FINAL PROJECT REPORT **YEAR**: 4 of 3

WTFRC Project Number: CP-13-102A

Project Title: Codling moth attract-and-kill with kairomonal lures

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Total Project Request: **Year 1:** $22,000 **Year 2:** $40,000 **Year 3:** $40,000

Other funding sources: **None**

Budget 1
Organization Name: USDA, ARS **Contract Administrator: Chuck Meyers**
Telephone: (510) 559-5769 **Email address: chuck.myers@ars.usda.gov**

Item	2013	2014	2015
Wages	$13,000	$13,000	$13,000
Benefits	3,000	3,000	3,000
Supplies	5,000	4,000	4,000
Travel	1,000	1,000	1,000
Total	$22,000	$21,000	$21,000

Footnotes: Supplies needed are the materials to construct the A & K stations, vials, sachets, and chemicals for the kairomone lures, and for additional and replacement BL traps and batteries. Travel costs are for trips to multiple field sites.

Budget 2
Organization Name: Plant and Food Research New Zealand
Contract Administrator: Claire Hall
Telephone 64 3 977 7340 **Email address:** claire.hall@plantandfood.co.nz

Item	2013	2014	2015
Salaries			
Benefits			
Wages		$16,000	$16,000
Benefits			
Equipment			
Supplies		$3,000	$3,000
Travel			
Plot Fees			
Miscellaneous			
Total	0	$19,000	$19,000

OBJECTIVES

The overall objective or goal of the project is to develop and demonstrate control of codling moths (CM) in orchard plots using the attract-and-kill approach (A & K). Our prior research has led to the use of a sticky trap as killing station and a recently developed 3-chemical kairomone attractant as the lure. The technical objectives of the work are to:

1. Determine a best A & K density (traps per acre) to use.
2. Determine interactions between deployment of A & K traps baited with kairomone and traps baited with pheromone lures.
3. Determine the interactions of mating disruption and A & K traps baited with kairomone lures.
4. Determine efficacy of A & K traps for reducing oviposition and for prevention of infestation of fruit in orchard blocks early season as well as at harvest.

SIGNIFICANT FINDINGS (for 2013, 2014, 2015. 2016 field seasons).

1. The adhesives used in Alpha Scents or Trece trap liners or with spreadable Tanglefoot were equally effective in holding captured moths. However, there was a problem with Tanglefoot spray, with reduced moth catch.
2. The synergy of acetic acid, pear ester, and N-butyl sulfide for male and female codling moths was confirmed in additional tests in New Zealand.
3. One-acre Washington field tests showed strong reductions in catches of female codling moth in kairomone traps but not males in pheromone traps. There is no indication of any incompatibility with mating disruption, as indicated by catches in kairomone traps. It is well known that it is more difficult to monitor the moth populations with the pheromone in orchards under mating disruption.
4. Field testing of a dispenser that combined all three chemicals (acetic acid, pear ester, and N-butyl sulfide) in one sachet indicated a weakness compared to the prior dispenser method of using polypropylene vials for dispensing acetic acid and N-butyl sulfide and a rubber septum for pear ester. The problem was determined to be the release of the pear ester from the mixture. Subsequent laboratory work produced a dual sachet system that provides adequate long term release of all three chemicals. The two sachets are attached back to back so as to employ a single device in the trap.
5. Four-acre Washington field tests were conducted in the summer CM flight of 2014, the spring and summer CM flight of 2015, and the spring and summer flights of 2016. In all five of these tests, there was much less infestation of apples in treated vs untreated plots in heavily infested orchards, following 30 days of kairomonal trapping with 50 traps per acre.

RESULTS AND DISCUSSION

Work prior to this project showed the superior attractiveness to female codling moth of the combination of acetic acid, pear ester and N-butyl sulfide (Landolt et al. 2014). Additionally, we concluded that using an adhesive-coated surface in place of a pesticide-treated surface for an attract-and-kill station target was suitable in commercial orchard settings where overloading of the surface is not a concern. Note that this approach is the same as prior attempts at “mass trapping” or “trapping out”, and maintains the primary advantages of the attract-and-kill concept of reducing or replacing insecticide use, and greatly reducing impacts on non-target insects including beneficial insects.

Early work on this project led us to conclude that we can use a commercial white Delta trap with commercial adhesive as an A & K trap. In addition, we settled on a formulation for our lure comprised of acetic acid + pear ester + N-butyl sulfide, to be used in the A & K traps. In 2013, we obtained preliminary evidence that a density of 50 A & K traps per acre significantly reduces numbers of adult codling moths, which we referred to as “knockdown”.

Much of the effort in 2014 replicated and confirmed evidence of knockdown of female codling moths in orchard plots, and then late in the season tested the hypothesis that the knockdown of moths results in reduced infestation of apples.   Field plot tests in 2015 and 21016 provided similar results, with greatly reduced increases in CM-damaged apples in treated plots compared to control plots, under heavy CM pressure.

<u>One acre plot moth knockdown</u>. Thirteen replicates of this paired test were conducted in the spring flight of 2014. Plot monitoring for the 3 days preceding attract and kill deployment indicated similar moth populations in treated vs control plots. A & K traps deployed in treated plots captured 28.8 ± 16.3 female and 35.2 ± 17.1 male codling moths during the 7 days of the test. Totals of 375 females and 458 males were removed from plots by these traps during the one week duration of the test. Both male and female codling moths captured in the kairomone-baited monitoring traps in treated plots were reduced compared to those in control plots. Numbers of male codling moths captured in pheromone-baited traps were similar between control and treated plots, and numbers of moths in light traps were numerically, but not statistically, reduced in treated plots.

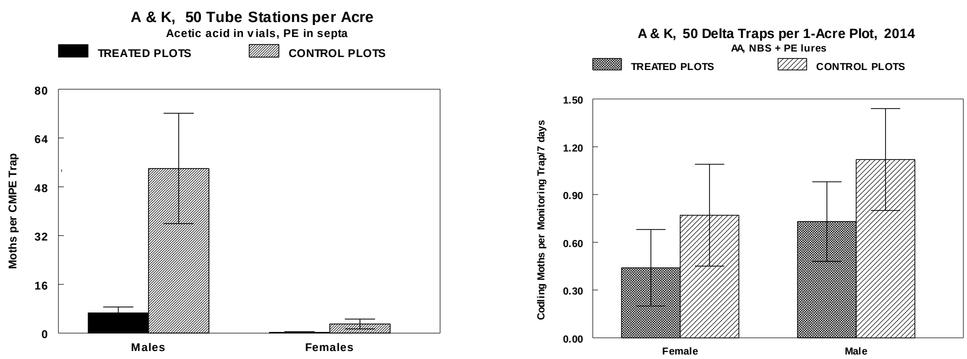

Figure 1. Mean numbers of codling moths captured in monitoring traps in A & K plots. On the left, in 2013, numbers of moths were greatly reduced in kairomone-baited monitoring traps in plots with tube shaped A & K traps. On the right, in 2014, numbers of moths in kairomone-baited monitoring traps were again reduced in plots with Delta-shaped A & K traps, but not so dramatically.

<u>Four acre plot infestation reduction</u>.   Pairs of 4-acre plots were set up in August of 2014, June of 2015 and August of 2015, to compare CM infestation rates in apples with and without deployment of attract-and-kill traps. A & K traps baited with acetic acid + pear ester + N-butyl sulfide, were evenly spaced at ca 50 per acre, and these were maintained for 20 to 30 days. Treated and control plots were each monitored with four pheromone traps and four kairomone traps (AA + PE + NBS). Two thousand fruit were inspected in the field in each plot to determine codling moth damage rates. In the first and second tests, fruit were inspected at the end of the test. In the third test, fruit were inspected both at the beginning and at the end of the test. Fruit samples were 20 apples inspected per tree, for 10 trees per row, for 10 rows of trees per plot.

Numbers of CM in kairomone-baited monitoring traps were reduced in treated plots compared to control plots (Figure 2), while numbers of male moths in pheromone-baited monitoring traps were similar between the plots. Percentages of apples that were damaged by codling moth were less with the deployment of the A & K traps, compared to the untreated plots in all three tests (Figure 3). Over the four weeks of each test, from 352 to 397 female CM were captured in the A & K traps of the treated plot, and numbers of males captured were generally higher.

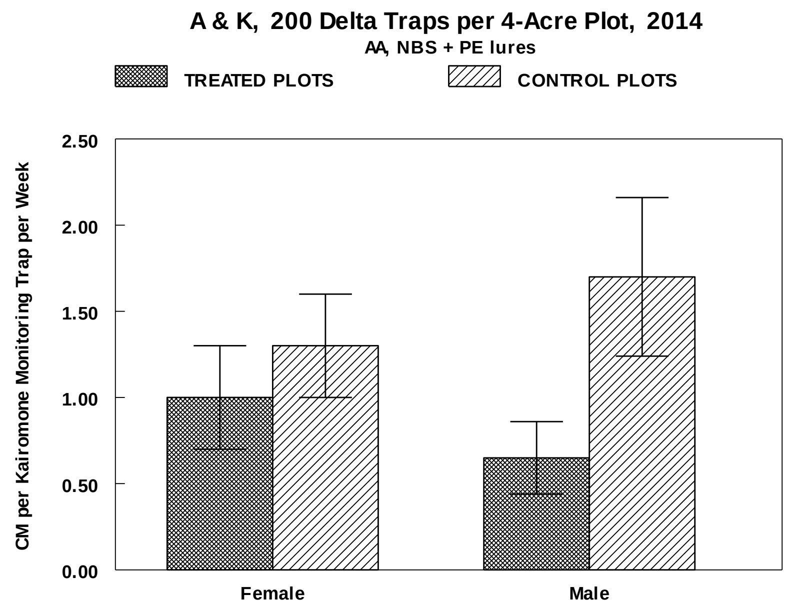

Figure 2. Mean numbers of male and female codling moths captured on monitoring traps baited with kairomone lures, in 4 acre plots treated with 200 A & K traps in untreated control plots.

Results of the field plot tests consistently indicate an impact of the A & K traps on CM; both reducing the numbers of moths in plots, and reducing the codling moth damage to fruit. However, additional replicates of the larger scale plot tests need to be conducted before firm conclusions can be drawn.

One might ask why the results with monitoring traps are not more dramatic, given the apparent strong prevention of infestation of apples. That is, with ca 50 A & K traps per acre, using a bisexual 3-component kairomone lure, why do we not see a complete elimination of codling moths in monitoring traps within the plot?. We suggest two possible factors; immigration and competition between stimuli. *Immigration*: In relatively small plots within larger orchards, moths can move freely from untreated to treated areas, confounding and obscuring results. With the use of chemical attractants, there is great risk of luring many moths into treated plots from untreated areas, again confounding and obscuring results. This was certainly seen in studies of mating disruption of CM, and the problem is diluted as an edge effect with an increase in the size of the treated area (such as in Areawide programs). *Competitive stimuli*: The moth response to the kairomone lures might be impacted by other sources of the same chemicals, by food sources, and by other types of attractants. For example, infested apples in the heavily infested orchard used for the 4 acre plot test could be a competing stimulus, and calling females and pheromone lures in monitoring traps could be competing stimuli that reduce male response to the kairomone lure. These are speculations, but call for the need for more research in what is a new area of exploration.

With the positive but varied trap catch results, the fruit infestation data from the 4 acre plots is most encouraging. Killing and removing female codling moths from the orchard is a reasonable goal, but the most important parameter to measure is the damage to the fruit. Although we will be conducting additional tests of lures, dispensers, and traps, we feel that the critical aspect of work to be done in 2016 is further replication of the 4 acre plot tests of the 50 kairomone A & K traps per acre, to provide rigor to conclusions regarding efficacy of this approach in protecting the fruit. Reducing the cost of the method is also an important goal, hence the continued focus on less expensive but effective dispensers and traps.

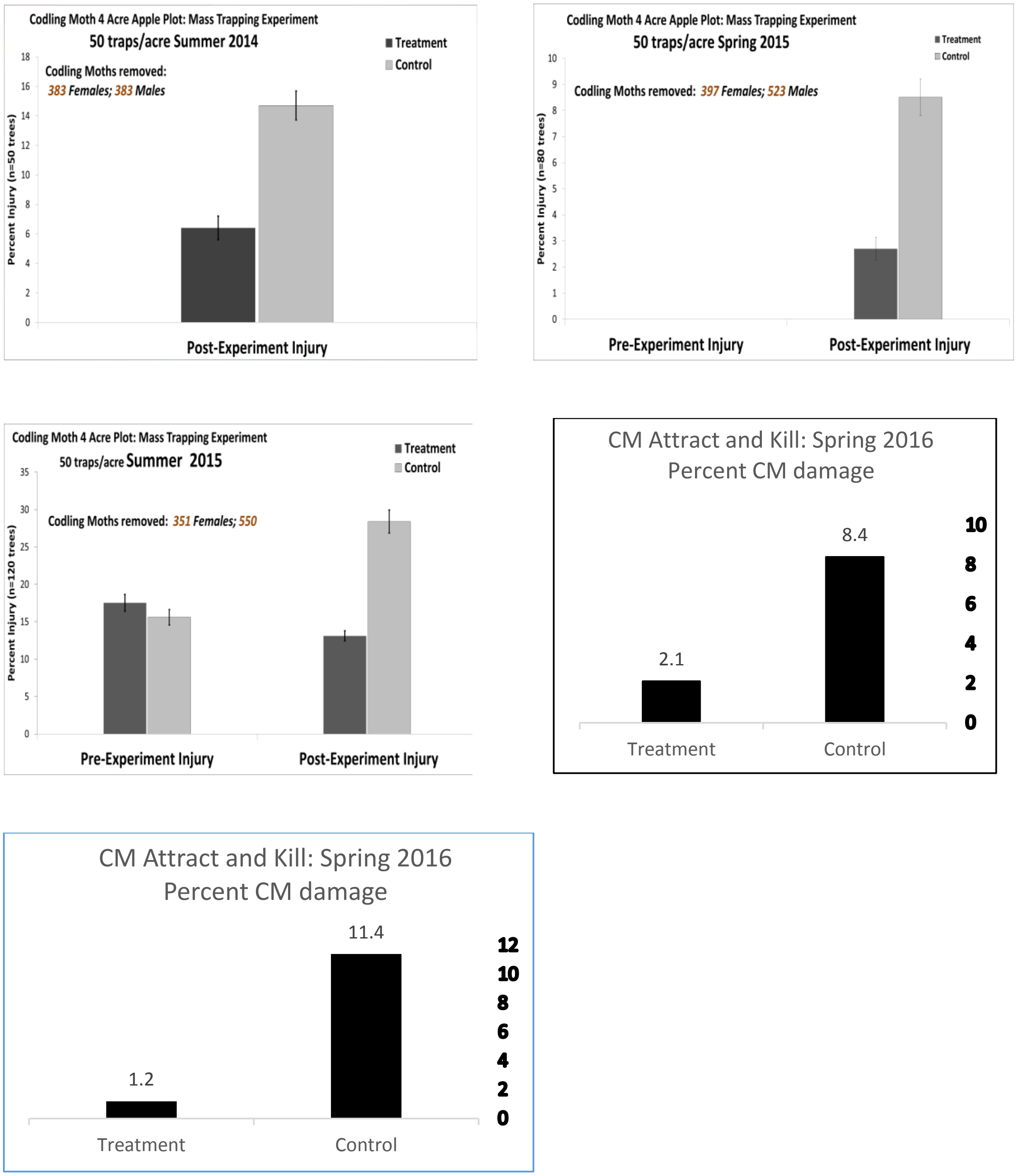

Figure 3. Mean percentages of apple fruit damaged by codling moth, in 4 acre apple blocks that were untreated controls, or were treated with 200 attract and kill traps at 50/acre.

REFERENCES CITED

Landolt, P. J., D. M. Suckling, and G. Judd. 2007. Synergism of a feeding attractant and a host kairomone for the codling moth (Lepidoptera: Tortricidae). Journal of Chemical Ecology. 33: 2236-2244

Landolt, P. J., T. S. Davis, B. Oehler, D. Cha, and J. Brunner. 2014. N-butyl sulfide as a co-attractant with kairomones for male and female codling moths, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae). Environ. Entomol. 43: 291-297.

EXECUTIVE SUMMARY

The codling moth remains the most important insect pest of apples. Control of the pest is usually obtained with applications of pesticides and pheromonal mating disruption, and other secondary measures. There remains a need for additional strategies and technologies (tools in the tool box) under some circumstances. For example, mating disruption loses its effectiveness where the moth population "escapes", and additional measures are then needed to bring that population level down to a point where MD works. Also, the measures used for control of CM in organic orchards are limited. The use of "mass trapping" to remove enough moths with traps to effect control could be a valuable tool to augment mating disruption. The method also has potential to meet organic certification requirements.

It is thought that attractants for females should be more effective for this type of approach, compared to sex pheromones that lure males, because the removal of females directly impacts oviposition and fruit infestation, while removal of males only indirectly and somewhat weakly impacts reproduction. Prior attempts in the 1970s to control CM using pheromone-baited traps gave mixed results that were mixed at best. Later work then has focused on the development of an increasingly stronger set of attractants for female CM, based on their need to locate oviposition sites and food. These efforts produced a lure comprised of acetic acid, pear ester, and N-butyl sulfide as a trap lure that provided a strong attractant for both male and female CM.

This lure has been evaluated for mass-trapping CM in apple orchards over a series of years. Earlier tests were conducted in one-acre plots and indicated strong reductions in the numbers of moths present in the block but not reductions in fruit damage. It was surmised that a problem existed with orchard edge effects that obscured the advantage obtained with the removal of those moths in traps, and perhaps the attraction of moths that were not captured in traps. Additional work on lure and trap optimization, and the expansion of the work to 4-acre apple orchard blocks resulted in consistent good evidence of fruit protection by the use of the new lure in Delta traps, at 50 traps per acre. All of these experiments were conducted in commercial orchards with strong CM pressure and high levels of damage. In total, the experiment was conducted 5 times, each time over a 30 day period at the peak of a flight. Two of these tests were conducted in the spring flight of the moth, and three were conducted during the second or summer flight. Apples were surveyed for CM damage either at the end of the 30 day test for spring flights (with a zero infestation at the start of the flight), or at the beginning and again at the end of the 30 days for the summer flight. This provided then estimates of damage incurred over the 30 day test period, with strong differences in damage incurred in control plots compared to trapped plots. These orchards with high populations of CM were purposely selected for the studies so that we could readily obtain the numbers needed (moths trapped, fruit infested) to determine the impact of the trap deployment.

Future Directions

These results demonstrate feasibility of this approach as a new means of controlling CM in apple orchards. We think it is necessary to pursue the approach further to 1) assess control over the entire field season rather than 30 day time periods, 2) reduce costs with less expensive lures and traps, and 3) continue to improve lure efficacy. Regarding #1 above, it is expected that the control of CM damage will only be more complete with maintenance of traps from first CM flight until harvest. Regarding #2 above, we have done much work to develop a sachet system as attractant dispensers for these chemicals, but additional field validation of lure efficacy needs to be done. Additionally, it appears that a simpler disposable trap that is a tubular shape would be cheaper to use than the Delta trap. And regarding #3 above, there always seem to be opportunities to change or improve the power or consistency of such lures.