FINAL PROJECT REPORT
WTFRC Project Number: CP-17-102

Project Title: Optimizing control for leafrollers and Western tentiform leafminer

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Total Project Request: **Year 1:** $78,428 **Year 2:** $81,565 **Year 3:** $38,934

Other funding sources: None

Total Project Funding:

Item	2017	2018	2019
Salaries[1]	45,000	46,800	22,725
Benefits[2]	17,069	17,751	7,817
Wages	9,600	9,984	4,800
Benefits[3]	259	270	77
Equipment	0	0	0
Supplies[4]	2,500	2,600	1,352
Travel	4,000	4,160	2,163
Miscellaneous	0	0	0
Plot Fees	0	0	0
Total	78,428	81,565	**38,934**

Footnotes:
[1] new position
[2] 34.1%
[3] 2.7%
[4] includes lab and field supplies
[5] w/in state travel

Original Objectives:

1. Evaluate different timing strategies for leafroller management using *Bt* and/or Entrust in organic orchards

2. Evaluate control strategies for leafroller in conventional orchards

3. Determine the causes of western tentiform leafminer (WTLM) outbreaks and evaluate how to optimize management to reduce effects on parasitoids.

Significant Findings:

- For the first 2 years, we put out the treatments for OBLR laid out in objectives 1 & 2, but populations in previously infested areas did not developed. We decided to drop these two objectives (with approval of Dr. Hanrahan), reduced the budget in the final year, and focused on objective 3.
- Comparison of conventional and organic orchards in all three years showed that western tentiform leafminer (WTLM) pheromone trap catches were higher in the organic blocks, and leaf samples showed all the leafmining activity was restricted to the organic blocks.
- Organic orchards where Entrust® was used in the early-mid May time period typically showed elevated levels of WTLM, often above 10 mines per leaf.
- We found that a new parasitoid, *Pholetesor ornigis*, was much more common in our Quincy and Sunrise sites than *Pnigalio flavipes*. This parasitoid had previously been reported in mid-western and eastern orchards attacking spotted tentiform leafminer, but not in surveys done in the late 1980's in Washington.
- The timing of the Entrust® application would have affected most of the parasitoid adults and also killed a significant fraction of the sap feeding stages of WTLM which are the primary host feeding target for the parasitoid *P. flavipes* and oviposition target for the parasitoid *P. ornigis*.
- Our data collection and literature search allowed us to develop a phenology model that predicts all stages of WTLM that can be included in the WSU-Decision Aid System.
- White apple leafhopper was also affected by the Entrust® applications and reached extreme levels in some of the organic orchards compared to the conventional paired orchard.
- The WALH parasitoid *Anagrus epos* was found to coincide with the emergence of the first generation of WALH, however, the second generation of parasitoids only occurred after the peak population of second generation WALH. This asynchrony means that any disruption of the first generation of *Anagrus* would allow the second generation of WALH to increase without any significant population suppression.

Objectives 1 & 2: *(1) Evaluate different timing strategies for leafroller management using Bt and/or Entrust in organic orchards (2). Evaluate control strategies for leafroller in conventional orchards*

These two objectives were not met. During both 2017 and 2018, we set up and sprayed blocks that had previously had severe problems with OBLR, but populations never developed. In season, we attempted to change plots to evaluate the different timings needed but could not find plots that were suitable. In 2018, we decided (in consultation with Dr. Hanrahan) to drop these two objectives and cut out budget to just fund the third objective.

Objective 3. *Determine the causes of western tentiform leafminer (WTLM) outbreaks and evaluate how to optimize management to reduce effects on parasitoids.*

Methods: From 2017-2019, we placed pheromone traps into orchards that used at least a single treatment of Entrust® during the early to mid-May period for control of OBLR (note this would also provide some control of codling moth). In 2017, we monitored two orchards in the Quincy area: one was an organic orchard treated with Entrust®, the other a paired conventional block across the road. We used pheromone traps, yellow panels (for parasitoids), and leaf samples collected throughout the season at weekly intervals. In 2018, we expanded into six blocks: three sites were in Quincy, two were near Sunrise Research Orchard and one site was located near Brays Landing. Two of the three Quincy blocks were Honeycrisp apples that were planted adjacent to each other; one was farmed organically and the other was farmed conventionally. The third Quincy site was a block of organic Red Delicious. The two blocks near Sunrise Research Orchard were adjacent to each other consisted of Red and Golden Delicious. One block was organic, the other was transitioning to organic. The site north of Orondo was a block of organically farmed Gala. In 2019, we set up three pairs of orchards, two pairs in Quincy and one in Brays Landing. As in previous years, we used pheromone traps, yellow panels, and leaf samples to evaluate population dynamics of tentiform leafminers. We were also able to evaluate white apple leafhopper populations that reached outbreak status in the orchard blocks in 2018-2019.

Timing of Entrust® Treatments:

Location	Date	JD	WTLM DD
Brays Landing	5/11/18	131	725
Quincy B	5/12/18	132	845
	5/24/18	144	1185
	7/4/18	185	2180
	8/12/18	224	3490
Quincy A	5/9/18	129	780
Sunrise	5/14/18	134	1000
Sunrise B	6/19/18	170	1965
	8/3/18	215	3470
Brays Landing	5/9/19	129	650
Quincy B	5/16/19	136	825
	8/3/19	215	2985
Quincy A	5/9/19	129	685

Results and Discussion:

Population trends of different stages:

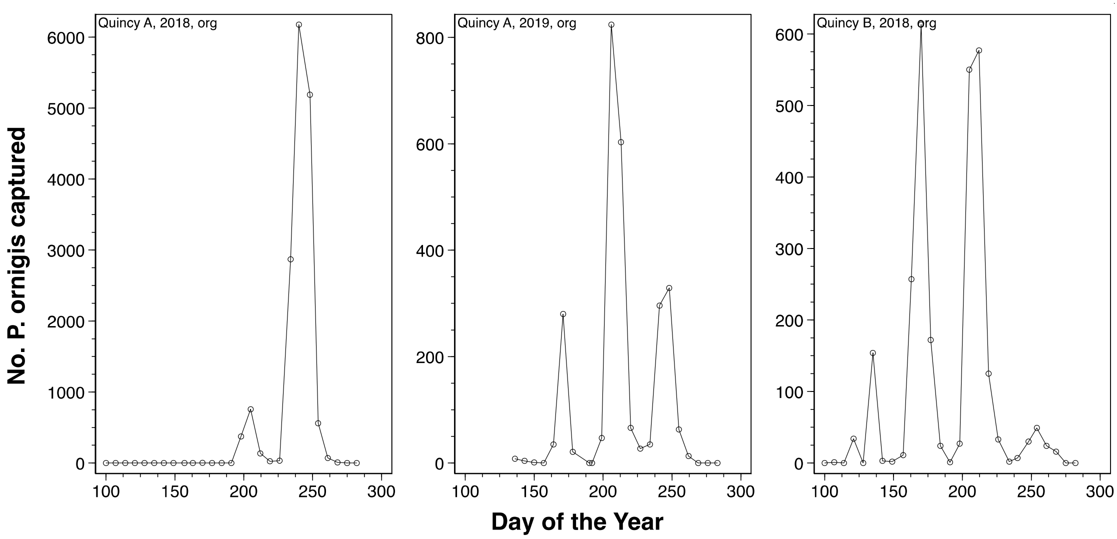
Parasitoids on yellow sticky cards. The number of parasitoids caught on yellow panels is important because it gives us not only the emergence patterns of the parasitoids, but also because it allows us to see which ones are dominant at the different sites. We expect that parasitoids will be more common in orchards where high density of leafmines are present, because the parasitoids both feed on the larval leafminers and because they are needed for maturation of the parasitoid immatures.

Bruce Barrett (a PhD student of Jay Brunner) worked with WTLM and the parasitoid *Pnigalio flavipes* in the late 1980's and showed the major parasitoid species in all the WTLM generations in Washington was *Pnigalio flavipes.* He found it constituted 85% of all parasitoid species reared.

Pnigalio flavipes prefers to lay its eggs in the tissue feeding stages (instars 4-5), and host feed primarily in the sap feeding stages (instars 1-3); the emergence of *P. flavipes* in the spring in Barrett's work was similar to the timing of WTLM adult emergence.

Our yellow panel studies in 2017-2019 showed that that *P. flavipes* was not the dominant leafminer parasitoid caught, with only 148 specimens caught at the six sites in 2019. We also evaluated how many were caught in before 1 June, which would be indicative of the potential impact of the parasitoid in early season. We found only 5 total *Pnigalio flavipes* were caught in the 11 orchards monitored in 2018 and 2019 (both conventional and organic orchards). Contrast this to 1985 and 1987 data collected by Bruce Barrett where 782 and 192 *P. flavipes* were caught before 1 June. In the entire seasons of 2018 and 2019, 1697 and 148 *P flavipes* were caught, mostly in the last generation and the majority in the organic orchard at Quincy A. The total numbers caught by Barrett in conventional orchards was 4686 and 3517, in 1985 and 1987, respectively. These statistics suggest that the suppressive effect of *P. flavipes* on WTLM currently was rather low to non-existent in these orchards compared to what historically was a major mortality source.

Fig. 1. Number of *Pholetesor ornigis* captured at the highest density sites in 2018-2019.



The most common parasitoid on our yellow panel traps was *Pholetesor ornigis* which is commonly found attacking the spotted tentiform leafminer in the eastern and mid-western US (STLM is not present in WA). This species was not reported by Barrett in his survey of parasitoids attacking WTLM in the late 1980's, so it is relatively new to the state. This species tends to emerge slightly later than *P. flavipes*, and we collected 224 parasitoids before 1 June, with the majority of them collected in a single site (194) when the sprays were on early (9 May). All season long, we collected 21,641 *P. ornigis* in our organic blocks (where leafmines were abundant) and only 615 in our adjacent conventional blocks (where leafmines were virtually non-existent, so we didn't expect to find many there). The vast majority were collected at the Quincy A site where we caught 16,624 in 2018 and 2,817 in 2019 (Fig. 1), but they were also captured at Quincy B and at the Sunrise orchard as well.

WTLM larvae and parasitoids: Leaf samples showed in all years that mines were restricted to the organic blocks – we only had 3 dates where we found any mined leaves in conventional blocks across all blocks and years. In 2018 and 2019, we found that the number of both tissue and sap feeders generally increased from generation to generation (Fig. 2). Early in the season, it is difficult to find mines, whereas during the 3rd summer generation, high levels of the two different stages of the larvae are common. Population increases from generation 2-3 averaged 17.5 fold (which is similar to lab studies show the reproductive rate/female WTLM), but varied from 6.7-32.5 fold. The number of tissue feeders per generation is always lower than the number of sap feeders as parasitism and host feeding both reduce the number of individuals that reach the tissue feeder stages (Fig. 2). The Quincy A sites (same sites used in 2018-2019) showed the populations were highest in 2018 and dropped sharply in 2019.

The leaf samples also allowed us to evaluate both parasitism and host feeding by the parasitoids at least later in the season when they become more common. In 2018, sap feeders were not parasitized to any significant degree all season long at any site (3.3%), but host feeding accounted for a significant amount of mortality (mean=53.1%) at all sites (Fig. 3). The tissue feeding larvae showed host feeding only 14.6% of the time, but 51.4% showed parasitism over the three sites (Fig. 4). Overall, these figures were similar in 2019 and parasitoid-caused mortality resulted in 60.5% reduction in WTLM larval survival. The parasitism of the larvae occurred primarily in the second and third generations of the tissue feeding stage.

Fig. 2. Number of sap and tissue leafmines in 2018 by generation.

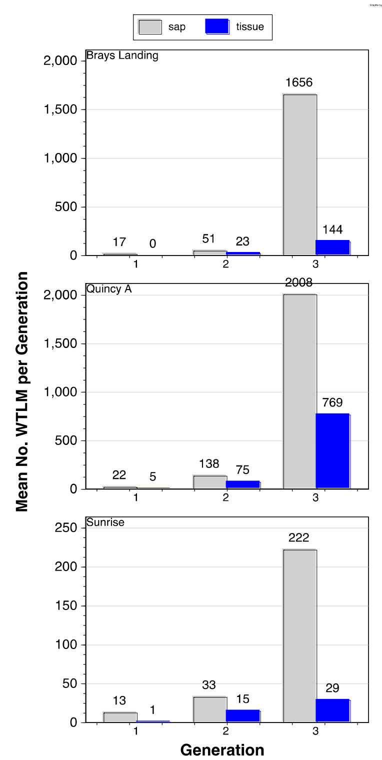


Fig. 3. Evaluation of the season trends in parasitism and host feeding effects on WTLM sap feeding stage in 2018.

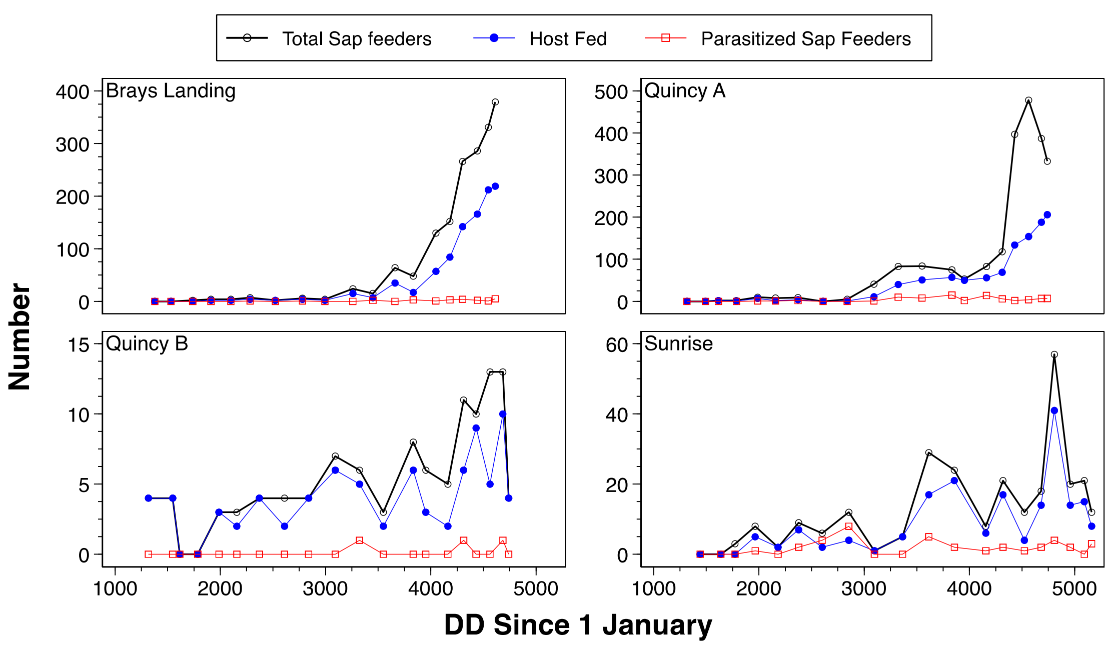
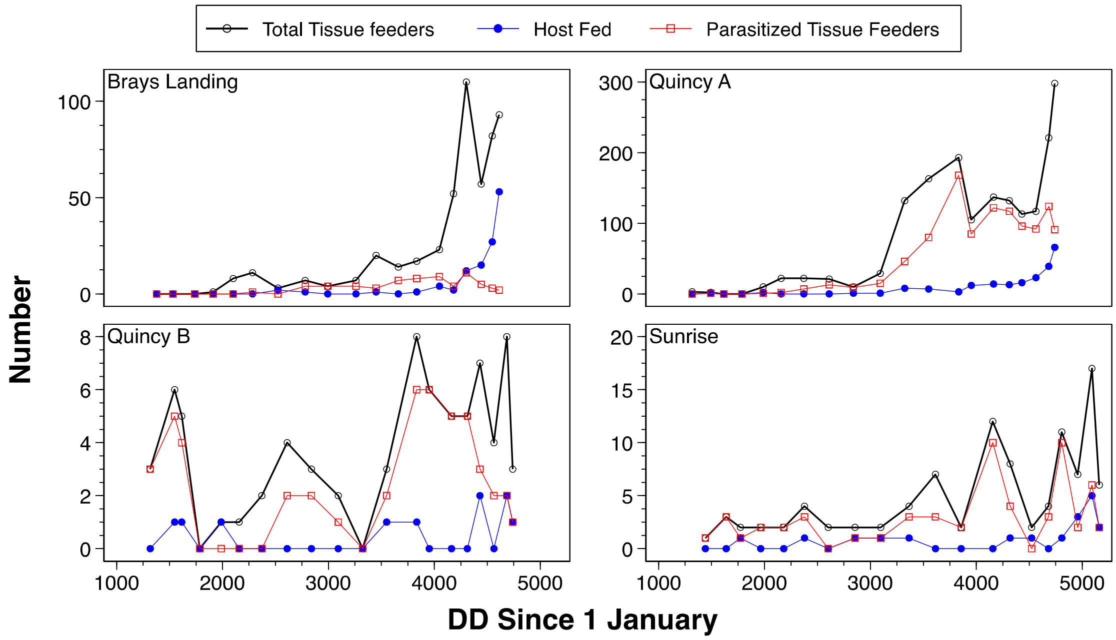


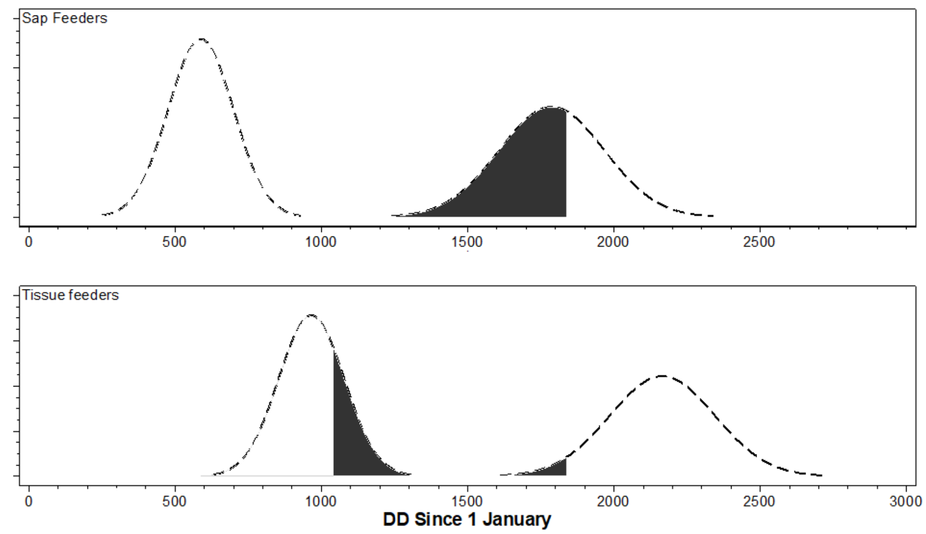
Fig. 4. Trends in parasitization and host feeding on the tissue-feeding stage of WTLM in 2018.



Summary: The effect of the early season Entrust applications happened in virtually all our orchards before the tissue feeding stages of WTLM were present. Both the adult WTLM and the adult *P flavipes* or *P. ornigris* would have been present at the times the sprays were applied and likely would have been affected by the spray program by coming into contact with the treated surfaces or potentially during the host feeding process which would have been common at that point in time. The low level of WTLM larvae of either stage at that point would require the parasitoid to be a very active searcher and thus would increase the probability that they pick up a lethal dose of the pesticide. *P. flavipes* is highly susceptible to Entrust® but Entrust® has been used to treat WTLM outbreaks, so it would be expected to provide at least short-term suppression of the larval stages of the leafminer. Likely, the early season application eliminated most of the sap-feeding larvae which would be used by *P. flavipes* for host feeding and by *P. ornigis* for oviposition and host-feeding. By reducing this resource early in the season, later generations of the two parasitoids would have to migrate into the treated orchard from surrounding blocks. It is interesting that two of the conventional orchards applied Delegate® (which is similar mode of action to Entrust®) at the same time as Entrust® in the paired organic block but did not experience outbreaks of WTLM. In both instances, roughly two weeks after the Delegate® application, the grower also applied Altacor® for codling moth control (the two sprays were applied 14 days apart). As WTLM is on the Altacor® label, it is likely that the outbreaks were suppressed by the Altacor® applications whose activity would have covered the first 62% of the second sap feeding generation and would have affected the latter part of the first tissue feeding generation and first part of the second tissue feeding generation (Fig. 5).

WTLM model: The pheromone traps allowed us to develop a phenology model that predicted emergence of the adult males in both conventional and organic orchards (Fig. 6). The model was developed using data from the conventional orchards in 2018 and 2019, and then validated using data from organic orchards in 2017 and 2019, as well as data from an attractant trap orchard in 2013, and data digitized from Bruce Barrett's dissertation (a PhD student of Jay Brunner's that worked on WTLM and *Pnigalio flavipes* in the late 1980's). The model fit well for the overwintering generation, and the 2nd and 3rd summer generation, but started slightly late in the first summer

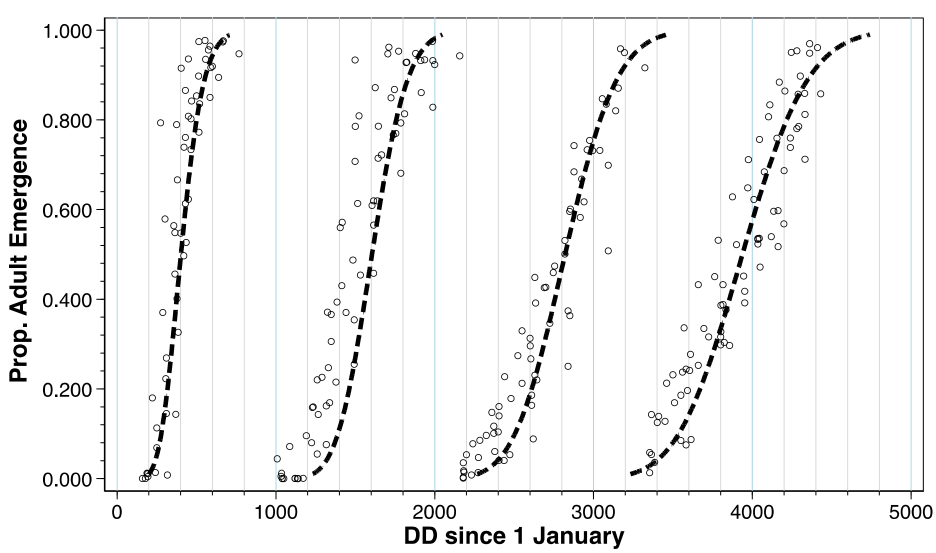
Fig. 5. The coverage of Delegate (gray area) and the two sprays of Altacor (black area) at the Quincy B conventional site in 2019. Either colored area would suppress WTLM occurring during those periods.



generation. We expect to implement this model next year on DAS.

We were also able to use some of the data in Barrett's dissertation to evaluate when the sap (early instars) and tissue (late instars) feeding larvae would be found. This data was used in conjunction with the adult catch to allow us to evaluate which stages of larvae would be found at any point in time. Our field data from the leafmines provided some data, but ultimately, we did not develop the model strictly from our sampling because there was virtually no data early in the year to evaluate the first several summer generations. Moreover, the data of Barrett added to our adult catch data predicted subsequent adult generations almost perfectly.

Fig. 6. Trap capture of male WTLM (open circles) versus model predictions (dashed lines). Model predictions generated from an independent set of data compared to the observed emergence.



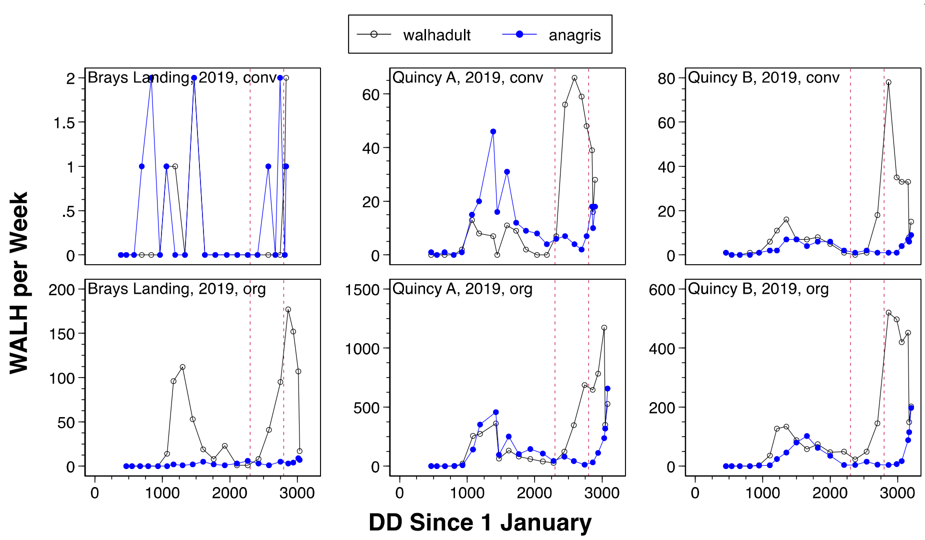
Effect of Entrust sprays on White Apple Leafhopper (WALH).

WALH population trends:

As with the WTLM, the organic orchards with Entrust applied in mid-May reached much higher levels than in the paired conventional orchards. If we just look at the 2019 data (Fig. 7), examination of just the scale of the y-axis, the organic orchards range from 7.5 to 100 times higher than paired conventional orchard. All the orchards (except Brays Landing conventional site) show a marked increase in the population level during the second generation, even though it appears that we did not complete the second generation at any of the sites.

Anagrus epos is the specific parasitoid of WALH. At the two paired Quincy sites, *Anagrus* responded to the first generation of WALH, but showed asynchrony in the second generation with population increases of *Anagrus* only occurring after the peak of the second generation WALH (around 2800 DD). The same asynchrony with *Anagrus* and WALH occurred in 2018 as well. The asynchrony in the second generation suggests that any disruption of *Anagris* in the first generation is the cause of the increase of the WALH which tends to happen right before harvest, because the second generation of parasitoids would not build up until after the WALH population had already peaked.

Fig. 7. WALH trap catches on yellow panels over the season at the three paired conventional and organic orchards in 2019.



Project Title: Optimizing control for leafrollers and Western tentiform leafminer

Keywords*:* Western tentiform leafminer, *Phyllonorycter elmaella*, WTLM phenology model, *Pholetesor ornigis, Pnigalio flavipes*, biological control, pesticide upset, *Typhlocyba pomeria*

Abstract. The biological control of western tentiform leafminer (*Pyllonorycter elmaella*) was found to be susceptible to disruption in organic orchards when Entrust was sprayed in early-mid May. These treatments resulted in very high levels of damage and also affected biological control of the white apple leafhopper, *Typhlocyba pomeria*.

Executive Summary.
Sprays of Entrust in early-mid May resulted in increased population levels at harvest of both the Western Tentiform Leafminer (WTLM – *Phyllonorycter elmaella*) and the white apple leafhopper (WALH- *Typhlocyba pomeria*). In the case of WTLM, we found very low populations of the parasitoid *Pnigalio flavipes*, which had been reported in the 1980's to be the most important natural enemy controlling WTLM. The timings of the sprays for oblique-banded leafroller, *Choristoneura rosaceana* occurred when *P. flavipes* adults had emerged from overwintering and coincided with the majority of the larval population being in the sap feeding stage. This is a critical period because the parasitoid adult was exposed to the pesticide residue, which lab studies have shown are very toxic. The pesticide also suppresses the WTLM sap-feeding larvae (instars 1-3), which restricted the ability of the parasitoid to host-feed, which is important for parasitoid females to achieve full reproductive potential. We also found that a new parasitoid, *Pholetesor ornigis*, was at very high levels at some of the Quincy area orchards. This parasitoid is best known from the mid-western and eastern apple orchards where it attacks the spotted tentiform leafminer (*Phyllonorycter blancardella*). This parasitoid was also affected because it tends to attack the sap feeding stages and parasitizes them (as well as host-feeding on the same stages). If this species has established in a wide area of Washington state, it could provide more stability in the control of WTLM, but it is also affected by the same timing as *P. flavipes*.

Our data also allowed us to develop a phenology model for all stages of WTLM and that model will be implemented on the WSU-DAS system in the next year.

The increased populations of the WALH also seem to be a result of pesticide-induced interference with its primary parasitoid, *Anagrus epos*. *Anagrus* normally has good synchrony with the first generation of WALH, however, the second generation of *Anagrus* starts to build well after the peak population of the second generation WALH population. Thus, any disruption of *Anagrus* during the first generation reduces its ability to regulate WALH populations by season's end. This results in high populations at harvest, when it becomes a nuisance pest for pickers.