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

Project Title: Pheromone technology for management of codling moth and leafrollers

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Cooperators: Mike Doerr, WSU-TFREC; Peter McGhee, Michigan State University.

Total Project Funding: Three Year Total: $ 344,866

Other funding Sources – Total cash and in-kind support from private and growers

- Private Company Funding (see below) - $209,000
- Private Company in-kind support - $150,000
- In-kind support from growers - $9,000,000 (value at $6,000/acre for 1,500 acres)

Funding

- Shin-Etsu: $80,000 to help fund evaluation of new dispenser technology
- Private Company: $60,000 for assessment of release rates, video recording and flight tunnel of behavior, and attraction of dispensers to codling moth
- Private Company: $39,000 for assessment of a novel attract-and-kill formulation
- Private Company: $30,000 for assessment of a novel mating disruption formulation

In-kind support

- Pheromone companies in-kind donation of dispensers for all trials plus donation of traps and lures to help with monitoring expenses. In-kind support over three years of this project totaled over $150,000.
- Growers provide in-kind support by allowing us to use commercial orchards for pheromone research. Over the duration of this project research was conducted on over 1,500 acres of grower-owned orchard. Based on in-kind value allowed for match in federal grants the value of this support would be over $9,000,000.

The financial information provided in addition to sponsor support simply communicates research program support costs vs. specific project cost-share commitment.

WTFRC Collaborative Expenses: None

Budget 1 History:
Organization: WSU-TFREC **Contract Administrator:** ML Bricker; Kevin Larson
Telephone: 509-335-7667; 663-8181 X221 **Email:** mdesros@wsu.edu; kevin_larson@wsu.edu

Item	2009	2010	2011	Total
Salaries [1]				
Technical – M. Doerr (3 month)	5,278	5,489	15,833	26,600
Res. Analyst III (Hebert prog.)	8,714	9,063	9,426	27,203
GRA – 9 mo appt @ 0.50FTE	22,014	0	0	22,014
Benefits				
Technical – M. Doerr (3 months)	1,689	1,757	5,051	8,497
Res. Analyst III (Hebert prog.)	4,270	4,441	4,619	13,330
GRA – 9 mo appt @ 0.50FTE	1,881	0	0	1,881
Wages (temporary labor)[2]	7,000	8,000	14,400	29,400
Benefits (15%)	1,260	1,440	2,160	4,860
Supplies	5,000	5,000	5,500	15,500
Travel [3]	2,085	2,085	2,085	6,255
Plot Fees	0	0	0	0
Total	59,191	37,275	59,074	155,540

Budget 2 History:
Organization: Michigan State Univ. **Contract Administrator:** Emily Flanner
Telephone: 517-355-5040 x256 **Email:** flanner@cga.msu.edu

Item	2009	2010	2011	Total
Salaries	26,187	26,981	27,782	80,950
Benefits	12,847	13,506	14,107	40,460
Wages	3,000	3,000	3,000	9,000
Benefits	172	172	172	516
Supplies	1,000	1,000	1,000	3,000
Travel	1,000	1,000	1,000	3,000
Total	44,206	45,659	47,061	136,926

Budget 3 History:
Organization: USDA-ARS, Wapato **Contract Administrator:** Chuck Myers
Telephone: 510-559-5769 **Email:** Chuck.Myers@ARS.USDA.GOV

Item	2009	2010	2011	Total
Salaries	0	0	0	0
Benefits	0	0	0	0
Wages	14,000	14,000	14,000	42,000
Benefits (10% of labor)	1,400	1,400	1,400	4,200
Supplies	1,000	1,000	1,000	3,000
Travel	1,000	1,000	1,000	3,000
Total	17,500	17,500	17,500	52,500

Project objectives:

1. Improve hand-applied dispenser mating disruption systems for codling moth by determining an optimized dispenser release rate and density.
2. Characterize adult moth behavior that leads to optimization of an attract and kill (A&K) technology for codling moth and leafrollers.

Significant findings 2009-2011

Optimization of hand-applied dispensers - Impacts

- This project leveraged each dollar of Commission funding into one dollar of support from private companies (cash plus in-kind support). The collaborative relationships we established with private companies provided access to new technologies, allowed us to expand the scope of our research, and influenced new product development for the benefit of the tree fruit industry.
- This project played a major role in the development of a new, more efficient, pheromone dispenser technology, Isomate CM Flex, which is now in commercial use. This technology has a more uniform pheromone release profile over time and provides flexibility in dispenser density of 200-400 per acre. Without this project's research showing the potential of maintaining CM control with lower release rates from dispensers it is very doubtful this new technology would have been developed.
- This project worked with a private company to help develop and evaluate a new automated delivery system for placing a pheromone dispenser in trees. This technology, Tangler®, reduces application time by 75%, has a high degree of retention in the canopy, and has performed equal to standard hand-applied technologies in suppressing moth capture in monitoring traps in WA and MI.
- The use of sterile CM moths obtained from the Okanogan-Kootenay Sterile Insect Release (SIR) Program allowed this project to challenge different pheromone treatments in commercial orchards. Using the SIR technology we were able to test different pheromone treatments in large replicated plots while keeping moth density the same across treatments.

Optimization of hand-applied dispensers - Research Results

- We showed that pheromone release rates and shape of dispensers influenced CM behavior, that is, attraction to and activity around pheromone sources. These behavioral changes where evaluated in field cages and small plot trials, which informed additional studies in large field plots.
- This project demonstrated that the impact of a meso-type dispenser, Isomate CM Ring, on CM was strongly dependent on dispenser density per acre. Additional studies with the Ring technology showed that rates of 20 to 40 dispensers per acre were as effective in suppressing CM behavior (attraction to monitoring traps) as a standard hand applied dispenser treatment, Isomate CM Flex, at 400 dispensers per acre.
- We showed that the addition of pear ester to the CideTrak CM dispenser did not provide additional impact on CM behavior relative to a CideTrak CM dispenser without pear ester. However, there was evidence that the impact of a meso-type CideTrak CM dispenser had a greater impact on CM behavior when pear ester was present.
- The use of video recording of CM moth behavior in the field showed that the number and duration of visits to pheromone sources varied with pheromone release rate. These results provided evidence that not only the amount of pheromone released from a dispenser was important, but that the shape of the dispenser was also important.
- A new attractant that originated from microbial chemistry was demonstrated in the field to be attractive to female and male CM. The new attractant was four times more attractive than acetic acid lures, and has then potential to be comparable to the acetic acid + pear ester attractant.

Attract and Kill (A&K) - Research Results

- Either Warrior or Assail in different formulations were shown to be good candidates for toxicants in A&K formulations. Exposure of CM moths to sublethal concentrations of a toxicant dramatically impacted the moth's ability to orient to females and mate. These results increase the potential for developing A&K technologies with low concentrations of toxicants.
- Different kinds of devices used in A&K technology have been evaluated. The shape and size of openings in an A&K device was shown to be important as well as the strength of attractant used.
- Progress has been made in developing an alternative to pear ester that could be used in A&K technologies, thus impacting both male and female CM. New technologies are important because the company holding the pear ester license does has not shown interest in using it in an A&K technology.
- Based on models and field cage studies, A&K technologies are four times more robust than mating disruption at controlling CM. Therefore, optimization of A&K technologies is worth the investment of energies and resources.
- Mini-traps looked promising in initial studies, but when evaluated in small or large field trials the designs used provided variable results. A simple tubular A&K device with a toxicant reduced male CM activity by 98% using only 50 units/A.
- There is good indication that an A&K technology would be effective to suppress populations of leafrollers.
- Video monitoring of moth behavior while extremely time consuming provides critical insights into moth behaviors associated with A&K technologies. Videos showed relative attraction to an A&K device over time and more importantly revealed barriers to source contact, which is critical to the success of this technology.

Methods

Methods used in this project were outlined in new project proposal (2009). Methods used in studies are included to some extent in the results and discussion section as a means of helping the reader understand how results were obtained.

Results and Discussion 2009-2011

Optimization of hand-applied dispensers. The first objective of this project was to improve hand-applied mating disruption systems for codling moth. A team effort focused on understanding the impact of pheromone release rates from different devices on codling moth behavior. This objective was expanded with additional resources from private companies to assess the value of meso-type and aerosol pheromone dispensing systems. Behaviors were assessed with pheromone-baited traps, in small and large field trials, field-cage studies, and with video recordings.

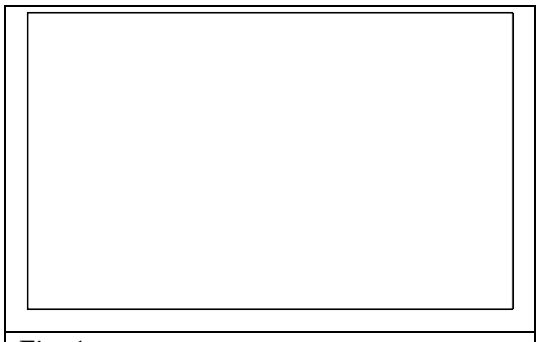

Fig. 1

Based on previous research we predicted that moth capture in traps would decrease as the pheromone release rate of a dispenser increased. With the exception of the Isomate Flex 25 tube-type dispenser, which captured more moths relative to lures loaded with 5, 10, or 20 mg of codlemone, there was a decline in moth captures as pheromone release rate increased. The release rate of the Flex 25

dispenser was expected to be the same as the 20 mg dispenser but it proved to be highly attractive when placed in a trap, though not as attractive as the 0.1 or 1.0 mg lures (Fig. 1).

Interpretation. While data from this experiment generally confirms previous studies, the relative attraction of the Flex 25 dispenser was unexpected. This result informed our interpretation of other studies and impacted the design of new dispensers now in commercial use.

Our studies continued with large field cages (enclosing 12 large apple trees) and small plot field trials. These studies were aimed at sorting out the relative impact of different pheromone treatments using dispenser densities approximating 200/A. Large cages provided the advantage of replicating treatments while keeping the density of CM constant. In small plot field trials the same treatments tested in field cages were evaluated against naturally occurring populations of CM.

In field cages there was little difference in CM disruption between low load dispensers (0.1 mg lures) and a full rate tube-type dispenser, Isomate CM Flex 100, when only males were released. However, when males and females were released in the cages there was greater disruption of CM by dispensers releasing more pheromone. In small plots there was a direct relationship between pheromone release rate and CM disruption, but the level of disruption caused by dispensers release very low amounts of pheromone was not much different from the Isomate CM Flex 100 (≈ Isomate C plus) dispenser.

Interpretation. Dispensers releasing very small amounts of pheromone can result in a significant reduction of a male moth's ability to locate a female. As pheromone release rate from a source increases there is only a slight increase in effect on male success in finding a female mimic. These results strongly suggested that to optimize a dispenser's impact its pheromone release rate should be tuned to maximize suppression of a male's ability to make multiple searches in the same night.

Video recording of moth behavior around various pheromone sources showed differences based on pheromone release rate and time of year. In May-June the number of visits was highest to dispensers with the lowest and highest release rates, while the duration of visits was highest with the highest release rate device. The percent of moths making source contact was small (10%) and only occurred with the 0.1 and 10 mg dispensers. In July the number of visits roughly doubled but the pattern was similar to the May-June observations, with a higher number of visits to the lowest and highest release rate dispensers. The average duration of visits was again highest to dispensers with the lowest and highest release rates (Fig. 2). Source contact was low (10-20%) and occurred only to the two lowest and two highest release rate dispensers.

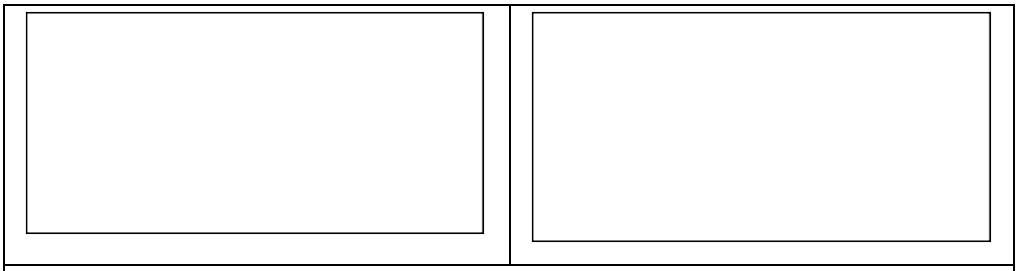

Fig. 2

Interpretation. Video recording helped us understand the relative activity of moths around different pheromone sources in the field. The number of visits was expected to mimic the capture of moths in pheromone traps; however, there were more visits and of longer duration to the high release rate dispensers than we expected. This result showed that the higher release rate dispensers were attractive and that moths often approached within at least 12 inches. This result is encouraging

because, based on other evidence, we believe that moths that approach close to high pheromone release rate dispensers have a reduced likelihood of being able to search for females the same night.

We collaborated to challenge several pheromone dispensing systems over three years in large plot field trials in WA and MI. These large plot trials were informed by field cage and small plot field studies or were used to evaluated new pheromone technologies and represent our efforts to test the best treatments and products under realistic conditions. A selection of results from these studies is reported here providing insights into the most important findings from our research.

CheckMate CM-O Puffer, Isomate CM Ring (Ring) meso-type dispenser, and Isomate CM Flex (Flex) represent a range of pheromone delivery technologies that are important to the tree fruit industry. In 2010, Puffers were evaluated at 1 unit/A, Flex at 320 dispensers/A, and Rings at 1, 2, 4, 8, 16, and 32 dispensers/A (disp/A). Sterile moths obtained from the Okanogan Kootenay Sterile Insect Release Program (SIRP) were used to challenge treatments. Treatments were evaluated by comparing the relative capture of sterile moths in monitoring traps (female mimics) in each treatment.

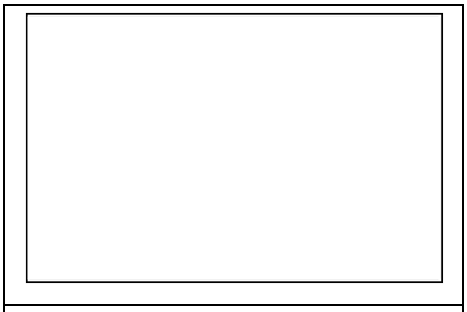

Fig. 3

There was no difference in sterile moth capture between the 1 Ring/A dispenser treatment and the no pheromone control. Trap shutdown relative to the no pheromone control increased as the density of Ring dispensers increased up to 32 disp/A, where trap shut down averaged 93.7 ± 2.0% (Fig. 3).

There was little difference between the best Ring treatment (32 disp/A) and the Flex and Puffer treatments. Percent trap shutdown was highest and had the smallest variance in the Flex treatment, 94.9 ± 0.8%, but was not statistically different from the Puffer, 92.8 ± 2.0%, or the Ring, 93.7 ± 2.0%, treatments.

In MI Rings and Flex dispensers were compared in six orchards over two years. Treatments were Flex at 40 and 400 disp/A and Rings at 4 and 40 disp/A. The Flex at 400/A provided the greatest reduction in trap captures. There was little difference between other treatments, including the Rings at only 4 disp/A.

In 2011, the Puffer and Ring technologies were again tested. A Puffer treatment (1 unit/A) was paired with a Flex treatment (400 disp/A) in 40 acre plots at three locations. There was no difference between the capture of sterile moths in these treatments. The Isomate Ring technology was evaluated at three dispenser densities, 20, 30 and 40 disp/A, and compared to an Isomate Flex treatment at 400 disp/A. Treatments were replicated four times. There was no difference in capture of sterile moths between the four treatments (Fig. 4).

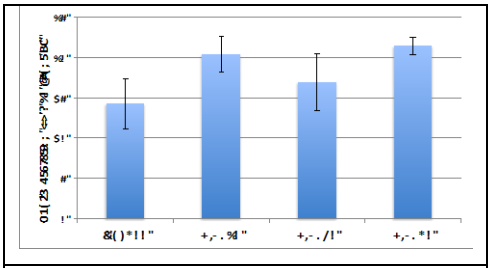

Fig. 4

In WA and MI we evaluated a reduced release rate technology, Isomate Flex in 2010. We compared Isomate C Plus (standard treatment), Isomate Flex (80), Flex 50 and Flex 25, all at 400 disp/A. The release rate from the Flex dispensers was proportional to the load. In WA there was little difference between the Isomate C Plus, Flex (80) and Flex 50 treatments though there was a slight reduction in trap shutdown with the Flex 25 treatment. In MI a no mating disruption (NoMD) control was included in studies. All three Isomate treatments, Flex (80), Flex 50 and Flex 25, reduced moth captures compared to the NoMD control in the first and second generation and the Flex 25 and Flex 50 treatments performed similarly in suppressing moth captures compared to the Flex (80) dispenser.

In 2011, MI challenged four Isomate Flex treatments with pheromone load rates from 10% (Flex 10) to 80% (Flex 80) relative to an Isomate C Plus dispenser. All Flex treatments were applied at 300-400 disp/A and replicated on eight farms. There was no difference in wild (or sterile) moths captured in monitoring traps (Fig. 5) and no fruit injury was detected in any of the pheromone treated plots.

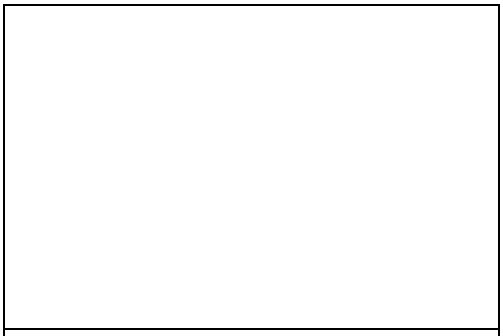

Fig. 5

The Tangler® is a newly-developed mating disruption technology developed by Ridge Quest, a Michigan-based company, and designed to automate the application process. The Tangler technology was evaluated at five sites in MI (2010). The Tangler formulation provided disruption equivalent to Isomate CM Flex. The automated deployment using the Tangler modules was nearly 4x faster than hand application of Isomate dispensers.

In 2011, the Tangler technology was evaluated in MI and WA. The launcher system (Fig. 6) was improved in 2011 and pheromone released from the module approached a zero order release rate over the summer and was similar to the release rate from the Isomate Flex dispenser. In field trials the Tangler provide suppression of moths in traps equal to an Isomate Flex treatment when both dispensers were applied at 400/A (Fig. 7). The Tangler modules were applied four to five times faster than the Isomate Flex dispensers and pheromone modules were retained in the canopy throughout the summer. Results similar to MI were observed in WA using the Tangler technologies.

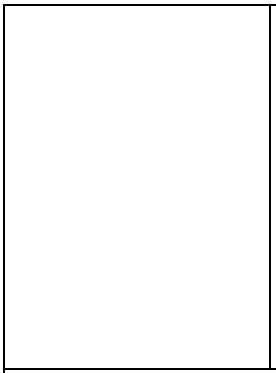

Fig. 6. Tangler launcher system left and pheromone module right.

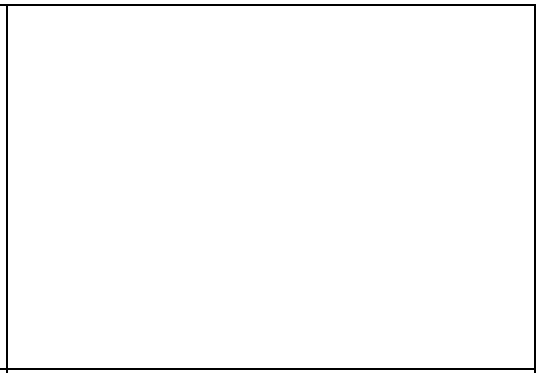

Fig. 7. Average native male captures in pheromone traps in plots treated with Flex, Tangler, and noMD.

Another pheromone company, Trécé Inc., approached us to evaluate a pheromone dispenser containing pear ester. This company had a commercially registered dispenser, Cidetrak CM. We evaluated the Cidetrak CM and a prototype dispenser Cidetrak CM/DA (with pear ester) in WA and MI in large replicated field trials. In both locations we observed no added value of including the pear ester in the standard Cidetrak dispenser. However, in MI a Cidetrak meso-dispenser (see image at right) was evaluated at 32 disp/A, with and without pear ester. In these comparisons the Cidetrak Meso CM/DA (with pear ester) increased disruption of CM from 85.9% (Cidetrak Meso CM) to 94.5%.

Interpretation. Because this project was funded by the industry we were able to access pheromone technology to evaluate and influence the development of new technology. We demonstrated that disruption of CM was possible with pheromone dispensers releasing one-tenth and one-quarter of pheromone being released by most commercial dispensers. These findings resulted in the development of a new dispenser, Isomate Flex, which is now available to growers. We demonstrated that meso-type dispensers at rates of 20-40 dsip/A provided good suppression of CM in large replicated plots. We were also able to show some difference in a meso-type dispenser when it contained pear ester. We demonstrated that aerosol pheromone dispensing technology, Puffers, provided good suppression of CM in large commercial plots equal to a standard hand applied pheromone technology. We were also able to demonstrate that a new technology, Tangler®, to apply pheromone dispensers had great promise by reducing application time by four to five times and that it disrupted CM in large plots equal to a hand applied dispenser when used at equivalent rates per acre. These results provide evidence that a wide variety of pheromone dispensing systems can be used to control codling moth and that pheromone release rates can be dramatically reduced and still achieve acceptable levels of suppression.

Collaborations with private companies allowed us to expand our research and to influence new product development. Using the volatile capture system (VCS) developed by Dr. Hebert we showed that a new tube-type dispenser, Isomate Flex technology, had a near zero order release profile and rates proportional to loading through 150 days – (Fig. 8).

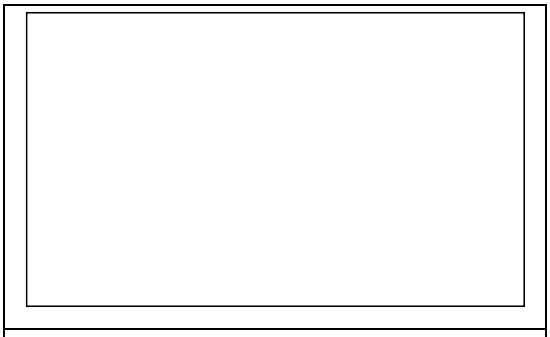

Fig. 8.

We also evaluated other hand-applied pheromone dispensers using the VCS and discovered pheromone release rate patterns that were not considered optimal. These results were shared with companies developing pheromone dispensers allowing them the opportunity to modify their products.

Interpretation. By working with commercial pheromone companies this project helped to improve dispensers in ways that should reduce costs to growers or at least maintain the current costs. Project findings played a role in the development of a more efficient dispenser that is now commercially available to growers, the Isomate CM Flex dispenser. Private companies provided financial support to scientists working on this project, which supplemented the core funding provided by the industry.

Attract and Kill (A&K) Research. The second objective of this project was to characterize behavior of adult CM and leafroller in order to optimize development of A&K technologies. A team effort focused on assessing moth behaviors in different environments; laboratory studies, large field cages, small replicated field trials, and two different A&K technologies; traps and toxic surfaces.

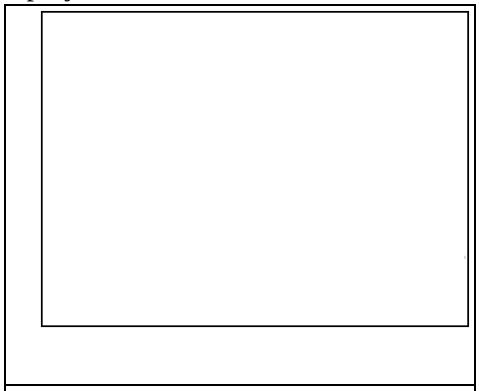

Fig. 9.

At MSU several different devices were evaluated in the wind tunnel to determine relative ability to impact codling moth. The preferred toxicant was Warrior (lambda-cyhalothrin), which caused high CM moth mortality occurred within 30 seconds. When CM male moths were exposed to a sublethal concentration of Warrior for 4 h prior to the wind tunnel bioassay they were not successful in orienting in to a pheromone source in the wind tunnel (Fig. 9). Warrior was

mixed with Vaseline and aged in the field for up to 126 days in a prototype A&K device. When male CM contacted 126 day-old Warrior residues, more than 90% died.

The USDA-ARS tested A&K devices made of clear vinyl cylinder of different diameters or a section of white PVC pipe. Assail mixed in a silicone grease was used as a toxicant. The 1¼ inch diameter cylinder showed the best ratio of moths contacting the A&K device. There was no repellency of Assail mixed with grease on moth orientation to, or contact with, the A&K device. The most effective concentration of Assail was 4% (w/w) causing 100% mortality in 24 hours.

Interpretation. There are two insecticides that quickly kill codling moth adults by contact. Exposure of moths to sublethal residues had a dramatic impact on their ability to orient to a pheromone plume. Different shapes of A&K devices, including the size of an opening, indicated that these were important factors in optimizing moth contact with a treated surface.

USDA experiments with kairomone attractants showed that and eight-component blend capture two times more moths than the AA+3-methyl-1-butanol lure (Fig. 10). Collaborations with a private company evaluating kairomones showed promise of a CM attractant capturing three to six times more moths than a pear ester lure.

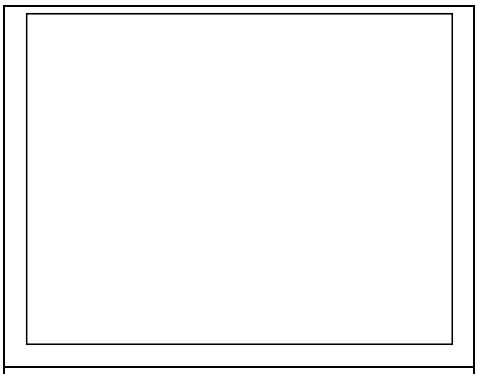

Fig. 10.

Interpretation. There are new kairomones or combinations that hold promise for capturing CM, including females, which would be very important in A&K research. Because the pear ester technology is tied up in a company with no interest in developing A&K technology it is important to continue investigations into alternative chemicals that would attract both males and females.

In MI several treatments were evaluated using the caged-tree design. In a direct comparison of male removal (delta trap with liner) and mating disruption (pheromone dispensers), male removal was shown to be four times more powerful than a full rate of pheromone dispensers in preventing mate location. Several kinds of A&K devices showed promise, although the large delta trap with a liner proved superior (Fig. 11).

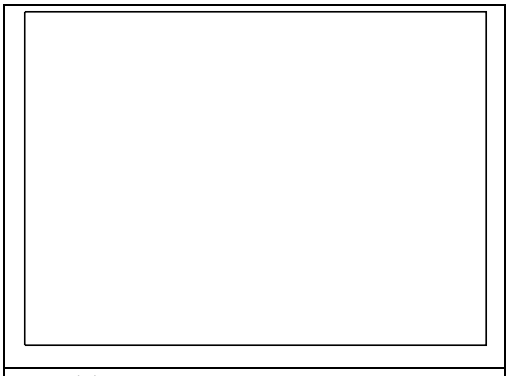

Fig. 11.

Interpretation. Field-cage trial results demonstrated that A&K was a more robust tactic than pheromone mating disruption when moth densities were controlled. The reason for the greater impact of A&K is because it limits the number of visits per night to a pheromone source (female).

In MI seven treatments, two experimental commercial formulations, two prototype A&K devices, a pheromone lure only, a large lined delta trap and untreated control were compared for male removal efficiency in replicated small plots (0.1 acre). Treatments were applied at a rate of 100 A&K devices/A. There was a significant reduction in male captures in monitoring traps but only the large delta trap with liner showed a significant reduction compared to a lure only treatment.

In MI direct comparisons of the efficiency of different trap types in capturing CM moths was part of an effort to develop a “trap out” system that would be economically feasible since field cage studies had shown that A&K is potentially four times more robust than mating disruption (see discussion above). Four different trap types were compared to the standard large delta trap in two

different field studies. None of the traps captured as many moths as the large delta but two, the lantern and box traps, showed some promise. When these different traps were taken to the field and evaluated in a replicated small plot study with release of sterile moths the delta trap removed more moths but the box and lantern traps captured 60-70% of the delta trap with much smaller trapping surfaces.

The effects of varying the density of MSU micro-traps on inhibition of CM catch in a central monitoring trap was evaluated in a small plot study in MI. Treatments included a no pheromone check, Isomate Flex at 200 disp/A, micro-traps at 50/A, 100/A, 200/A, and 400/A. All micro-traps were baited with L2 lures. A single monitoring trap baited with an L2 lure was placed centrally in each plot to assess treatment effects. All pheromone treatments reduced the capture of CM in the central monitoring trap. The three highest micro-trap application rates significantly reduced CM capture in the monitoring trap compared to the lowest micro-trap rate. CM capture rates were statistically equal between the mating disruption standard at 200 disp/acre and the micro-trap rates of 100/acre and 400/acre (Fig. 12).

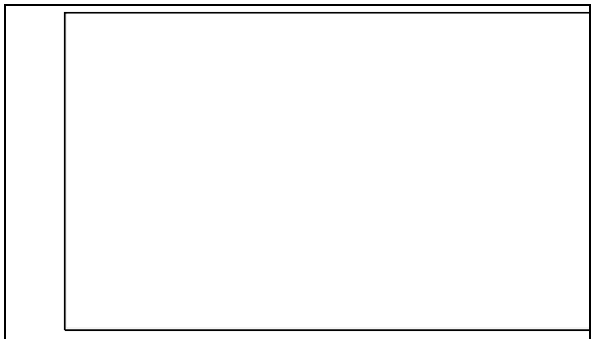

Fig. 12.

In MI a large plot attract-and-remove trial was conducted to compare a standard mating disruption program to a trap-out control scenario for reduction of CM male activity. Treatments included a no pheromone control, Isomate Flex, non-sticky micro-traps, and sticky micro-traps. Treatments were applied to 0.5-acre plots at an application rate of 200/A. All micro-traps were baited with L2 lures for first flight and 0.1mg lures for second flight. All pheromone treatments were effective at reducing the capture of CM in central monitoring traps (Fig. 13). During first flight, the attract-and-remove approach was more effective at reducing CM capture in the monitoring traps than either of the other treatments. In the second flight the attract-and-remove approach was statistically superior to the commercial mating disruption standard, even with a use of lower load lures, 0.1 mg.

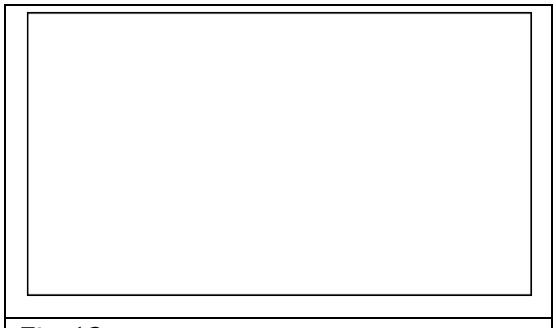

Fig. 13.

In WA an attract-and-remove study was conducted as a replicated small plot trial using lantern mini-traps at 200/A, 200 0.1 mg lures/A, an Isomate Flex treatment (400 disp./A), and a no pheromone control. In the second generation pheromone trap captures were lower in the Flex treatment in pheromone monitoring traps but not in acetic acid/pear ester (AA/PE) baited traps. There was no difference in the sex ratio of CM captured in AA/PE traps, which was expected if the lantern mini-traps were removing males from the population at a significant rate. At the end of the first generation there was about half the fruit injury in the Flex treatment compared to other treatments. At harvest fruit injury was high in all treatments with no differences between treatments.

Because mating disruption for leafrollers is not as robust as it is for CM, A&K or attract-and-remove (trap out) is a possible alternative approach. A small plot attract-and-remove trial was conducted in MI to compare a standard mating disruption treatment to a trap out program for OBLR. Treatments included Isomate OBLR/PLR, Pherocon IIB traps baited with standard OBLR lures (attract-and-remove treatment), and a no pheromone control. Treatments were applied to 0.5-acre

plots at 200-point sources per acre. Both pheromone treatments were effective at reducing the capture of OBLR leafroller in monitoring traps. During both flights, the attract-and-remove approach was more effective at reducing OBLR capture in the central monitoring traps than the commercial mating disruption standard (Fig. 14). The attract-and-remove approach for OBLR appears to have greater potential compared to a mating disruption approach. Developing a cheap device to remove leafroller males from orchards could reduce the need for chemical control treatments or, when combined with soft chemical controls like Bt, enhance biological control in IPM programs.

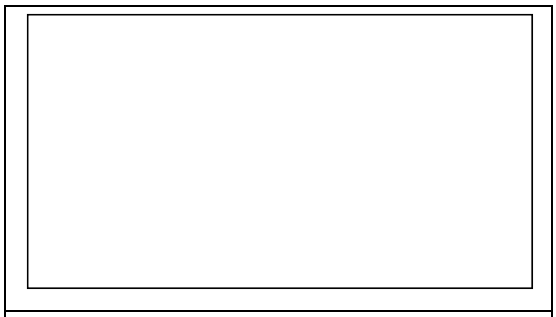

Fig. 14.

A similar attract-and-remove approach for OBLR was tried in WA in replicated small plots. Treatments include an untreated control, Pherocon IIB traps baited with OBLR lures, and OBLR lures only. The OBLR treatments were applied at 200 trap or lures/A. The treatments went out at the end of the overwinter generation flight. OBLR capture in pheromone monitoring traps was suppressed in the trap and lure only treatments by about 85% relative to the untreated control. In AA/PE monitoring traps, there was no difference in moth captures between any of the treatments and the sex ratio was similar in each. Trap out does not seem to be a robust enough approach for managing OBLR, at least in these small plots.

A private company approached us to evaluate an A&K technology they were developing. Treatments were established in WA and MI that were compatible but not duplicative. In MI the A&K technology, with and without the toxicant, was compared to an Isomate Flex treatment and untreated control. The A&K treatments suppressed moth capture in traps relative to the control and similar to the Isomate Flex treatment. However, there was no difference between the A&K technology treatment with and without the toxicant, suggesting that there was a mild mating disruption effect but not an A&K effect. In WA different rates of the A&K technology was tested in replicated small plots challenged with release of sterile moths. There was a slight suppression of CM capture in pheromone monitoring traps relative to the untreated control, but with no real differences between the different rates of the A&K technology. In AA/PE baited monitoring traps there was also no differences between CM captures, males or females, between the untreated control and A&K technology treatments. Data from these studies has been shared with the company, which is evaluating its next steps with the technology.

Attract and kill stations were deployed in apple orchards at a rate of 50/acre to determine their impact on catches of CM moths in monitoring traps baited with pheromone lures or a feeding attractant lures. The station design was a short length of white tubing, a lure at the bottom center of the inside of the tube, and a killing agent coating the interior of the tube. Each attract-and-kill experiment was conducted over 8 days, with comparisons of treated versus untreated plots, in both spring and summer flights attract-and-remove. The percent reductions in moths captured in pheromone monitoring traps were initially low and not statistically significant, but steadily improved to reach 98% reductions of males and 80% reductions of females in traps baited with codling moth/pear ester lures, and 82% and 85% reductions of males and females in traps baited with acetic AA/PE lures.

Interpretation. All of the field trials point to a good potential for use of attract-and-remove or attract-and-kill as a strategy for CM and possibly for OBLR management. There is developing technology that could make this approach economical. The micro-trap is much smaller than the delta trap, yet still catches 25-60% as many moths. This is encouraging considering it was designed to be deployed at densities of 100/A.

Video monitoring of behavior around A&K devices is an effective tool in identifying limitations of designs and the relative effect of different attractants. For example, a kairomone in the USDA-ARS A&K device was only half as attractive as the device baited with a pheromone lure (Fig. 15-left), however, the duration of visits was equal between the two attractants (Fig. 15-right). Contact with the A&K device was low, 3%, and was the same for both lure-types.

Video recordings to a private company's A&K device showed that there was no impact of attractant (pheromone) load rate on the number of visits but the duration of visits increased slightly with load rate and was similar to a 0.1 mg pheromone lure. With this A&K device there was a consistent but low level of contact by moths, 10-25%.

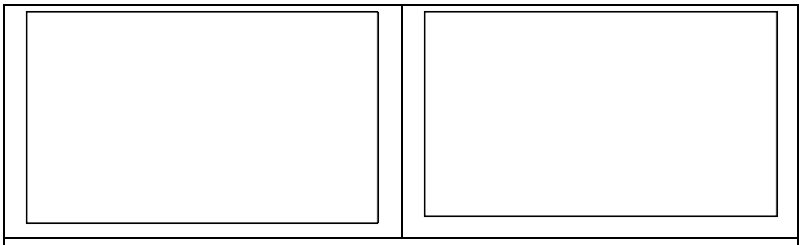

Fig. 15.

When another companies A&K technology was evaluated using video cameras, results showed that the technology was attractive, though much less so than a 0.1 mg lure. The attraction of the A&K technology remained for over three months and actual duration of visits increased as the A&K technology aged. However, the contact of CM moths with the A&K technology, which is critical for efficacy, was very low relative to the 0.1 mg lure. These data support observations of the small plot field trial with this technology where the effect seemed attributable more to a mild mating disruption effect than to an A&K effect.

Interpretation. Video monitoring was shown to be a powerful tool to demonstrate the relative attraction to potential A&K technologies and the actual level of contact with devices. The lack of moth contact with experimental devices suggests that lure strength is important in enhancing contact. Our results also showed that the shape of a device is important in enhancing or limiting contact. These results helped point to ways to improve upon A&K devices and attractants employed in them.

Executive Summary

This project developed collaborative relationships with private industry and leveraged each dollar of Commission funding into one dollar of support from private companies (cash plus in-kind support). The collaborative relationships provided access to new technologies, allowed us to expand the scope of our research, and influenced new product development for the benefit of the tree fruit industry. An impact of this project's research was the development of a new, more efficient, pheromone dispenser technology, Isomate CM Flex, which is now in commercial use. This project significantly influenced the development of the Tangler® technology which reduces application time of pheromone dispensers by 75% while providing CM control equal to hand-applied dispensers. The use of sterile CM moths obtained from the Okanogan-Kootenay Sterile Insect Release (SIR) Program allowed this project to challenge different pheromone treatments in commercial orchards. Using the SIR technology we were able to test different pheromone treatments in large replicated plots while keeping moth density the same across treatments.

We showed that pheromone release rates and shape of dispensers influenced CM behavior. These behavioral changes where evaluated in field cages and small plot trials, which informed additional studies in large field plots. A new meso-type dispenser, Isomate CM Ring, showed that rates of 20 to 40 dispensers per acre were as effective in suppressing CM behavior as a standard hand applied dispenser treatment, Isomate CM Flex, at 400 dispensers per acre. We also showed that the addition of pear ester to the CideTrak CM hand-applied dispenser did not provide additional impact on CM behavior. However, there was evidence that the impact of a meso-type CideTrak CM dispenser with pear ester was had a greater impact on CM behavior than when pear ester was absent. Video recording of CM moth behavior in the field proved to be a valuable tool providing evidence that not only the amount of pheromone released from a dispenser was important, but that the shape of the dispenser was also important. A new attractant that originated from microbial chemistry was demonstrated in the field to be attractive to female and male CM. The new attractant was four times more attractive than acetic acid lures, and has then potential to be comparable to the acetic acid + pear ester attractant.

Based on models and field cage studies, A&K technologies were shown to be four times more robust than mating disruption at controlling CM. Therefore, optimization of A&K technologies is worth the investment of energies and resources. This project demonstrated that either Warrior or Assail in different formulations were good candidates for toxicants in attract-and-kill (A&K) formulations. Exposure of CM moth adults to sublethal concentrations of a toxicant dramatically impacted the moth's ability to orient to females and mate. These results increase the potential for developing A&K technologies with low concentrations of toxicants. We showed that the strength of attractant and the shape and size of openings in an A&K device are important in optimizing efficacy. Mini-traps looked promising in initial studies, but when evaluated in small or large field trials the designs used provided variable results. However, a tubular A&K device with a toxicant reduced male CM activity by 98% using only 50 units/A. There is good indication that an A&K technology would be effective to suppress populations of leafrollers. Video monitoring of moth behavior while extremely time consuming provides critical insights into moth behaviors associated with A&K technologies. Videos showed relative attraction to an A&K device over time and, more importantly, revealed barriers to source contact, which is critical to the success of this technology. Progress has been made in developing an alternative to pear ester that could be used in A&K technologies, thus impacting both male and female CM. New technologies are important because the company holding the pear ester license is not interested in using it in an A&K technology.