FINAL PROJECT REPORT

Project Title: Enhancing BC in apples: how do conventional and organic systems differ?

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Other funding sources

Agency Name: USDA-SCRI grant (Enhancing BC in Western Orchard Systems)
Amount awarded: $2.25M. Approx.
Notes: $60K from that grant will be used for this project.

Total Project Funding: **Year 1:** $96,916 **Year 2:** $99,133 **Year 3:** $103,775

Budget History:

Item	**2011**	**2012**	**2013**
Salaries	55,000	55,000	55,000
Benefits	18,920	17,820	17,186
Wages	13,440	14,112	18,000
Benefits	2,016	2,117	3,042
Equipment	0	0	0
Supplies	4,600	6,997	7,306
Travel	2,940	3,087	3,241
Total	96,916	99,133	103,775

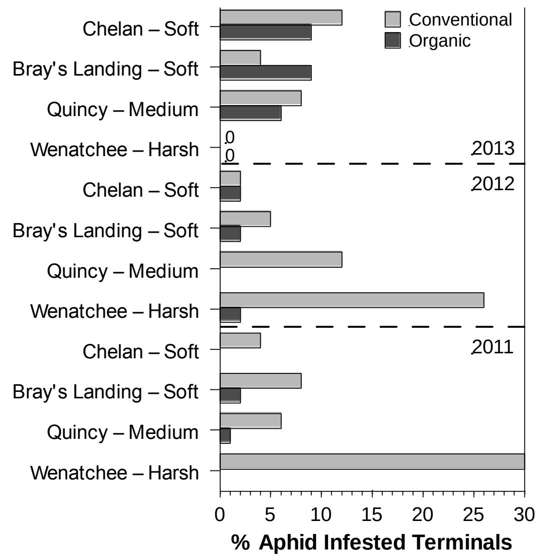
Objectives:
1. Compare the natural enemy (NE) complex in conventional and organic orchards to determine differences in diversity and abundance.
2. Evaluate low dose pesticide applications to minimize pesticide impacts on NE and reduce residues, while maintaining low pest damage.
3. Evaluate attractant traps' attractive radius and determine the feasibility of "herding" NE to improve BC and integrate BC better with chemical controls.

Significant Findings:
- The organic orchards evaluated tended to have larger NE populations and lower aphid populations.
- The pest control intensity is probably more important in predicting pest problems than the "conventional" versus "organic" labels. Many conventional orchards use very soft programs (virus, *Bt*) and can be actually softer than a harsh organic program.
- Comparison of the use of organic, full rate of Delegate and 10% field rate of Delegate at the WSU-Sunrise orchard showed that there was no sigificant change in damage from codling moth, leafroller, woolly apple aphid, green apple aphid, rosy apple aphid, or San Jose Scale between the treatments.
- Natural enemy populations increased from year to year in the three different treatment programs, likely because of decreased early season sprays. Second generation sprays tended to increase differences in NE numbers between the organic or reduced rate of Delegate treatments compared to the full rate of Delegate treatments.
- NE numbers increased around NE lures and resulted in lower aphid numbers two weeks after lures were placed in the field, suggesting that NE concentration via lures can contribute to localized suppression of aphid populations. The studies also showed greater NE egg-laying occurred near the lures, suggesting that the effect of short term baiting will have longer suppressive effects because after egg hatch, the relatively immobile immature stages would be present in higher numbers in the baited areas.
- Previous studies had shown the squalene lure-baited traps were highly attractive to the lacewing *C. nigricornis*. Those studies did show that >93% of the capture was male, which potentially meant that it would disrupt the mating process. However, studies in this grant showed that female *C. nigricornis* were also attracted near the lures (just not into the traps), so that squalene should be useful for herding *C. nigricornis* without concern that it would disrupt mating behavior of this key predator.

Results and Discussion:
Objective 1. Compare the natural enemy (NE) complex in conventional and organic orchards to determine differences in diversity and abundance.
Methods: We sampled four pairs of orchards (one conventional and one organic) where orchard pairs were separated by <0.5 mile. We sampled the orchards for differences in natural enemy (NE) populations using our HIPV and floral volatile traps and earwig (corrugated cardboard) bands. All orchards in this objective were under mating disruption. These orchards are classed in terms of program harshness to NEs: two pairs were very soft with few differences in the management programs between the conventional and organic treatments (e.g., virus + oil were used in both pairs of orchards – Bray's Landing and Chelan), in one pair both conventional and organic had harsh programs (large number of disruptive treatments - Wenatchee), and in the final pair (Quincy) both conventional and organic had medium programs (one to several harsh treatments and a few softer materials used at other times in the season). In 2013, we set up a new orchard pair in Quincy, because the orchards used in 2011-12 were pulled by the grower. We also changed the conventional orchard used in the Chelan location in 2013 to get a closer match of cultivars between the two orchards. The

discussion is focused on the aphid NEs for brevity. To simplify the analysis and presentation, we use a “natural enemy-day” analysis, which is calculated by taking the number of average density of the aphid feeding natural enemies between two sample dates and multiplying that by the number of days between samples. This gives us an estimate of the amount of potential predation/parasitism and can be accumulated over the season to give overall differences between orchards. One caution is that each of the NEs kill different amounts of prey and the generalists may eat more than just aphids, thus this is a simplification and the data is skewed by the most common aphid feeding NEs (the lacewings *Chrysopa nigricornis* and *Chrysoperla plorabunda*, the parasitoid of the woolly apple aphid, *Aphelinus mali*, *Deraeocoris brevis* and the European earwig). Aphids monitored included WAA, green apple aphid (GAA), and rosy apple aphid (RAA).

Fig. 1. Percentage terminals infested by aphids at the end of the season 2011-2013.



Results: Over the three-year period, percentage of aphid infested terminals tended to be highest in the conventional orchards (Fig. 1). The damage tended to be inversely related to the number of aphid natural enemies, which was greatest in the organic orchards in three of the four orchard pairs (Fig. 2). Abundance of aphid natural enemies, especially *C. nigricornis*, *A. mali*, and *D. brevis* was generally higher in the organic orchards at Bray’s Landing, Chelan and Wenatchee. In contrast, the conventionally managed orchard in Quincy

Fig. 2. Cumulative aphid NE days versus day of the year for the orchard pairs, 2011-2013.

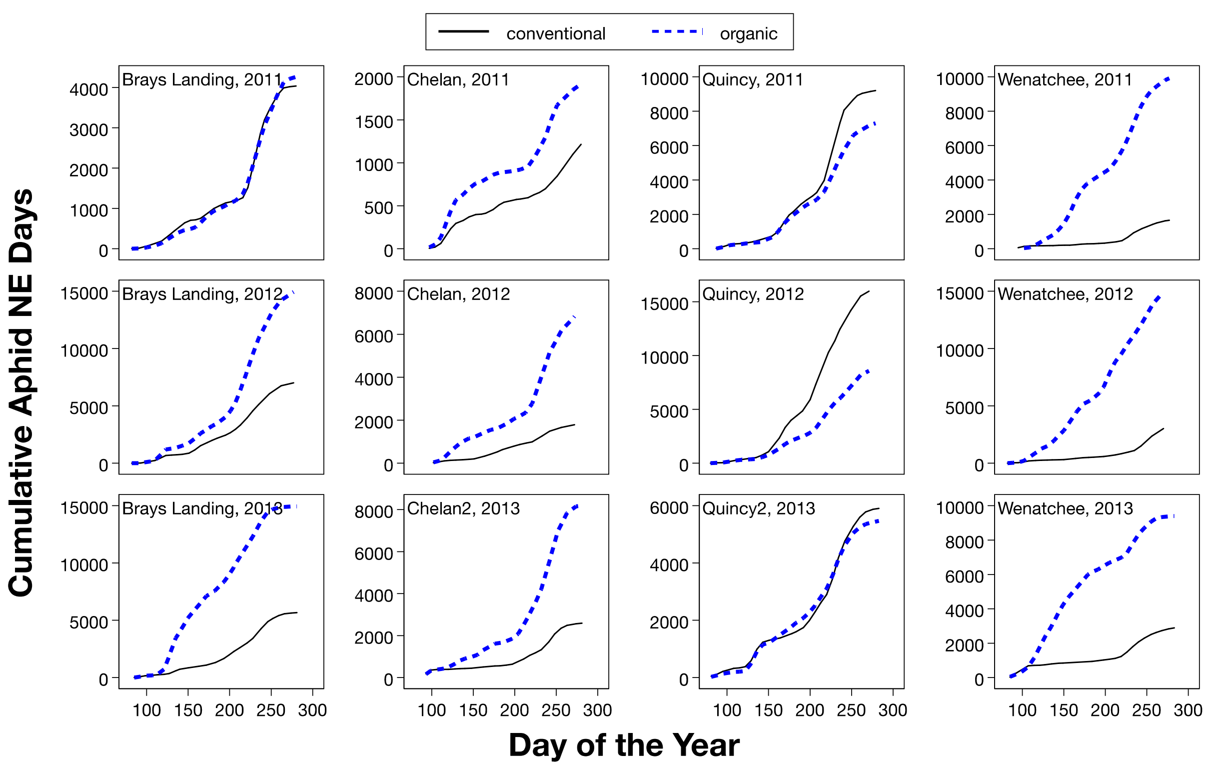
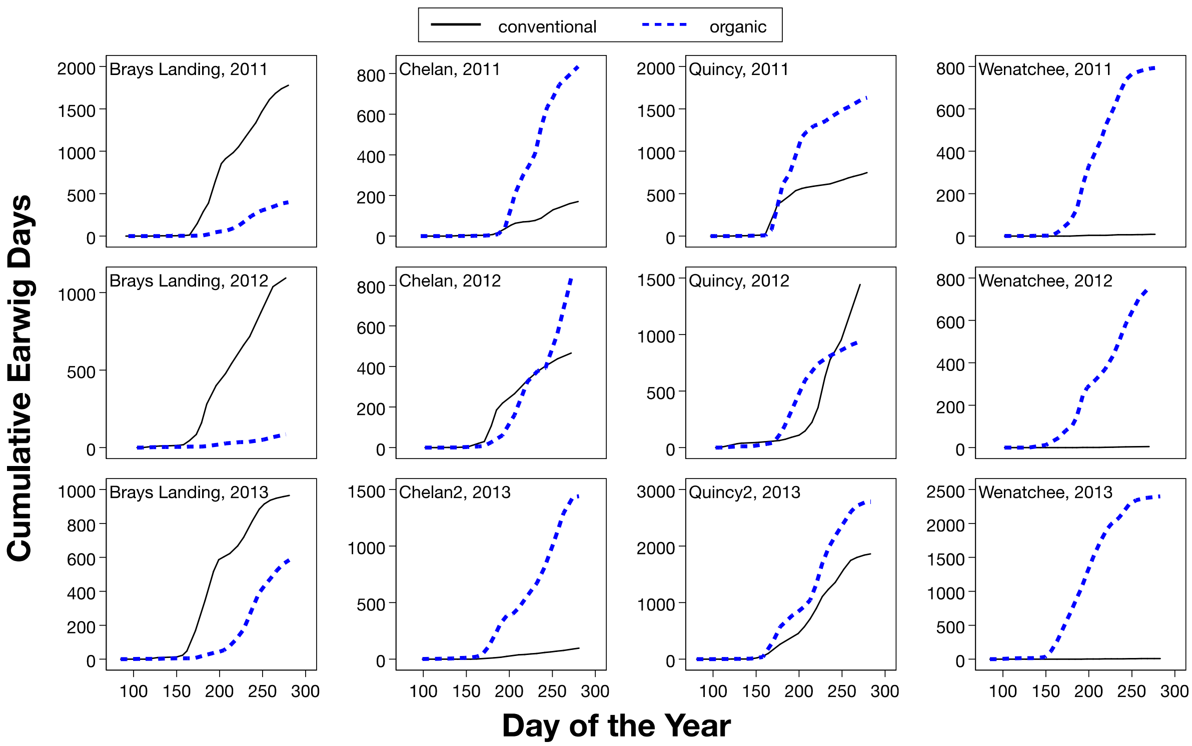


Fig. 3. Cumulative earwig-days from banding data versus day of the year for four pairs of orchards 2011-13.



orchard had consistently higher natural enemy abundance in the 2011-2012 seasons (there was no difference in aphid natural enemy days 2013 in the new orchard pair). The cumulative aphid natural enemy days started to diverge between the organic and conventional blocks about the time that five oil (+ virus) sprays targeted at codling moth were applied (2011) and four oil and either virus or Entrust were applied in the organic block (2012). In the conventional block, treatments at the time of divergence were minimal with two sprays in 2011 (Proclaim at the start of the divergence and Altacor near the end) and one spray in 2012 (imidacloprid). Even though there were more cumulative natural enemy days associated with the conventional block in 2011 and 2012, damage was still highest in the conventional block, which suggests that other factors may also be important in this orchard pair. Earwig densities were highest in the organic block in 2011 all year and 2012, until just before our aphid evaluation (Fig. 3). Thus, the earwigs appear to be a dominant factor in the suppression of aphids in the Quincy organic orchard.

Interestingly, the conventional orchard in Wenatchee accumulated aphid natural enemy days at only 16-31% of that in the organic orchard (both orchards were classified as harsh management programs, Fig. 2). We have not yet received spray records from the conventional Wenatchee orchard for 2012 or 2013, so we cannot yet explain the sharp drop in aphid populations in 2013 (we have been promised they will come soon).

Examination of the earwig banding data (Fig. 3) showed that the abundance of earwigs was typically greatest in the organic blocks, with the glaring exception of the Bray's Landing orchard pair. In that orchard pair, the organic block had under-tree irrigation that wet our bands resulting in them falling apart and extremely lowering earwig capture. However, we know that the earwigs occurred likely at higher densities in the organic block because our HIPV and floral volatile traps (which are ≈40 fold less efficient at trapping earwigs than the bands) captured ≈63% more earwigs in the organic block than in the conventional block. The lack of earwigs in the Wenatchee conventional block was not caused by irrigation issues, but more likely by pesticide use as we caught only 1 earwig in our attractant traps over the three-year period we monitored that orchard.

Across all the orchards and years, we collected an average of 29 different natural enemy taxa that attack aphids. Despite this diversity, the dominant species was nearly always the lacewing *C. nigricornis* or the WAA parasitoid *A. mali*. The mirid bug *D. brevis* was the next most common predator (particularly in the Chelan orchard pairs), but also in 2012 in the Brays Landing and Quincy orchard pairs. Other natural enemies that were abundant at various locations and years included the lacewing *C. plorabunda*, the syrphid fly *Eupeodes fumipennis*, and the aphid parasitoid *Ephedrus* spp. Diversity indices done on the yearly data did not show significant differences trends between conventional and organic blocks, but further analysis examining the diversity at monthly intervals needs to be performed to see if there are trends masked by averaging over the entire season.

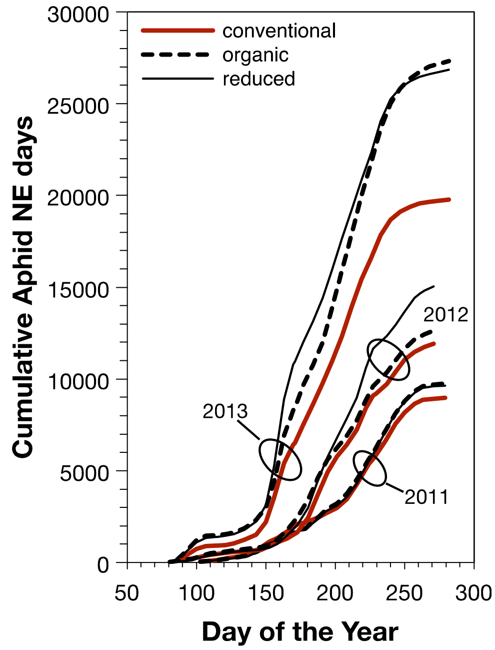
Objective 2. Evaluate low dose pesticide applications to minimize pesticide impacts on NE and reduce residues, while maintaining low pest damage.

Methods: For a three-year period, we have followed a 15-acre plot at WSU-Sunrise that was originally an organic block. In 2011, we divided the plot into twelve 1.25-acre plots, which were randomly assigned to either a conventional, organic or reduced rate treatment. All plots received mating disruption in all three years. The pesticide used in the conventional and reduced rate treatments was Delegate, which is considered to be relatively harsh to natural enemies, based on bioassays done in objective 1 of the SCRI "Enhancing biological control in Western apple, pear, and walnut orchards". The conventional treatment in 2011-2012 was the full rate of Delegate applied twice in the first CM generation with a delayed first cover. Thus, oil was applied at 375 DD and then at 525 DD the first Delegate spray was applied and ≈ 2 weeks later a second cover was applied. The organic treatment during this period also had a delayed first cover (i.e., oil applied at 375 DD) and the first cover of CM virus was applied at 525 DD, then three more times at ≈ 1-week intervals. The reduced rate treatments were applied at the same timing as the organic treatments, but used a 10% field rate of Delegate in place of the virus. These treatments would be considered very light conventional and organic treatments, with no other pesticide or oil sprays used other than as described above.

In 2013, we had an outbreak of apple mealybug (present throughout the entire northern part of the Sunrise orchard, both inside and outside our plots). Therefore, we used the same treatment timing as 2011-12 in the first CM generation, but added oil to all the treatments (e.g., virus + oil or Delegate + oil) and added an additional oil treatment at the end of the first and second CM generations on 17 June and 12 August to help suppress apple mealybug. We also added treatments for the second generation which were applied starting at 1375 DD (oil only to all treatments), the first cover (either Delegate + oil or virus + oil) at 1525 DD, and then applied the appropriate treatment 2 weeks later (full rate Delegate + oil) or at weekly intervals (virus + oil or the 10% field rate of Delegate + oil), in an attempt to see if second generation treatments affected natural enemy populations.

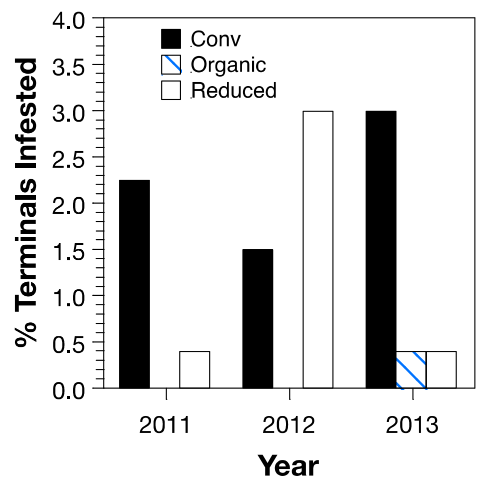
Results: In all treatments the aphid natural enemy populations built up over time, with increases occurring each year (Fig. 4). The first year showed very little differences between the treatments and even the full rate of Delegate not causing much disruption. Differences in the cumulative aphid natural enemy days started to appear in 2012 and expanded in 2013, with the full rate of Delegate being 20.7% and 28% lower in 2012 and 2013, respectively. The reduced rate of Delegate and the organic treatments were similar in all three years, with the largest discrepancy occurring in 2012 were the organic treatment showed a 15.9% reduction, but that disappeared in 2013. The heavier treatments in 2013 did not reduce natural enemy populations compared to the previous two years, but probably exacerbated the effects of Delegate by suppressing late season increases of earwigs, and the lacewings *C. plorabunda* and *C. nigricornis*. During the three-year period, there was a relatively sharp drop off of *C. nigricornis* populations and equally sharp increase in *C. plorabunda*, probably because we eliminated the delayed dormant sprays that occur when *C. plorabunda* has already emerged. Earwigs were the dominant predator each year, and also increased steadily from year to year, without showing any fruit damage.

Fig. 4. Cumulative aphid NE days 2011-2013 at the WSU-Sunrise orchard in the conventional, organic and reduced rate treatments.



The aphid counts (WAA, GAA, RAA), leafroller, and codling moth damage estimates showed no significant differences occurred in any year for any pest between the different treatments. Peak damage of codling moth occurred in 2012, when 0.3, 0.1, and 0.1% of the fruit showed codling moth damage in the conventional, reduced rate, and conventional treatments, respectively, but no damage occurred in any treatment in 2011 or 2013. The percentage of terminals infested with WAA or RAA were < 0.5%, but GAA showed peak damage in 2011 at 2.25, 1.5, and 3.0% for the conventional, organic and reduced treatments, respectively. In 2012 and 2013, aphid infestations were only detected at 0.5% GAA (conventional) and 0.25% WAA (reduced treatments). We never observed SJS scale in any of the treatments over the three-year period. Leafroller damage did not appear to follow any particular trend in the conventional or reduced rate treatments between years, while the organic treatment had no detectable damage in 2011-2012 and only minor (0.4% terminals damaged) in 2013 (Fig. 5).

Fig. 5. Percentage of terminals infested by leafrollers at the WSU Sunrise orchard in the conventional, organic and reduced rate treatments 2011-2013.



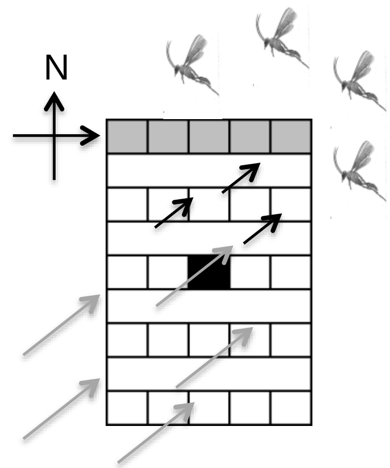
Objective 3. Evaluate attractant traps' attractive radius and determine the feasibility of "herding" NE to improve BC and integrate BC better with chemical controls.

<u>Biological control contribution of NEs responding to HIPVs</u>

Methods: A field study was conducted during June 2013 in an organic apple orchard (>6 acres) to evaluate the direct impacts of NEs, responding to HIPV lures baited with squalene, 2-phenylethanol + geraniol (PE+GER), and acetic acid + methyl salicylate + 2-phenylethanol (AMP), on aphid populations. Eight blocks consisting of 25 trees each were located where aphid populations were high, and during the first week of June, apple aphids (woolly, green, and rosy) were counted to determine a baseline infestation. Natural enemy eggs, larvae, and adults were also recorded. Lures were placed in the center tree of half of the blocks, while the other half were non-lured and served as controls, giving us four pairs of blocks to examine. To eliminate visual attraction, we used clear interception traps. Traps were placed on trees at various distances (0, 6, 12, 18, 15, 30, and 45 ft) and directions (north, south, east, and west) from the center tree (lured or non-lured) to trap NEs. Aphid and NE counts were taken again two weeks after lures were set in place. We anticipated lower aphid populations and higher NE populations in HIPV lured plots.

Results: Natural enemies caught in traps and observed on trees included green lacewings, brown lacewings, ladybird beetles, syrphid flies, the parasitoid wasp, *Aphelinus mali*, and braconid wasps. We found that traps in lured blocks caught significantly more NEs than non-lured blocks (9.3 ± 1.4, 4.75 ± 1.1, average ± SE, respectively) in the northeastern quadrants of blocks on trees 15 and 30 feet from the lure location. Natural enemies tend to fly upwind in response to odor plumes coming from the opposite direction, and because winds originated from the southwest (daily average 218°) during the time lures were in the field, NE most likely responded to volatile plumes coming from this direction (Fig. 6), resulting in higher NE response in the northeast portion of blocks. Surprisingly we did not see significant reduction in aphid colony counts in trees directly adjacent to the lure, but we did find a greater reduction in the most northern row of trees (30ft from lures) in lured blocks (lured, 11.3 ± 1.6; non-lured, 4.3 ± 2.6; average reduction per tree ± SE). These results suggest that NEs attracted to HIPV lures are contributing to biocontrol, but wind direction needs to be considered.

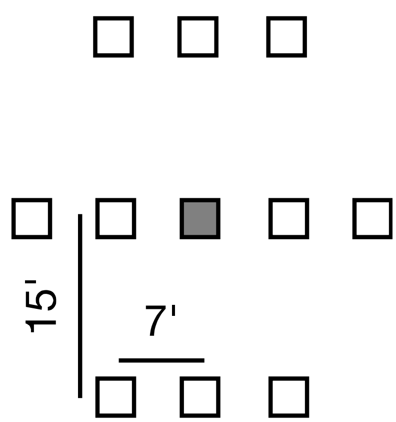
Fig. 6. NE are attracted to volatile plumes (black arrows) caused by SW wind (grey arrows), resulting in a reduction of aphid numbers in northern most trees (grey boxes). Boxes represent trees, and the black box represents the lured tree.



<u>*Are female C. nigricornis attracted to squalene lures?*</u>

Methods: During July and August 2013, field experiments were conducted to determine if female green lacewings, *C. nigricornis*, are attracted to (and not repelled by) squalene lures. Previous studies showed few females were caught (≈3.3%) in squalene-baited traps. In the first set of experiments, we placed squalene lures in specific trees, then captured adults using sweep nets and determined their sex. Our experimental unit was an 11-tree set of trees (Fig. 7), where the center tree had either a squalene lure or a control (blank) lure, where the two treatments were replicated four times each throughout the orchard. Our analysis tested if the numbers of adult *C. nigricornis* caught or *C. nigricornis* egg masses laid were significantly different between the treated and the non-treated replicates.

Fig. 7. The experimental unit consisted of 11 trees, the center (gray) tree had either a squalene or a blank lure.



Results: Similar numbers of males and females were captured on foliage near squalene lures on all four sampling dates (males 9.3 ± 0.5, females 7.5 ± 2.1). The number of egg masses laid was significantly higher in center row trees in the squalene-treated areas than the same location in the non-treated areas (10.7 versus 5.0 per block). However, the effect did not extend to non-lured areas adjacent to the row with the lure present (i.e., the top and bottom rows in Fig. 7), showing that the lures are acting on a relatively small spatial scale.

Our data shows that females are not repelled by squalene lures, similar numbers of males and females are present in foliage near lures, and females are ovipositing more eggs in the vicinity of lures. This sort of response had been previously found for the lacewing *Chrysopa oculata* where males are caught in high numbers in traps baited with the lure iridodial, but females were found on the foliage around the lure, but not in the trap. In addition, our 2011 and 2012 work with protein markers, suggests that green lacewings are quite mobile, easily moving in large numbers 200 feet or more in 2-3 days. These results suggest that effective recruitment of a generalist predator, like *C. nigricornis*, to pest hot spots with our NE lures is possible.

Executive Summary:

The organic versus conventional orchard evaluations showed that there are wide differences in the intensity of management even within each orchard type. Several of the conventional orchards used very soft programs, based on mating disruption plus virus and *Bt* for control of codling moth and leafroller. These orchards also tended to have lower pest populations, high natural enemy populations and little difference in damage from their organic comparison orchard. We noticed most of the differences occurred in our pairs of orchards where the pest control program was considered harsh or medium. In those situations, the organic orchards had a better overall balance of natural enemies and lower aphid damage. Comparisons of the diversity of natural enemies did not reveal consistent differences between the conventional and organic orchard pairs. This may have been at least partially caused by averaging the diversity over the entire season, and further analysis will be required to evaluate this factor. We collected an average of 29 taxa that attack aphids over the four orchard pairs, although an average of 2-3 taxa comprised 75% or more of the total numbers collected. The most common natural enemies were earwigs, the lacewings *Chrysopa nigricornis* and *Chrysoperla plorabunda, Deraeocoris brevis,* the syrphid *Eupeodes fumipennis*, and the woolly apple aphid parasitoid *Aphelinus mali*.

The test of using low rates (10%) of a normally disruptive material (Delegate) at the timing normally used for organic materials was highly successful. We observed no differences in damage or abundance for a broad range of pests (CM, OBLR, WAA, GAA, RAA, SJS) and natural enemy populations were similar in number to those found in the organic treatment. This sort of use does not lead to increased resistance because selection pressure for the development of resistance is lower and has the advantage of reducing costs, residues, and impacts on natural enemies. Another reason for the efficacy of this approach is that the more frequent applications used in organic programs allow less shoot/fruit growth between applications, so that there is less unprotected foliage/fruit, especially in the spring when shoot growth in a week can result in an average of three nodes (20% of the total) being unprotected (data from our other project). The change in rates and timing was done in the commercial section of WSU-Sunrise, so it is applicable to commercial settings and this appears to be a very promising technique that needs further investigation.

The work on use of NE attractants to herd natural enemies revealed three important points: (1) natural enemies do aggregate downwind of the lures and may contribute to lower pest population levels; (2) squalene, one of our more attractive lures, attracts both sexes near the lures, but only males enter the traps; and (3) lacewings laid more eggs adjacent to lures. These three points suggest that we should be able to deal with orchard pest hot spots using either HIPV or floral lures. Marking studies in 2011 and 2012 also showed movement of lacewings was common within 200 feet of a lure, so that we can attract and retain NE within a reasonable radius of a lure. We still need further work to decide which of 3-5 lures are best for suppressing aphids and how long they should remain in the field, but this also appears to be a promising tactic that we need to follow up on in the future.