Development of a Holistic Management Plan for the Apple Flea Weevil

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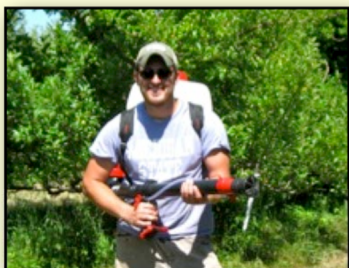

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PROJECT OVERVIEW

Apple flea weevil (AFW) is a serious emerging pest of organic apple production in Michigan. Heavy AFW infestation has caused yield losses greater than 90%. Damage from AFW typically goes unnoticed as it is easily confused with frost damage and/or sulfur phytotoxicity. AFW causes two main types of damage: adult feeding on buds and blossoms and adult and larval feeding on young foliage. In addition to the loss of fruit, extensive leaf feeding by the adults can eventually kill the tree. In Michigan, AFW has one generation per year with adults moving to the leaf layer/soil as early as July, where they overwinter. Prolonged contact with the soil makes this a likely place to target control tactics to reduce overwintering populations and hence, spring damage. Organic farmers in the Great Lakes region are desperate for a solution with some facing the possibility of choosing to convert to conventional orchard practices in order to save their trees. In order to provide these growers with holistic solutions to this pest problem, we explored the management potential of targeting AFW overwintering in the soil. To accomplish this, we compared applications of the myco-inseciticide MycotrolO®, cultivation and burning. Treatments were applied during Summer and Fall 2011 at two Michigan organic orchards. Reduction of AFW populations was measured Spring 2012. The effect of treatment on AFW population was not found to be significant at either site.

Executive Summary:

Project Rationale: *The apple flea weevil has rapidly become a serious pest of organic apples in Michigan. Adult feeding on flower buds is the most significant damage caused by this pest. Adults also feed on leaves and larva develop within leaf mines. While apple flea weevil was a recognized pest of apples as late as the 1950's, little research has been conducted on this pest since the advent of synthetic organic insecticides.*

Methods Overview: *We conducted a one and a half year study on the feasibility of managing apple flea weevil with cultural control methods and biopesticides. We tested the use of Fall burning, cultivation and application of the mycopesticide —MycotrolO®. Research was conducted at two organic farms located in Michigan. We have also conducted field experiments evaluating Spring and Summer applications of Entrust® to manage adult apple flea weevils.*

Cultural and Biopesticide Results: *MycotrolO® applications and burning did not have any impact on apple flea weevil. Cultivation may have had slight impacts.*

Non-Target Impacts of Cultural and Biopesticide Tactics: *Biopesticide applications, burning, and cultivation did not appear to have consistent negative impacts on soil dwelling beneficial insect or nematode populations.*

Entrust®Results: *Entrust® applications significantly reduced adult apple flea weevil populations when applied in Spring or Summer. Half rate Summer applications killed a similar number of apple flea weevil compared to full rate applications.*

Management Suggestions: *Based on our results we suggest that apple flea weevil be managed using a combination of Entrust® applications and Fall cultivation. We suggest that Entrust® applications should be made in the spring in orchards experiencing moderate to heavy damage in the previous summer. Applications appear to function best when applied during the "tight cluster" stage of bud development. Summer applications of Entrust® could also be used to reduce the overwintering populations. Applications targeting this generation should be applied after summer adult emergence begins and might be integrated into a codling moth or Oriental fruit moth management program. Strip cultivation within the orchard "drip-line" may also impact apple flea weevil populations if made between late July and November. Because apple flea weevil has only one generation per year our suggested integrated management program would be to cultivate each year and apply Entrust® targeting the current Summer or following Spring generations in years where the pest is causing moderate to heavy damage (3 or more feeding sites per leaf).*

Future Research: *Additional research performed at the OPM lab has addressed apple flea weevil phenology and biology, trapping and biological control. Much more work is needed on this pest before an accurate phenological model will be available. Future biopesticides should also be screened although Pyganic®, diatomaceous earth, kaolin clay and Neem products do not cause significant mortality in laboratory trials (data not included in this report).*

2. INTRODUCTION TO THE TOPIC

Apple flea weevil (*Orchestes pallicornis,* Say) (AFW), a native leaf-mining weevil, is reemerging as a serious pest of Michigan apple production (Fig 1). Apple flea weevil damage has largely been observed in organic orchards. One theory for the lack of observations in conventional orchards is the high incidental mortality from conventional insecticides targeting other pests. In Michigan organic orchards, apple flea weevil has gone unchecked for several years, with some Michigan growers experiencing >90% fruit loss.

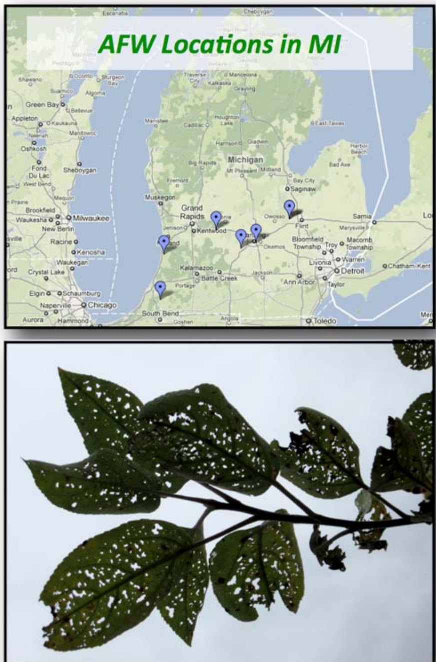


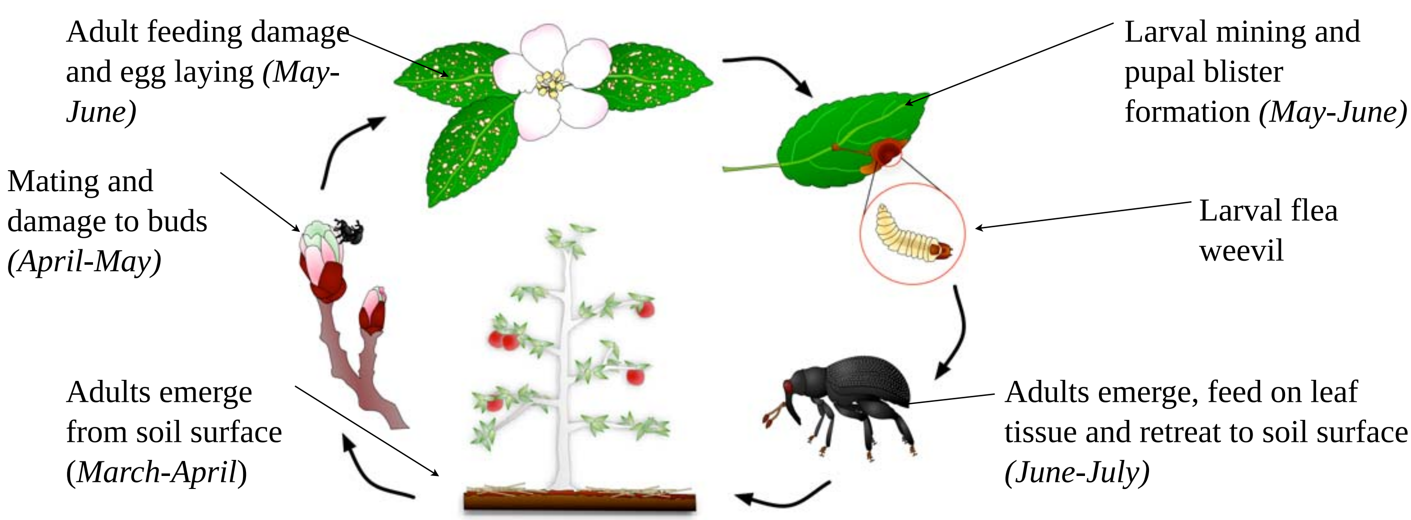
Figure 1: ***Above:*** Known AFW infestations ***Below:*** Heavily AFW damaged leaves

First identified in 1831, early literature described apple flea weevil as a sporadic pest, with great outbreak potential under certain orchard-management conditions. The introduction of broad spectrum insecticides, beginning with arsenate of lead and followed by DDT, is credited with limiting the impact of this pest in recent history. And the majority of apple flea weevil literature was produced prior to 1930.

The adult form of apple flea weevil is small (<3 mm long) and black with enlarged saltatorial hind legs (Fig. 2). Overwintering AFW adults emerge in the early spring and travel to apple tree canopies where they immediately begin

Figure 2: Dorsal and ventral views of adult AFW

APPLE FLEA WEEVIL LIFE CYCLE



2. INTRODUCTION TO THE TOPIC (CONTINUED)

mating and feeding. After mating, gravid females oviposit single eggs within or adjacent to the mid-vein of leaf undersides. Eggs hatch after seven days and emerging larvae chew through the leaf epidermis under the egg and enter the intra-dermal layers. Apple flea weevil larvae consume tissue within the leaf, constructing characteristic mines that gradually widen from the point of oviposition to the leaf margin where pupation occurs. Pupation cells, or blisters, cause necrosis of external leaf tissues (Fig. 3). The leaf margin turns brownish-black leading to frequent misdiagnosis of apple flea weevil populations as sulfur burn or frost damage. Summer adults emerge by Mid- to Late- June, feed briefly and begin to overwinter. Apple flea weevil adults overwinter in duff at the base of trees and are completely absent from the orchard canopy by Mid-July.

Figure 3: Larval blister

Economic damage primarily occurs from adult apple flea weevil adults feeding externally on fruiting buds in early spring (Fig. 4). Bud-feeding by adults can lead to termination of fruit development and heavy leaf feeding and larval mining has been reported to lead to reduced tree vigor and even death. An initial survey of OMRI approved insecticides indicated that Entrust®, a compound known to be detrimental to parasitoids and predators, is the most efficacious compound for use against apple flea weevil.

Figure 4: Damage buds

Several species of parasitoid including *Zatropis incertus* Ashm., *Trichomalus inscitus* Walker, and *Chrysocharis pentheus* Walker have been collected from apple flea weevil pupal cases (Fig. 5). Rates of apple flea weevil parasitism were significantly higher at an unsprayed research orchard than a commercially managed organic orchard (data not presented). With the success of biological control in managing other leaf mining pests, and the high observed apple flea weevil parasitism rates under no-spray management, non-chemical tactics for controlling apple flea weevil should be explored.

Figure 5: AFW pupal parasitoid.

Apple flea weevil spend over 75% of the year overwintering in the duff and top soil layers. Early researchers realized the potential for control during this phase of the apple flea weevil life cycle and tested several floor cover management strategies including flaming and cultivation. Eventually these strategies were abandoned in favor of more cost effective chemical insecticides (including lead arsenate and DDT), all of which are now prohibited. However, contemporary organic growers frequently utilize the same non-chemical soil manipulation techniques to control weeds. The objective of this study was to determine if sufficient apple flea weevil suppression could be attained through implementation of various floor cover management systems.

3. PROJECT OBJECTIVES

Objective #1: To determine the efficacy of cultural and biopesticide based management tactics for AFW adults. *Significant Revisions:* Due to poor success extracting AFW from soil samples, pyramid traps deployed in the spring were used as the primary mode of efficacy determination for this objective.

Objective #2: To determine the non-target ecological impact of organic management practices on soil arthropod biodiversity in an orchard setting. *Significant Revisions:* None.

Objective #3: Identify the most appropriate management tactic based on economic cost, pest suppression, biodiversity impact, and feasibility. *Significant Revisions:* None

4. MATERIALS AND METHODS

Location and Layout: Experiments were conducted at organic farms in Berrien County (Earth First Farms) and Genesee County (AlMar Orchards), Michigan. Treatments at the Berrien County site were applied to plots bearing mixed varieties planted in a low moisture sandy-loam. The Genesee County site had mixed apple varieties planted in heavy clay-loam. Before the application of treatments, all plots were mowed to ensure consistent vegetation height. Treatments were applied to rectangular plots including three trees and the associated inter-row drip lines. Treatments at both sites were organized in a randomized complete block design with eight replicates. All blocks consisted of a single row containing four experimental units, with a buffer tree between each.

Treatments: Our experiment consisted of three treatments and an untreated control replicated eight times in a randomized complete block design. Each experimental unit consisted of an approximately 20' long x 6' wide strip of tree row —the distance among three trees. Our three experimental treatments were: a July 2011 application of MycotrolO®, a September 2011 tillage event, and a September 2011 burning event.

MycotrolO® is a biological insecticide isolated from the soil fungus *Beauvaria bassiana* used to control soil-dwelling insects. It is believed to be more effective against mobile than quiescent insects. In order to target adult AFW entering the soil to over-winter MycotrolO® was applied earlier than burning or cultivation treatments. We applied MycotrolO® to the necessary plots at 1 quart/acre using a Solo® 400 series motorized backpack mist blower. In total, MycotrolO® was applied three times per site (1/wk for 3 wks) beginning in Mid-July and finishing by the end of July.

Cultivation was achieved using a BCS® 3000 series tiller at the deepest setting (~8"). At this setting, all vegetation had been completely up-turned after treatment (clean-cultivated).

Experimental plots receiving burning were flamed using a Weed Dragon torch kit and propane fuel tanks. Torches were used at the maximum setting but total burning time per plot varied as a result of weather, site and microclimate. Plots were considered completely burned when no above ground vegetation remained, although some root

4. MATERIALS AND METHODS (CONTINUED)

Backpack Sprayer for Mycotrol O®

BCS® 3000 cultivator

Weed Dragon ® weed flamer

Torched Orchard Floor

and stem material persisted immediately adjacent to the soil surface. Control plots received no treatments. However, to guard against artificial mortality effects from application of the MycotrolO® treatment, water was applied to the control plots using the same methods, volume and equipment as in the MycotrolO® plots.

Evaluation of Treatment Efficacy: We deployed pyramid traps in early spring 2012 to assess over-wintering mortality. Pyramid traps were installed adjacent to the center tree of each plot and checked every two weeks. Yellow sticky cards were deployed immediately adjacent to pyramid traps and were also checked every two weeks.

Treatment Effects on Soil Organisms: Soil ecosystem health is an important characteristic of ecological farm management practices and is key to successful organic production. To determine the effect of treatment on soil arthropod diversity, we collected soil samples from the center of each experimental unit (i) prior to application, (ii) 14 days after treatment and (iii) 45 days after treatment. We ran these samples through a Berlese funnel for ~7 days to extract any living soil arthropods. After extraction, we observed the abundance of key taxa of soil macro-arthropods in each sample. Macro-arthropod diversity was also examined with pitfall traps that were collected 14 and 45 days after application of treatments. To determine if any treatments negatively effected soil nematodes, we sampled for these organisms 45 days after treatment using a specialized nematode soil corer. Nematode community analysis was assessed for each sample at the Michigan State University Diagnostic Center. Diversity of the nematode community and organisms collected through soil samples and pitfall traps was determined by calculating Simpson's Diversity Index for each sample.

Note: *The following research was funded by the CERES Trust in a leveraged project.*

Spring Entrust®Trial: In Spring of 2012, the effectiveness of of Entrust®applications at two phenological stages of apple bud development was tested at two Mid-Michigan organic orchards (AlMar Orchards, Flushing and The Country Mill, Pottersville). Entrust® (80% Spinosad, DowAgro) was applied at the label rate (3oz./ acre) at Pink stage or at Tight Cluster stage. Efficacy of each timing was measured in two ways: 1.) Ten groups of ten weevils were bagged on bud bearing terminals immediately following treatment.

4. MATERIALS AND METHODS (CONTINUED)

Weevils were removed from the terminals 48 hours later. The number of surviving weevils was observed and recorded at 48 and 72 hours. 2.) Beat sampling was performed on trees within treatment rows prior to and immediately following treatment. The number of apple flea weevil captured during sampling were counted and recorded.

Summer Entrust®Trial: In the Summer of 2012, the effectiveness of Entrust®applications at full label rate (3oz./ acre) and half the label rate (1.5oz./ acre) was was tested at the same Mid-Michigan organic orchards. Entrust®was applied at the peak emergence for the Summer generation of apple flea weevil. Efficacy of each timing was measured in two ways: 1.) Ten groups of 10 weevils were bagged on bud bearing terminals immediately following treatment applications. Weevils were removed from the terminals 48 hours later. The number of surviving weevils was observed and recorded at 48 and 72 hours. 2.) Beat sampling was performed on trees within treatment rows prior to and immediately following treatment. The number of apple flea weevil captured during sampling were counted and recorded.

5. PROJECT RESULTS

Evaluation of Treatment Efficacy: None of our treatments significantly reduced the number of apple flea weevil caught in pyramid traps (F=0.15 , df=10, 21; p=0.952) although cultivation numerically reduced apple flea caught at AlMar (Fig. 6). Yellow sticky cards deployed at Earth First were destroyed in unusually heavy Spring storms. None of the treatments significantly reduced the number of apple flea weevil caught on yellow sticky cards at Almar (F = 0.763, df=10, 21; p=0.661) but once again we caught numerically fewer apple flea weevil in the cultivated plots (Fig. 7).

Treatment Effects on Soil Surface Arthropods: MycotrolO®, cultivation, and flaming did not have a significant impact on soil surface arthropods —as measured via samples and pitfall traps— at either site 15 or 45 days after treatment. We made statistical comparisons of Arachnids (spiders and their kin) ants, and springtails as well as Simpson's diversity index (Fig. 8).

Figure 6: Mean (±SEM) AFW captured in pyramid traps located in the center of each ground management plot

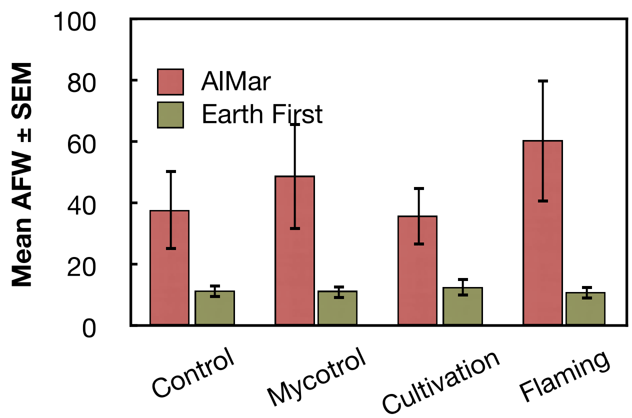
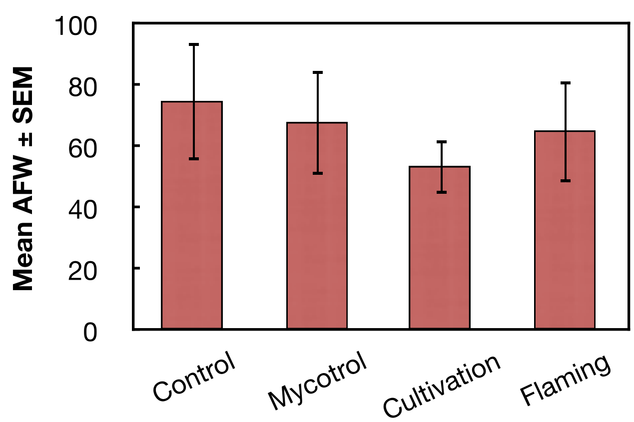


Figure 7: Mean (±SEM) AFW captured in sticky cards traps located in the center of each ground management plot at AlMar orchards



5. PROJECT RESULTS (CONT'D)

Impacts on Nematode Communities: MycotrolO®, cultivation, and flaming did not have a significant impact on nematode community structure. Earth First farm did have 5-8 times more bactieriavore nematodes compared to the AlMar site. (Fig. 9)

Spring Entrust®Trial: Entrust® caused significant mortality to bagged weevils at pink and at tight cluster timings compared to the untreated controls ($t = 8.7011$, $P < 0.001$) and ($t = 8.5905$, $P < 0.001$), respectively (Fig. 10 a). Entrust® also significantly reduced natural populations of apple flea weevil collected via beat sampling for applications made at pink and tight cluster and tight cluster ($t = 2.5979$, $P = 0.034$) and ($t = 3.4254$, $P = 0.018$), respectively (Fig. 10 b).

Figure 9: Total nematode community by feeding guild for experimental treatments at Earth First and AlMar orchards. Cultivated and flaming plots share a control.

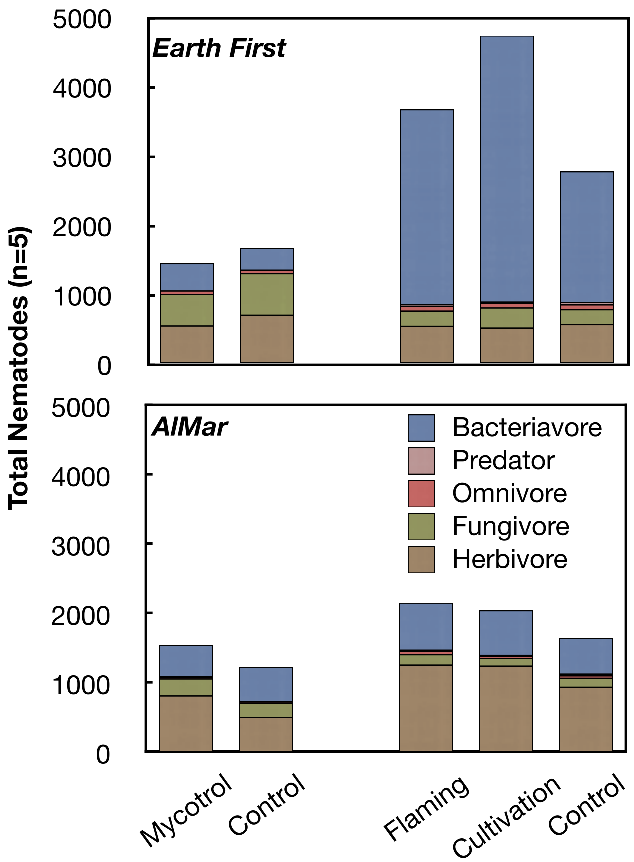
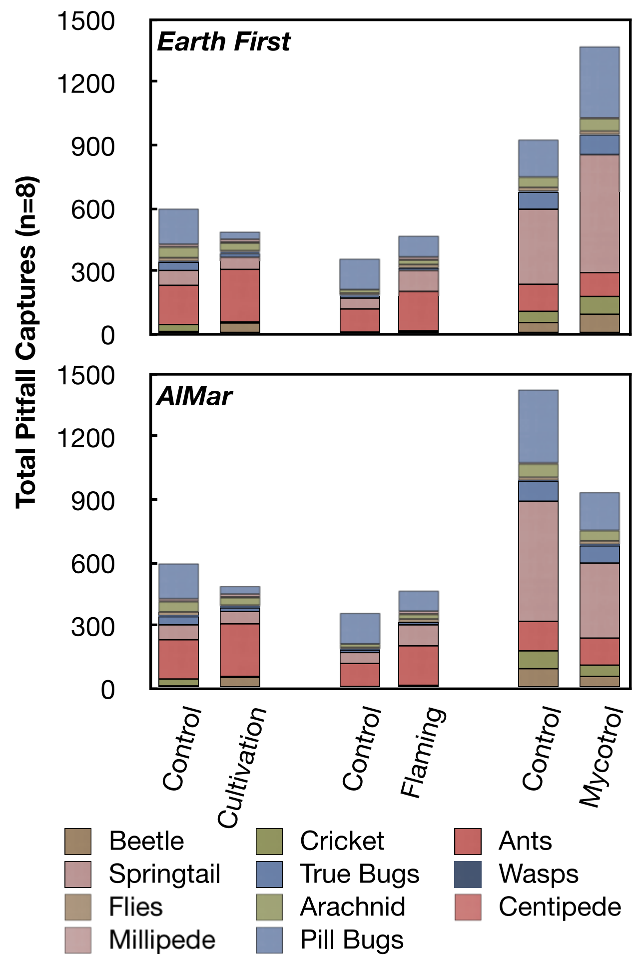


Figure 8: Total pitfall captures by feeding taxa 15 days after experimental treatments at Earth First and AlMar orchards.



Summer Entrust®Trial: Entrust® applications significantly increased mortality of bagged weevils ($F = 28.19$, $df= 2, 11$, $p = <0.005$) compared to the control. The full label rate application caused 7% higher mortality than the half label rate but this effect was not statistically significant (Fig. 11 a). Entrust®application rate did not have significant effect on natural apple flea weevil populations collected via beat sampling ($F = 1.587$, $df= 2, 11$, $p = 0.248$) (Fig. 11 b).

5. PROJECT RESULTS (CONTINUED)

Figure 10: a) Proportion bagged apple flea weevil mortality and **b)** change in wild apple flea weevil population during Spring Entrust® field trial. "*" indicates a significant reduction compared to control.

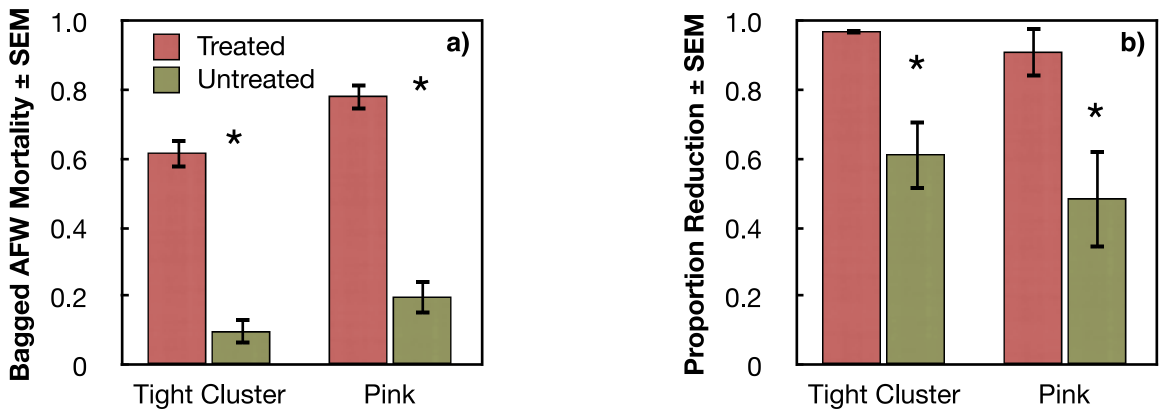
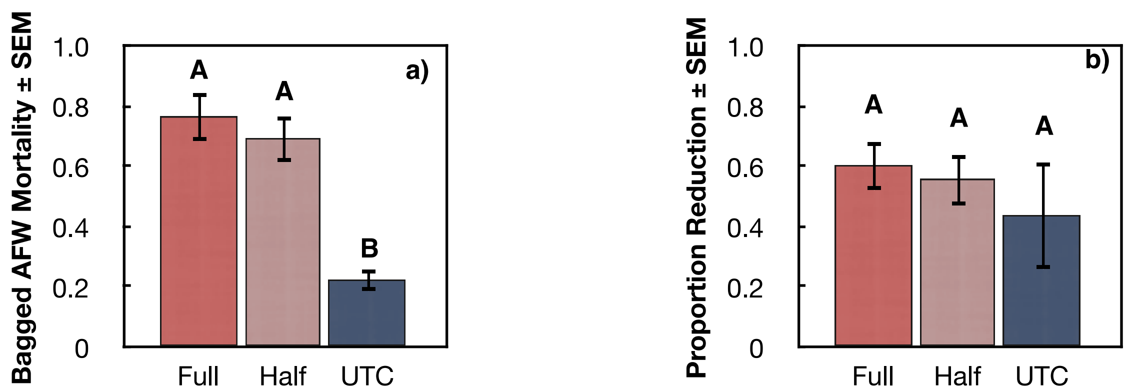


Figure 11: a) Proportion bagged apple flea weevil mortality and **b)** change in wild apple flea weevil population during Summer Entrust® field trial. Bars with differing letters are significantly different.



6. PROJECT CONCLUSIONS

1. Applications of MycotrolO®, strip cultivation and orchard burning did not significantly impact apple flea weevil, soil surface insect or nematode populations.
2. Strip cultivation may have numerically reduced apple flea weevil at the AlMar site.
3. Applications of Entrust® targeting either the Spring or Summer generations of apple flea weevil caused significant mortality of sentinel weevils and Spring applications reduced wild weevil populations.
4. Our suggested integrated management plan is to implement summer and fall strip cultivation within tree drip-lines and treat heavily infested blocks with Entrust® at either the 3 oz or 1.5 oz rate during the pink or tight cluster stages of apple bud development. Care should be used when using Entrust® to preserve pollinators and natural enemy populations —*i.e.* applications should be made at dusk.

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