Final Report

Project Title: Management of Codling Moth

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Objectives:

1. Optimizing the use of microencapsulated sex pheromone for codling moth.
2. Refine and field-test the A.K.I.S.S. (Attractive Killing Interception Sensory Station) baited with the DA lure (pear ester) for control of codling moth.
3. Monitoring the mating success of codling moth under different sex pheromone-based control programs.

Significant findings:

- Apple orchard plots treated with an ultra low volume application of a microencapsulated sprayable sex pheromone formulation for codling moth had significantly lower levels of fruit injury than similar plots treated with a standard air blast application and untreated check plots.
- The ultra low volume application deposited nearly seven times more capsules per leaf than the air blast application. The lower leaf surface in the upper canopy had the highest mean capsule density.
- Apple, pear, and walnut leaves treated with 40 capsules per leaf remained attractive for at least 4 weeks under field conditions. The influence of rain was to primarily remove capsules from the top of leaves.
- The addition of Asana to the sprayable sex pheromone killed moths for two weeks and mortality was dependent on the density of capsules deposited per leaf.
- The addition of Asana with the sprayable sex pheromone further reduced moth catch 80% for two weeks in replicated orchards.
- A new formulation of the microencapsulated material significantly extended the disruption of sex pheromone-baited traps with commercial formulation from 2 to 5 weeks.
- A killing station (AKISS) was developed and field-tested in 28 apple plots during 2004.
- Data from 16 orchards were summarized at mid-season and fruit injury was reduced ca. 50% versus the untreated orchard plots.
- Several problems were encountered with the killing station including, breakage, loss of residue from foliage, repellency, lack of clarity with the grease, and poor positioning of the lure.
- A new improved killing station has been designed and tested in the laboratory.
- Other fruit volatiles tested were less effective in catching female codling moth than the pear ester.
- Greater than 85% of female codling moths caught in traps baited with pear ester were mated in orchards treated with Pheromone Mops, microencapsulated sex pheromone, hand-applied dispensers, and left untreated.

Methods:

Microencapsulated sex pheromone. Studies were conducted in replicated (n = 5) 1-2 ha apple blocks to compare the efficacy of applications of Checkmate® CM-F (Suterra Inc., Bend, OR) with either an air blast (926 liters per ha) or an ultra low volume sprayer (12 liters per ha). Codlemone was applied in all plots at a rate of 49.0 g A.I. per ha. Six applications were made 2-4 weeks apart during the season. Spray intervals of less than 4 weeks were used in some cases due to the occurrence of rainfall and indications that the air blast application was failing. Untreated blocks were included in the study. All plots received three insecticide applications during the season. Blocks were monitored with traps and fruit injury was sampled at mid-season and prior to harvest. Transformed injury data were analyzed with ANOVA.

The density and distribution of microcapsules deposited with the ultra low volume and air blast sprayers were estimated by spraying a similar formulation with 0.50% fluorescent dye added. The density of fluorescent microcapsules per leaf were counted on ten leaves from twenty shoots collected from the lower and upper canopy. Capsule density as a function of canopy height and between the top and bottom of leaves were analyzed with a paired t-test for each spray method separately. Apple, pear, and walnut leaves were treated with 40 microcapsules per leaf surface. Codling moth males (n = 3) were flown in a flight tunnel to detached leaves (n = 5) weekly for five weeks. The apple test was repeated due to the occurrence of rainfall during the first test.

The impact of adding an insecticide to the ultra low volume application of microencapsulated sex pheromone was evaluated in two types of tests. In the first test, the maximum rate of Asana XL (14.6 fl oz) was added to the microencapsulated sex pheromone plus the fluorescent dye and sprayed on potted apple trees. Leaves with 0 – 150 microcapsules per leaf were identified and labeled. Every 7 days leaves with a range of microcapsule densities were selected. Moths were touched to the upper leaf surface for 3 seconds and mortality was assessed after 24 hours. Asana XL (14.6 fl o z) was added to the microencapsulated sprayable material and applied with the ultra low volume sprayer to four apple orchards. Each block was split in half and treated with sex pheromone plus Asana on half and only sex pheromone on the other half. Two sex pheromone-baited traps were placed in each block and monitored for two weeks.

A new formulation of Suterra's microencapsulated sex pheromone was tested during August and September. Five apple orchards were split into halves. Each half was sprayed either with the commercial formulation or the new formulation. Two sex pheromone-baited delta traps were placed in each orchard half and monitored weekly for 6 weeks.

Development of a killing station. The AKISS design developed during 2003-04 was a clear 0.1 m^2 square plastic sheet coated with a clear FDA-approved food service grease (Royal Purple) mixed with 6.0% esfenvalerate. Eight apple plots were established (0.5 – 1.2 ha) in Orondo and 20 plots in Moxee during 2004. All plots were treated with 60 killing stations per ha. Treated plots were paired with similar untreated plots. Plots in Orondo were treated with 2 insecticide applications and plots in Moxee were treated with two applications of microencapsulated sex pheromone. Fruit injury from the Orondo plots and 8 Moxee plots was assessed in early July and transformed data were analyzed with ANOVA.

A new AKISS design was developed during 2004 that uses an open plastic grid design coated with a clear water-white gel mixed with 6.0% esfenvalerate. The lure was placed in the center of the trap. A series of male codling moths were flown to either the 2004 design or the new design in a flight tunnel. Killing stations were hung from an artificial apple branch with foliage.

Studies were conducted to evaluate the attractiveness of several reported fruit volatile kairomones for codling moth: pear ester, Dimethyl nonatriene, Z-3 Hexenyl Acetate, Beta Farnesene, and Farnesol. Compounds were loaded into gray halobutyl elastomer septa and placed in delta-shaped traps in a heavily infested orchard on 14 July. Sex pheromone-baited traps and traps baited with a solvent control were included in the study. Traps were checked and rotated every few days until 26 July.

Mating success of codling moth. The mating success of female codling moths was assessed with 100 delta-shaped traps placed within 20 apple orchards treated with Pheromone Mops in the Brewster area and in 10 orchard plots treated with microencapsulated sex pheromone in the Moxee area. Similar data were also collected from two orchards treated with Isomate-C PLUS dispensers, and five orchards left untreated. Data are presented for the first and second moth flight (> 5 July).

Results and discussion:

Microencapsulated sex pheromone. Moth counts were reduced 68% and 92% in the air blast and ULV-treated plots versus the untreated plots (Fig. 1). Significant differences occurred in the levels of fruit injury among treatments with the ULV treatment having significantly less injury than the untreated plots (Table 1). The mean density of microcapsules in the air blast treatment was 2.9 per leaf, and the highest density was 14 microcapsules per leaf. The ULV application deposited an average of 19.7 microcapsules per leaf and a maximum of 157 per leaf (Table 2). Significantly more capsules were deposited in the upper than lower canopy with the ULV application. Both application methods deposited nearly twice the number of microcapsules on the underside than on the top of leaves in the upper canopy. Apple, pear, and walnut eaves treated with 40 microcapsules loss their attraction gradually over time and some leaves were still attractive after 5 weeks (Table 3). Natural rainfall reduced the attractiveness of apple leaves treated on their upper surface but not with leaves treated on their lower surface. Significant levels of adult mortality occurred following a 3-s contact with leaves sprayed with the microencapsulated sex pheromone and Asana (Fig. 2). A strong linear dose response was found and the toxicity of treated leaves declined over time. The occurrence of rainfall reduced the toxicity of treated leaves. The addition of Asana to the microencapsulated sex pheromone further reduced moth catch 80% versus the sex pheromone-alone treatment over the two-week test period (Table 4). The new microencapsulated formulation significantly reduced moth catch for 5 weeks while the commercial formulation was effective for only two weeks in this test (Fig. 3).

The use of microencapsulated sprayable formulations for codling moth has been widely field tested for more than 5 years in the United States but have not been adopted by growers. Despite their promise of a flexible tactic that can be applied with standard equipment and is compatible with other pesticide applications they have not performed well. This poor performance has been blamed on their short residual activity in the field due to instability of their formulations. Alternatively, my studies have focused on improving their efficacy by increasing the deposition and retention of capsules within the orchard canopy. The preliminary studies reported here suggest that the use of ultra low volume applications can dramatically improve their performance. The effectiveness of the ultra low volume applications was first demonstrated in 2000 and last year I began to work with these materials with the idea of creating hundreds of attractive point sources on trees. My research has suggested that the current hand-applied dispenses are not effective in disrupting mating and that sex pheromones reduce populations through a combination of disruption and a delay in mating. Similar results have been found for oriental fruit moth and European corn borer. Studies are needed to expand the evaluation of the ULV approach to grower orchard trials and to compare this approach with the standard use of hand-applied dispensers. Furthermore, a number of factors associated with the use of microencapsulated sex pheromones need to be explored to further optimize this technology, such as spray pressure, amount of water, addition of stickers, angle of nozzle and nozzle type.

Development of a killing station. Significant and near significant differences in fruit injury occurred with the addition of killing stations (Fig. 4). Plots treated with killing stations averaged 9.4% versus 16.6% fruit injury in the untreated plots in Orondo ($P = 0.06$) and 0.8% versus 2.1% in Moxee ($P = 0.02$), respectively. A number of problems were noted with this approach during the season and the test was terminated at midseason. These included a loss in the toxicity of the panes due to removal of grease from abrasion by foliage and the cumulative effects of rain and wind; and the breakage of stations due to wind. Fruit injury data from 12 of the Moxee plots were not collected due to the loss of most of the stations. Repellency of the killing stations and placement of the lure above the station were later found to have reduced moth contact with the treated surface of the station.

Moth contact with the killing station was affected by several factors. The insecticide mixture was found to be repellant after 24 h and not at 120 h of field aging. During June the contact toxicity of the killing stations was reduced after 4 weeks (15% alive) and after 7 weeks (25% alive). In contrast, stations hung free of foliage last season and again this year both caused 100% mortality for 10 weeks. Similarly, the new open grid design was 100% effective during an 8-week trial this fall. The loss in toxicity observed in early summer this year was thought to be due to contact with foliage and weathering from rainfall and wind. During the season we noticed that the grease was not clear and stations did not get covered with scales or other insects that we typically see with the use of STP-coated traps. Flight tunnel tests found that the grease was somewhat repellant (Table 5). The new open grid design with the lure placed in the center had a significantly higher proportion of moths contacting the killing station than the solid pane design with the lure clipped at the top.

In studies with several apple volatiles traps baited with the pear ester were the only ones to catch female codling moths. The sex pheromone-baited traps averaged 70 moths per trap and the pear ester traps averaged 5 males and 4 females during this trial. Traps baited with the other volatiles averaged < 1 moth per trap.

The potent attraction of the pear ester for female codling moth has offered a new approach to manage codling moth. Killing stations could become an important addition to sex pheromones especially along the borders of orchards and near bin piles and other extra-orchard sources of codling moth. This ongoing research is focused on developing an effective tactic that is also cost effective and user friendly. Future studies will continue to focus on an improved design and to better understand the link between moth behavior and trap design.

Mating status of codling moth. Very high levels of mating by female codling moths were found in all orchards regardless of sex pheromone treatment (Table 6). The percentage of mated females was somewhat lower in the ULV microencapsulated-treated orchards. Pear ester lures are known to be somewhat biased for mated versus virgin female codling moths. However, this year's data are the highest percentage of mated females trapped in orchards treated with sex pheromones than any other in the past six years. This extended data set supports the idea that reductions in populations of codling moth in orchards treated with sex pheromones are likely due to a combination of mating disruption, delay of mating, and enhanced biological control.

Budget:

Item	Year 1 (2004)
Salaries[1]	22,388
Benefits (34%)	7,612
Equipment	0
Supplies	0
Total	**30,000**

[1] Six months salary for a GS-7 term .

Table 1. Mean percent fruit injury in plots (n = 5) treated with two application methods of microencapsulated sex pheromone and an untreated control. All plots were sprayed with three applications of insecticides.

	Mean % ± SE fruit injury	
Treatment	Mid-season 8 July	Pre-harvest 1 Sept.
Untreated	9.2 ± 2.3a	27.8 ± 8.7a
Air blast	4.9 ± 2.2ab	8.7 ± 2.3b
ULV	1.2 ± 0.2b	3.3 ± 1.1b
ANOVA df = 2, 12	$F = 4.78, P < 0.05$	$F = 6.04, P < 0.05$

Table 2. Mean deposition of microcapsules on the bottom and top of leaves within apple canopies following either an air blast or an ULV spray application.

	Mean ± SE microcapsules						
	Lower canopy			Upper canopy			Tree
Treatment	Bottom	Top	Average	Bottom	Top	Average	Average
Air blast	2.2 ± 0.3	0.6 ± 0.1	2.8 ± 0.3	2.0 ± 0.2	0.9 ± 0.1	2.9 ± 0.3	2.9 ± 0.2
ULV	7.5 ± 2.3	9.8 ± 1.0	17.3 ± 2.7	15.8 ± 2.8	6.3 ± 0.8	22.1 ± 3.3	19.7 ± 2.1
P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

A fluorescent dye was added to the microencapsulated formulation to facilitate counting of capsules.

Table 3. Mean proportion of apple, pear, and walnut leaves treated with 40 microcapsules per leaf surface and aged in the field for 1 – 35 d that were contacted by male codling moths flown in a flight tunnel.

		Mean ± SE percent male moths contacting leaf					
Leaf surface	Start of test date	1 d	7 d	14 d	21 d	28 d	35 d
Apple top	4 June	0.9 ± 0.1	0.2 ± 0.2[a]	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.2
Apple bottom		0.8 ± 0.1	0.7 ± 0.2[a]	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.5 ± 0.2
Walnut top	9 June	0.8 ± 0.1	0.6 ± 0.2	0.5 ± 0.2	0.3 ± 0.1	0.2 ± 0.1	0.1 ± 0.1
Walnut bottom		0.9 ± 0.1	0.9 ± 0.1	0.3 ± 0.2	0.6 ± 0.2	0.4 ± 0.2	0.4 ± 0.2
Pear top	17 June	0.7 ± 0.1	0.5 ± 0.2	0.4 ± 0.2	0.3 ± 0.2	0.1 ± 0.1	-
Pear bottom		0.9 ± 0.1	0.7 ± 0.2	0.5 ± 0.2	0.5 ± 0.2	0.3 ± 0.2	-
Apple top	21 July	0.7 ± 0.1	0.7 ± 0.2	0.5 ± 0.2	0.2 ± 0.1[a]	-	-
Apple bottom		1.0 ± 0.0	0.9 ± 0.1	0.6 ± 0.2	0.6 ± 0.2[a]	-	-

[a] Leaves were exposed to 0.5" rainfall prior to this date.

Table 4. Reductions in trap catch of male codling moths in sex pheromone-baited traps in apple orchards (n = 4) sprayed with microencapsulated sex pheromone with and without Asana added or untreated.

	Mean ± SE moth catch per trap		
Weeks after spray	Untreated	Sex pheromone	Sex pheromone + Asana
1	26.8 ± 4.6	2.5 ± 1.1	0.6 ± 0.5
2	26.8 ± 6.2	1.1 ± 0.7	0.1 ± 0.1

Table 5. Flight tunnel tests of new open grid AKISS design. The sex pheromone lure was placed in the center of the open grid and at the top of the solid pane in these tests.

	Proportion moths contacting:					
	No foliage		Foliage added			
	Station		Station		Foliage	
Test	Solid pane	Open grid	Solid pane	Open grid	Solid pane	Open grid
Station only	0.86a	0.79a	-	1.00a	-	0.13a
Station w'grease	0.60b	0.50b	0.40A	0.84bB	0.84B	0.28bA
Station'w grease + Asana	0.60b	0.60ab	0.36A	0.76bB	0.92B	0.36bA

Column (small letters) and row means (cap letters for tests with foliage for either station or foliage contact) followed by different letters were significantly different, $P < 0.05$.

Table 6. Mating status of female codling moth in apple orchards treated with Pheromone Mops, microencapsulated formulations, hand-applied dispensers, and no sex pheromone during 2004.

	Percentage females mated	
Sex pheromone treatment	1st flight	2nd flight
Pheromone Mops (n = 20)	97.2	94.7
Microencapsulated (n = 10)	87.9	92.5
Hand-applied (n = 2)	100.0	100.0
Untreated (n = 5)	96.4	90.8

Figure 1. Weekly moth catch in apple plots treated with microencapsulated capsules either sprayed with an air blast sprayer or an ULV sprayer and in plots left untreated.

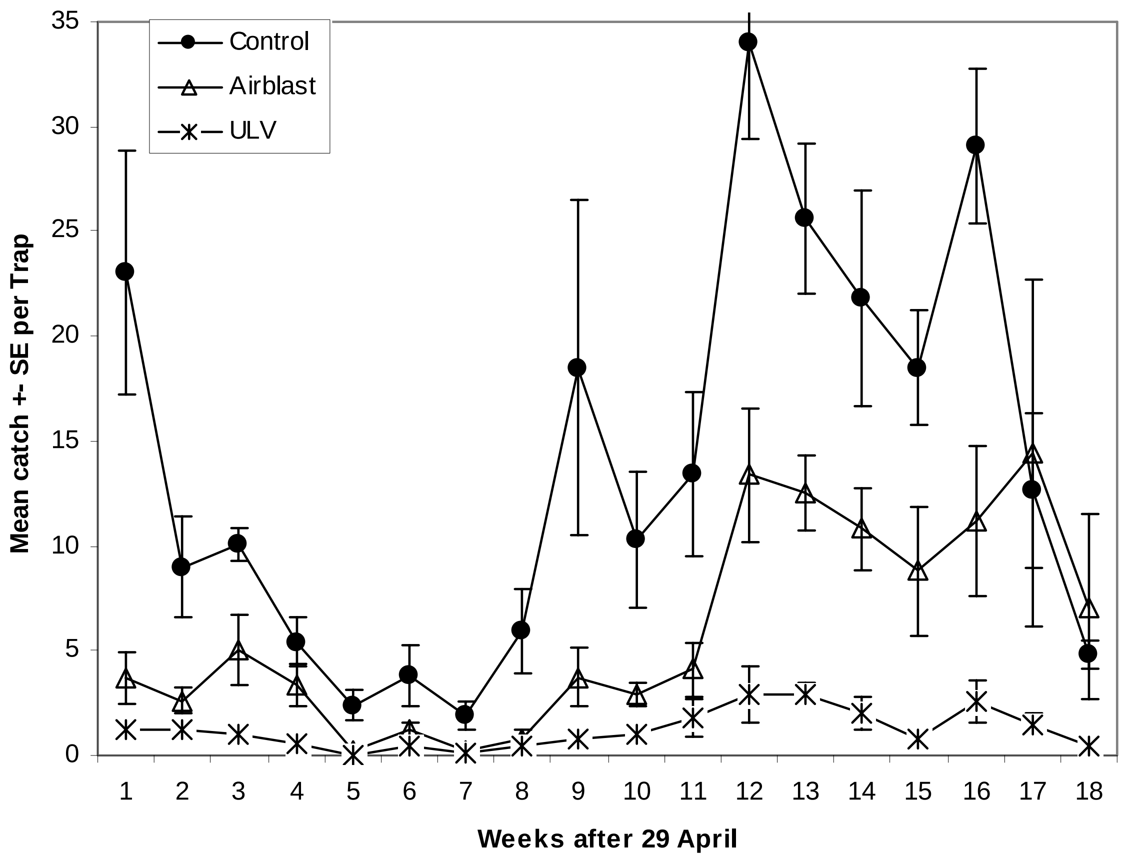
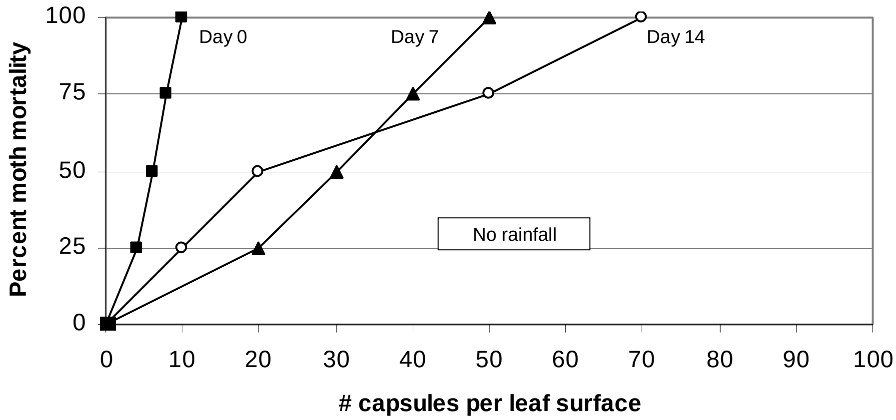


Figure 2. Mortality of adult codling moths exposed to leaf surfaces for 3 s treated with variable numbers of microcapsules plus Asana. No rainfall occurred during test 1 but nearly 0.5” occurred on day 3 after the start of the second test.



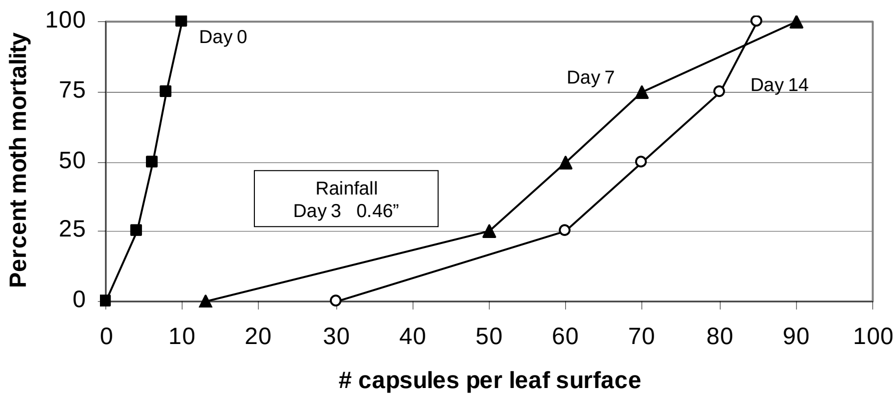


Fig 3a. Comparison of moth catches in four apple orchards sprayed with a new formulation of Suterra's Checkmate CM-F. Moth catches were significantly reduced in the treated blocks for five weeks.

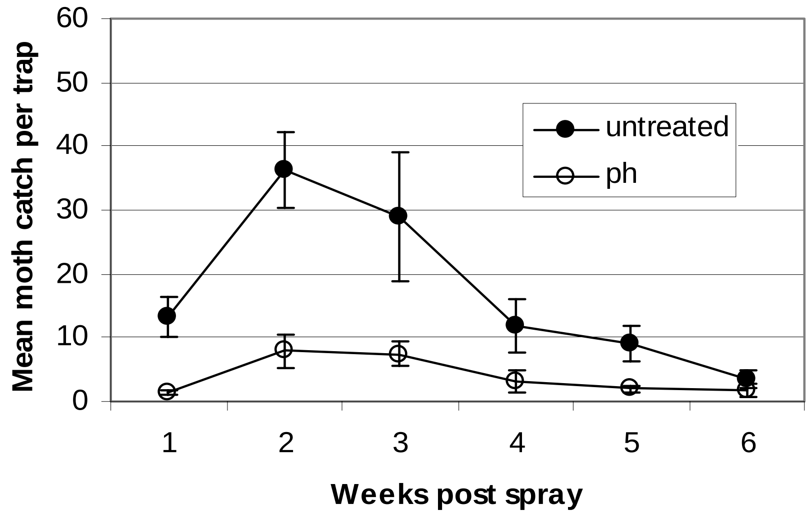


Fig 3b. Comparison of moth catches in four apple orchards sprayed with the standard formulation of Suterra's Checkmate CM-F. Moth catches were significantly reduced in the treated blocks for two weeks.

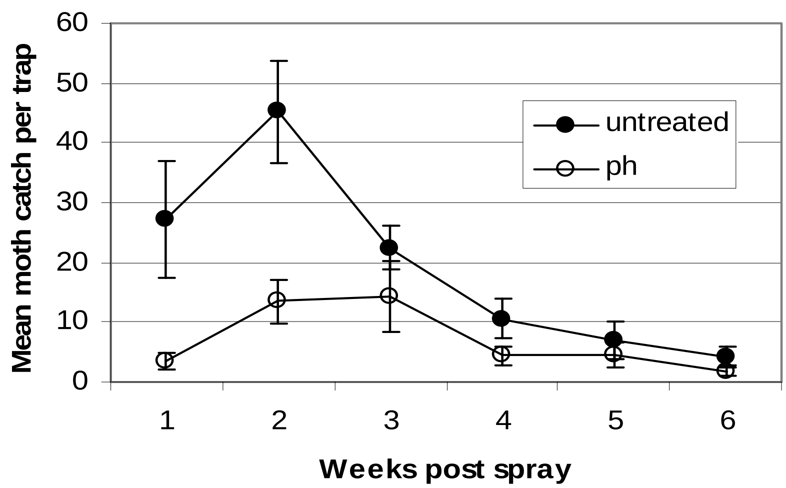


Figure 4. Percent fruit injury in replicated apple blocks (n = 8) treated with and without pear ester and sex pheromone-baited killing stations (AK). Moxee orchards were also treated with microencapsulated sex pheromone and Orondo orchards were sprayed with insecticides.