21 Dispersive Distance: 87m Population Est.: 273/ha Trap area: 2.38 ha # Traps / 4.05 ha: 1.70	Recapture: 0.365% n=15 Dispersive Distance: 90m Population Est.: 616/ha Trap area: 2.54 ha # Traps / 4.05 ha: 1.59	Recapture: 0.440% n=19 Dispersive Distance: 88m Population Est.: 445/ha Trap area: 2.43 ha # Traps / 4.05 ha: 1.66	Recapture: 0.637% n=19 Dispersive Distance: 85m Population Est.: 217/ha Trap area: 2.27 ha # Traps / 4.05 ha: 1.78
	None	Recapture: 0.446% n=17 Dispersive Distance: 93m Population Est.: 315/ha Trap area: 2.72 ha # Traps / 4.05 ha: 1.49	Recapture: 0.377% n=18 Dispersive Distance: 92m Population Est.: 475/ha Trap area: 2.66 ha # Traps / 4.05 ha: 1.52	Recapture: 0.578% n=18 Dispersive Distance: 90m Population Est.: 238/ha Trap area: 2.54 ha # Traps / 4.05 ha: 1.59	Recapture: 0.359% n=20 Dispersive Distance: 92m Population Est.: 267/ha Trap area: 2.66 ha # Traps / 4.05 ha: 1.52	Recapture: 0.576% n=18 Dispersive Distance: 91m Population Est.: 278/ha Trap area: 2.60 ha # Traps / 4.05 ha: 1.56

Table 1. Codling moth monitoring decision matrix table. The first line in each cell (overall treatment recapture average and n) are the field findings and number of replications used in the analysis. Dispersive distances, population density estimates when one moth is captured, trap area, and recommended number of traps needed per acre are calculated from recapture data. Lower population density estimates indicate more accuracy in lure/mating disruption combinations' capture in traps.

EXECUTIVE SUMMARY

Project Title: Quantifying codling moth capture, lure plume reach, and trap area

Keywords: *Cydia pomonella*, mating disruption, management, monitoring, population dynamics

Abstract: Codling moth, the key apple, pear, and walnut pest worldwide, is managed with applications of insecticides and mating disruption in Washington State. Their populations are monitored using baited traps, but current population predictions are based on management without mating disruption using a pheromone-only trap lure. Those predictions are not relevant to current management and monitoring practices. This project clarifies population predictions in orchards using no mating disruption, and orchards using both passive and active mating disruption technologies when monitoring traps used one of five currently available lures. The lures tested were the CML2 (pheromone-only), CM10x (pheromone-only), CMDA (pheromone/kairomone), CMDA+AA (pheromone/kairomone), and the Megalure 4K (kairomone-only). There were thus, 15 mating disruption + lure combinations tested in this project. Using previously established analysis methods, and a mark-release-recapture study, we herein provide population density predictions for each of the 15 combinations tested. This study further clarifies capture in monitoring traps in modern orchards that use mating disruption.