Project Title: Coordinating SWD and X Disease Management

Report Type: Final Project Report

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Project Duration: 3 Years

Total Project Request for Year 1 Funding: $ 24,865
Total Project Request for Year 2 Funding: $25,800
Total Project Request for Year 3 Funding: $26,772

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Funding Duration: 2020- 2024
Amount: Beers: 18,634, 17,751, 16,890; Northfield: 72,197, 73,313, 73,817
Agency Name: USDA Specialty Crop Research Initiative
Notes: This USDA-SCRI project is a national collaboration of SWD researchers covering sweet cherries and berries. Funding is for 4 years (Sept. 1, 2020 through August 31, 2024); total amount $5,355,186.

WTFRC Collaborative Costs: none

Budget 1
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Item	Year 1: 2021	Year 2: 2022	Year 3: 2023
Salaries[1]	13,752	14,302	14,874
Benefits[2]	4,839	5,033	5,234
Wages[3]	3,900	4,056	4,218
Benefits[4]	874	909	946
RCA Room Rental			
Shipping			
Supplies	$1,500.00	$1,500.00	$1,500.00
Travel			
Plot Fees			
Miscellaneous			
Total	$24,865.00	$25,800.00	$26,772.00

Footnotes: [1]Salaries: 0.25 FTE post-doc; [2]Benefits (salaries): 35.2%; [3]Wages: $15/hr, 20 hr/week, 13 weeks/yr; [4]Benefits (wages): 22.4%.

Objectives:
(Objectives 1-5 are the objectives in the leveraged SCRI grant covering a broad range of US regions and crops affected by SWD; Objective 6 is an additional objective solely for Washington cherry and is the main focus of this final report.)

1. Implementation of best management programs for sustainable management of SWD in collaboration with grower influencers.
2. Develop economics-based decision aid tools to support the identification and implementation of profit-maximizing SWD management strategies.
3. Evaluate sustainable alternatives to insecticides for long-term SWD management.
4. Assess and reduce the risk of insecticide resistance development.
5. Develop and disseminate actionable recommendations that enable producers to optimize pest management decisions, and evaluate their impact.
6. Determine the impact of SWD controls on leafhopper vectors of X-disease.
    a. As the sustainable alternatives to SWD insecticides (Obj. 3) are currently being tested and adapted for the unique climate and growing conditions that defines Eastern Washington cherry production, Obj. 6 was altered to assess the impacts of X-disease leafhopper vector management on SWD populations in Eastern Washington cherry orchards.
    b. Given the potential horticultural benefits of Extenday and Surround WP kaolin clay foliar application and recent findings on the potential for these products to control leafhopper vectors of X-disease phytoplasma, the aim of the revised objective was to assess these products as part of an integrated approach to SWD management in Eastern Washington cherry production.

Significant Findings (Obj. 6):
There are multiple lines of evidence that soil barriers such as Extenday and weed mats will suppress SWD populations used either pre-harvest or post-harvest. The mechanism appears to be physical rather than behavioral. These methods are may also be used for leafhopper vectors of X-disease, and thus are complementary in sweet cherry IPM.
2024:
- Growth chamber experiments indicate that soil barriers (Extenday, weed mat) do not affect SWD pupation or adult emergence; however, the arena may have allowed cryptic places for pupation.
- A field experiment demonstrated that the majority of SWD fall from the fruit as larvae to seek a pupation site, and do so during the daylight hours; thus, they should be negatively impacted by soil barriers, supporting the results of the 2021-2022 field experiments.

2023:
- Behavioral disruption: Extenday and weed mat do not significantly reduce SWD oviposition in comparison to the control.
- Physiological effects: Over a 24-hour exposure period, Extenday and weed mat did not significantly reduce egg viability (lab-emerged adults post experiment) compared to the control.

2022:
- At Cashmere 1, Extenday reduced SWD adult trap counts by 58.2% in comparison to the control.
- At Cashmere 2, Extenday applied postharvest reduced SWD adult trap counts by 67.6% in comparison to the control.

2021:
- At the Wenatchee site, Extenday applied postharvest reduced SWD adult counts by 65.83% while Surround reduced SWD adult counts by 66.60% in comparison to the control. Mowed blocks were comparable or hosted more SWD than the control.
- At the Wapato site, Extenday applied postharvest reduced SWD adult trap counts by 47.34% while Surround reduced SWD adult trap counts by 37.32%.

Methods (Objective 6)

Growth Chamber Soil Barriers 2024: Based on the negative results for behavioral influences of soil barriers in 2023, we investigated their ability to cause physical disruption in 2024. The first was a growth chamber experiment using small cages to determine the effect of covering the soil, preventing SWD from reaching their natural pupation site.

This experiment was performed in February of 2024 in controlled atmosphere room as a preliminary test of the concept of a physical barrier as the mechanism of reducing SWD. Three treatments were tested: Extenday, a black plastic weed barrier, and a soil control in a 10 x 10 square container in a small cage. The test used organic red sweet cherries purchased at Safeway. Oviposition arenas were set up with 5 cherries. Each arena contained a 94 mm filter paper and a cotton ball in a plastic cup moistened with 1 ml of water to provide humidity. The cherries were exposed to 10 adult female SWD for ≈5 hours, then the females removed. The number of ovipositions in each cherry was counted, and the treatments were randomly assigned in a RCB design. Cherries were moved to the barrier arenas to incubate (larval maturation, pupation, adult emergence). The cherries with eggs were suspended over square containers with one of the three treatments in small mesh insect cages. The number of emerged adults (male and female) were evaluated after 24 days later using a sticky card and aspirator. Three variables were analyzed: ovipositions/cage (this occurred prior to treatment, and was a check on bias in randomization); adults/cage, and fertility (adults/ovipositions). Data were analyzed with SAS (SAS ver. 9.4) using a mixed model analysis of variance (PROC MIXED) for an RCB and the Tukey adjustment for multiple comparisons.

Larval Drop Field Experiment, 2024: This experiment was performed in a block of mixed tree fruit species on the TFREC home farm. The test had 10 replicates, spaced around the periphery of a 'Montmorency' tart cherry tree. SWD females were taken from a laboratory colony in the Overley lab growth room, and used in the trial when they were ca. 7 d old. The replicate branches had ≈5 undamaged cherries, and surrounding vegetation was trimmed away. A fine mesh paint strainer bag was tied to the branch, enclosing the cherries (Plate 1). Five females from the colony were introduced into the bag on 27 June, and allowed to oviposit until they were removed on 30 June.

Plate 1. Mesh bag enclosing SWD-infested cherries.

Plate 2. SWD pupa in cherry.

Twice-daily checks of the bags (roughly 12 h apart, or ca. 8 am and 8 pm) began on 3 July (6 days after the introduction of the female SWD), and concluded on 14 July. Counts on a given replicate ceased when all fruit had dropped. The bag was replaced at each collection time, and the bag and its contents were labelled and stored in a cold room to arrest development until the sample was counted. The contents were categorized by stage (larva or pupa), and whether the SWD dropped to the bottom of the bag, or were contained in a cherry (Plate 2). The number of SWD were summed over all collection dates for each replicate, and comparisons made between SWD stage (larva v. pupa), type of drop (free or in a cherry), and time (daylight vs dark). Data were analyzed with a mixed model analysis of variance (PROC MIXED, SAS 2024) using a model for a completely randomized design, and means of the key variables (drop type, collection time, and stage) were separated with the least significant difference test. The interaction between two key factors, drop type and stage, was also tested.

Behavioral Mesocosm Test, 2023: There were two primary mechanisms that would explain the trap suppression seen in 2021-2022: behavioral or physical. In 2023, we tested the behavioral hypothesis that the observed reduction in SWD trap capture in Extenday blocks was due to reflected light in those blocks disrupting host orientation behavior. This mechanism has been observed for other orchard pests such as pear psylla (Nottingham and Beers 2020, Nottingham et al. 2022). We speculated that the reflective nature of Extenday would disrupt female host-finding and oviposition, whereas a non-reflective black weed mat (providing the same soil coverage) would not. This trial was conducted in late September, providing environmental conditions conducive for improved fly survival in our experimental cage setup.

Three treatments (Extenday, weed mat, and uncovered sod control) were assessed in mesocosm cages (56 in x 23 in x 23 in screen cages, Raising Butterflies LLC, Salt Lake City, UT). Five replicate cages for each treatment were placed in three adjacent rows in a randomized complete block design at the TFREC pear orchard (15 × 20 ft spacing). The pear orchard provided an environment with the shade normally associated with mature trees, along with the temperature and RH of an orchard floor. Cages were spaced 10 ft apart within rows (Plate 3). Each cage contained two trays (20 in x 10 in plastic growing trays) of bluegrass sod (Harmony Outdoor Brands, Lakewood Ranch, FL) (Plate 2). The sod in the Extenday and weed mat cages were covered with a 56 in x 23 in rectangle of Extenday reflective groundcover or black polypropylene landscape fabric (Greenscapes Inc, Calhoun, GA) respectively. In each cage, a 1 gal plastic container holding four cherry branches was placed between the two sod trays in the center of the cage (Plate 4). Cherry branches (~1-1.5 ft in length) were sourced from an unsprayed cherry orchard at WSU Sunrise Research Orchard. Each cherry branch had five 'Sweetheart' cherries attached with a binder clip resulting in 20 cherries per cage. No other food sources or oviposition substrates were present. Adult female SWD (100/cage + 20 males) were released into each cage at 12 pm on Sept 21. They were allowed to oviposit for 24 hours before adults were removed and ovipositions were counted (Plate 5). The fruit was kept for 3 weeks in the lab to assess SWD emergence.

Plate 3. Mesocosm cages in an orchard row.

Plate 4. Cherry branches and sod trays in mesocosm cages.

Plate 5. SWD oviposition in sweet cherry.

One cage of each treatment hosted light sensors and environmental dataloggers. The datalogger (HOBO Pro v2 dataloggers, Onset Computer Corporation, Bourne, MA) was hung from the south facing cherry branch, and continuously measured temperature and relative humidity. Reflected light (measured as Photosynthetic Photon Flux Density; SQ-520 Full Spectrum quantum sensors, Apogee Instruments Inc, Logan, UT) measured reflected light. The quantum sensor was affixed to cage's ceiling, suspended over the various surfaces. Point measurements of the intensity of different wavelengths of light (Lighting Passport Essence Pro spectrometer; Asensetek Inc, New Taipei City, Taiwan) reflected by the surfaces were taken at 2 pm (21 Sept.), 9 am, and noon (22 Sept).

Large Plot Field Trials, 2021-2022: In 2021, the impacts of Extenday ground cover (Plate 6) and Surround (kaolin clay) (Plate 7) canopy sprays on SWD trap capture were compared to an untreated control. Both treatments were candidate control measures for suppression of the leafhopper vectors of X-disease. The treatments were deployed in two sweet cherry orchards near Wapato and Wenatchee, respectively. The Wapato cherry orchard consisted of 28 acres of ‘Sweetheart’ cherries (12 × 18 ft spacing) and was conventionally managed. The Wenatchee cherry orchard consisted of ~25.9 acres of ‘Coral Champagne’ cherries (10 × 15 ft spacing) and was in the first year of transitioning from conventional to organic management. The three treatments were 1) Extenday ground cover (Extenday USA Inc, Union Gap, WA), 2) Surround kaolin foliar application (NovaSource, Phoenix, AZ) and 3) an untreated control. Each treatment had 4 replicate blocks 200 ft x 12 rows arranged in a RCB design. Treatments were maintained from mid-July until early November.

Plate 6. Extenday ground cover

Plate 7. Kaolin clay spray application.

Adult SWD were monitored throughout the treatment period using a modified 32 oz plastic jar containing a lure (Scentry Biologicals Inc., Billings, MT) suspended over a water-based drowning solution (Plate 7). Each replicate had two traps, one at 50 ft and one at 150 ft from the block’s edge in the middle (seventh) row. Drowning solution was changed and trap contents collected every two weeks. Trap contents were assessed under a dissecting microscope (Leica Microsystems, Wetzlar, Germany) and the number of SWD males and females were counted. The lures were replaced every 6 weeks.

The Wapato site was similar to the Wenatchee site, except there were only 2 replicates, but with 4 traps each (at 50 feet in row 5, 100 feet in rows 6 and 8, 150 feet in row 7). The treatment deployment period was mid-July through mid-October; the block was removed in November due to the high incidence of X-disease.

In 2022, we assessed two candidate control practices (Extenday and herbicide) compared to an untreated control at two conventionally managed orchard sites near Cashmere, WA. The first orchard (Cashmere 1) consisted of 5.37 acres of ‘Rainier’ sweet cherries (9 × 15 ft spacing), and the second orchard (Cashmere 2) (Plate 8) consisted of 3.13 acres of ‘Rainier’ sweet cherries (10 × 18 ft spacing).

At each orchard, the three treatments (Extenday, herbicide, and untreated control) were replicated twice. Each replicate block was 130 ft long and 6 rows wide. Treatment blocks were set up in late May and maintained until the end of October. The herbicide treatments consisted of one preharvest groundcover application of SPUR (Clopyralid, Albaugh LLC, Ankenny, IA) on 20 May and one postharvest groundcover application of Venue (Pyraflufen ethyl, Nichino America Inc, Wilmington, DE) on 25 July. These herbicides were applied to row middles to control broadleaf weeds. At Cashmere 1, the Extenday blocks were maintained for the duration of the experiment. At Cashmere 2, Extenday was deployed by the grower across all 3 treatments from 30 May 30-27 June to improve color during fruit ripening. The Extenday was removed from all Cashmere 2 blocks by June 2 for harvest and was then re-applied solely to the designated Extenday Blocks on 15 July. As such, our Cashmere 2 analyses consist only of post-harvest comparisons.

Plate 8. Cashmere 2 site showing treatment arrangement (Yellow: Extenday; Pink: Herbicide; Blue: Control).

Monitoring for SWD adults was conducted as described for 2021, except the traps were checked weekly. Each replicate had two traps, one in the second row at 30 ft from the block's edge and another in the third row at 65 ft from the block edge.

Results and Discussion:

Growth Chamber Soil Barriers 2024: There were no differences in oviposition numbers at the beginning of the trial. After larval development and adult emergence, there were no significant differences total adults emerged (Fig. 1) or in adults/initial oviposition (data not shown).

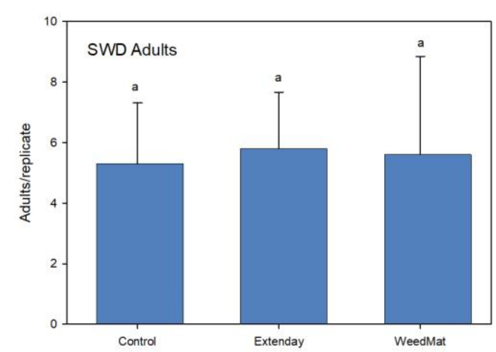

Fig. 1. SWD adults produced in three soil barrier treatments in a growth chamber.

There are several possible explanations why neither of the physical barriers interfered with adult emergence. First is that pupation occurred within the fruit, and thus the larvae never contacted the barrier. Second is the small size of the arena, and incomplete nature of the barrier (larvae seeking a pupation site could crawl under the barrier into the soil beneath, and pupate there). These results bring up two additional questions to determine if the physical nature of the barrier is the mechanism for reductions in trap catch. First is the location of pupation sites. Pupation has been observed in the fruit (Plate 1); if this is true for the majority of the population in cherry, then soil barriers should have little or no impact. However, research in berry crops indicates that the majority of pupation occurs in the soil (Woltz & Lee 2017), thus barriers should be a major impediment. Secondly is the potential for survival if the larva does drop onto one of the barriers vs the soil. This could depend on the temperature of the barrier's surface, which could vary depending on the amount of solar radiation it is exposed to (day/night, sun/shade). The first of these questions was explored in the following field experiment (larval drop experiment).

Larval Drop Field Experiment, 2024: A total of 17 SWD (larvae+ pupae) were found in all replicates at end of the experiment. There was no significant difference between the numbers of SWD that dropped directly to the bottom of the bag vs those that dropped inside a cherry (Fig. 2), although the number dropping into the bag was ca. 3.25× higher. This group represents larvae or pupae that would have dropped to the ground, and thus potentially affected by a soil barrier. Those SWD which were still in a fruit when it dropped may potentially have been protected to some extent. It should be noted that a third possible outcome (fruit retained on the tree, with pupation occurring inside it) was not found in this trial; this could be due to the cultivar, or the amount of manipulation the fruit were subject to (removal and replacement of the bags twice daily). Observations in sweet cherry orchards indicate that while the majority of unpicked fruit drop to the ground, some are retained until fall; in this case, any SWD contained in these fruits would not be subject to the influence of soil barriers.

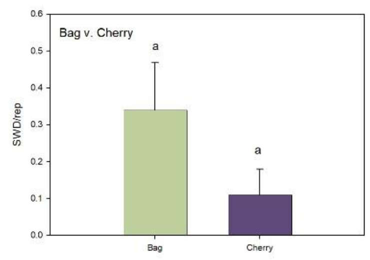

Fig. 2. Numbers of SWD dropping into the bottom of the cage vs in a cherry.

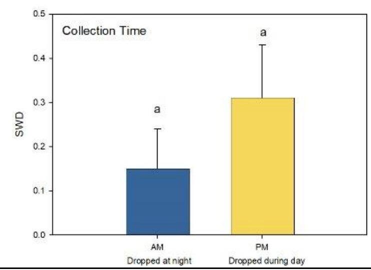

Fig. 3. Numbers of SWD dropping during the night vs during the day.

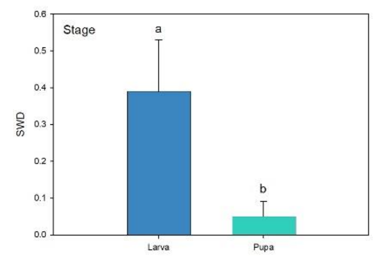

Fig. 4. Numbers of SWD dropping as larvae vs pupae.

Similarly, there was no significant difference found in the numbers of SWD in the morning vs evening collection, although about twice as many dropped during the day (pm collection) (Fig. 3). Presumably, larvae or pupae that dropped during daylight hours would be more subject to higher surface temperatures on soil barriers. We hypothesize that larvae that drop onto a heated surface of a barrier have a very poor chance of survival and will die before reaching an appropriate pupation site (soil or litter).

Significantly more SWD were found in the larval than in the pupal stage (Fig. 4). In theory, larvae would be more mobile, and better able to seek a suitable pupation site after reaching the ground. When the interaction between the drop type and stage was examined, no significant interaction was detected. However, the interaction-level means indicate that larvae dropping into the bag [ground] was the most common outcome which supports the idea that SWD will be vulnerable to soil barriers.

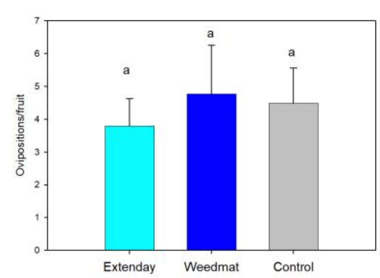

Fig. 5. SWD ovipositions/fruit in soil barrier field cage treatments compared to a control (sod).

Although statistical differences were lacking, this work supports the findings of Woltz & Lee (2017) which found that the majority of SWD pupated in the soil vs in the fruit (blueberry and raspberry). The same behavior appears to hold in cherry, although these fruits are typically larger than berries, and theoretically better able to support pupae.

Behavioral Mesocosm Test, 2023. There was no significant effect of Extenday or weed mat on SWD ovipositions/cage, with ovipositions in being comparable to control cages (Fig. 5).

As expected, Extenday had the highest levels of reflected light, followed by the grass control, with black weed mat having the lowest levels (Fig. 6). The relative intensity of red, orange, yellow, green, blue, violet, and ultraviolet light reflected by Extenday was greater than those same wavelengths reflected by the weed mat or control (Fig. 7). Although recorded temperatures were similar among the three treatments (Fig. 8A), the relative humidity in the Extenday and weed mat cages was lower than in the control (Fig. 8B).

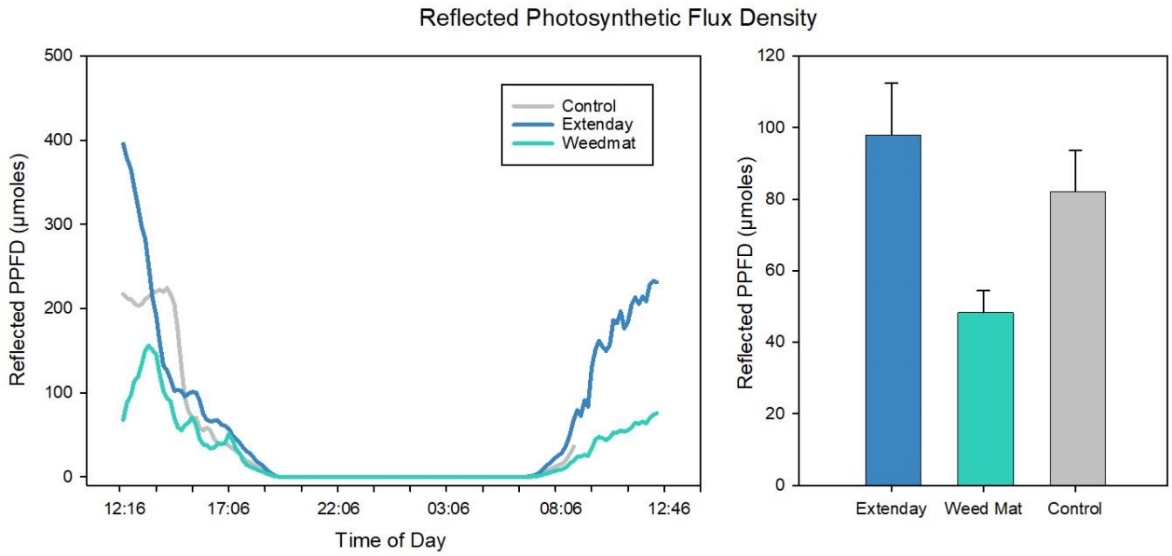

Fig. 6. Reflected photosynthetic flux density in three soil barrier treatments

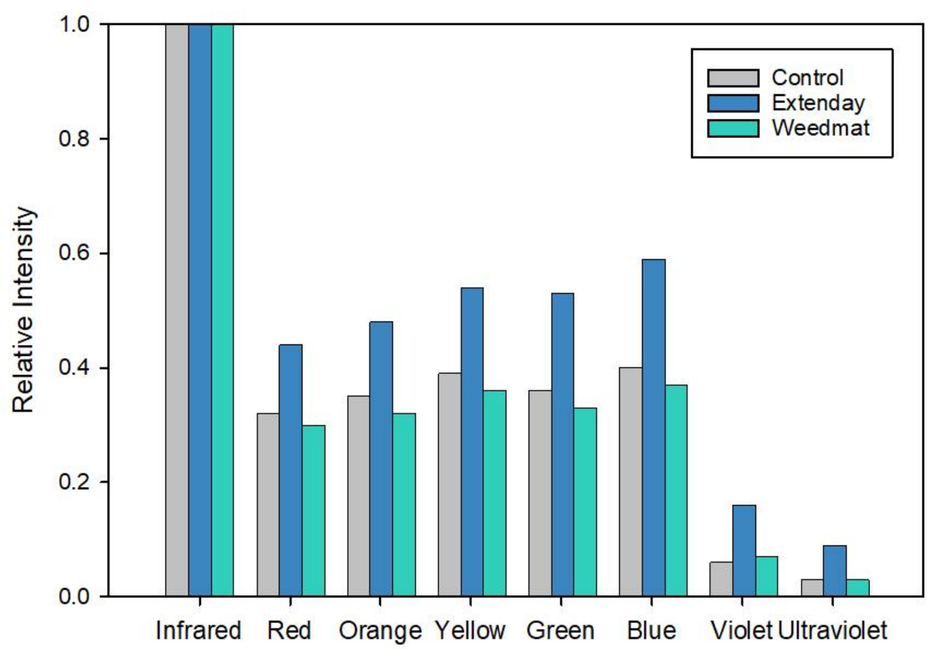

Fig. 7. Relative intensity of different wavelengths of light in three soil barrier treatments.

Although the amount and intensity of light was greater in Extenday than in the other blocks, the reflected light did not interfere with SWD egg laying behavior; this suggests that mechanisms other than reduced oviposition are responsible for the suppression of SWD seen in Extenday blocks. Prior studies with plastic mulches in raspberry noted that plastic mulches (metallic, black, and white) significantly reduced SWD larval counts in fruit as well as adult trap capture compared to the control (McIntosh et al. 2021, McIntosh et al. 2023). Those studies noted that reduced larval development in fruit might be due to plastic mulch induced changes in canopy microclimate. It is also possible that the Extenday serves as a physical barrier that prevents SWD larvae and pupae from completing their development in the soil. In raspberry, dropped larvae and pupae suffered increased mortality after 4 h on plastic mulches compared to a grass control (C. Guédot, personal communication). With leafhopper vectors, Extenday is thought to reduce trap capture by preventing access to broadleaf weeds and other ground cover hosts (Marshall et al. 2023), thus the mechanisms may be analogous for the two pests.

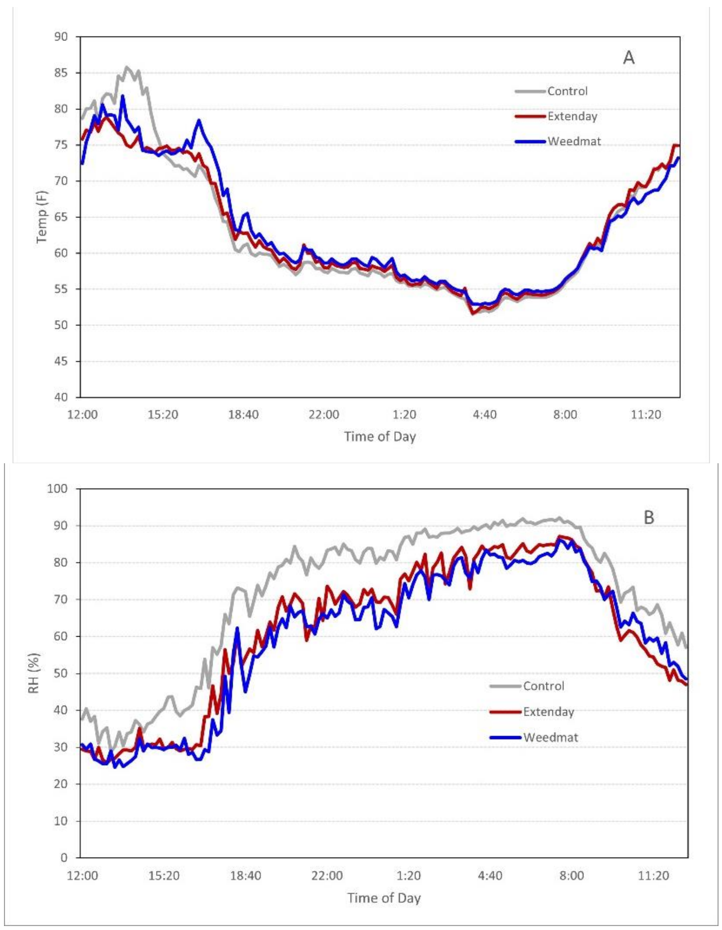

Fig. 8. Temperatures (A) and relative humidity (B) in mesocosm cages (three treatments) during the 24 h experiment.

Large Plot Field Trials, 2021-2022: In 2021, SWD counts across all treatments were initially low, likely due to the extreme heatwave events that the Pacific Northwest experienced during the summer of 2021. At Wapato, SWD counts in traps started to increase in late August while at Wenatchee, SWD counts remained low until late September (Fig. 9A, B). At the Wenatchee site, there was a significant effect of treatment on SWD collected per trap. Extenday applied postharvest reduced SWD adult counts by 72% while Surround reduced SWD adult counts by 71% in comparison to the control (Fig. 9C,). At the Wapato site, there was a significant effect of treatment on SWD collected per trap. Extenday applied postharvest reduced SWD adult counts by 47.9% while Surround reduced SWD adult counts by 41.3% (Fig. 9D).

In 2022, SWD counts in traps at both Cashmere sites remained low until mid-September (Fig. 10A, B). At Cashmere 1, there was a significant effect of treatment on SWD collected per trap. Extenday reduced SWD adult counts by 58.2% while herbicide reduced SWD adult counts by 17.8% in comparison to the control (Fig. 10C). At Cashmere 2, there was a significant effect of treatment on SWD collected per trap. Extenday applied postharvest reduced SWD adult counts by 67.6% while herbicide treated blocks increased SWD adult counts by 37% (Fig. 10D).

The results from 2021 suggest that postharvest canopy and groundcover management practices may provide a dual benefit in suppression of SWD and leafhopper vectors in cherry orchards. The 2022 trials support the use of Extenday, but not herbicides, to suppress SWD; however, herbicide use that reduces weed hosts may suppress leafhopper densities. These preliminary results suggest that these integrative management options may be viable under a wide scale of potential pest pressure.

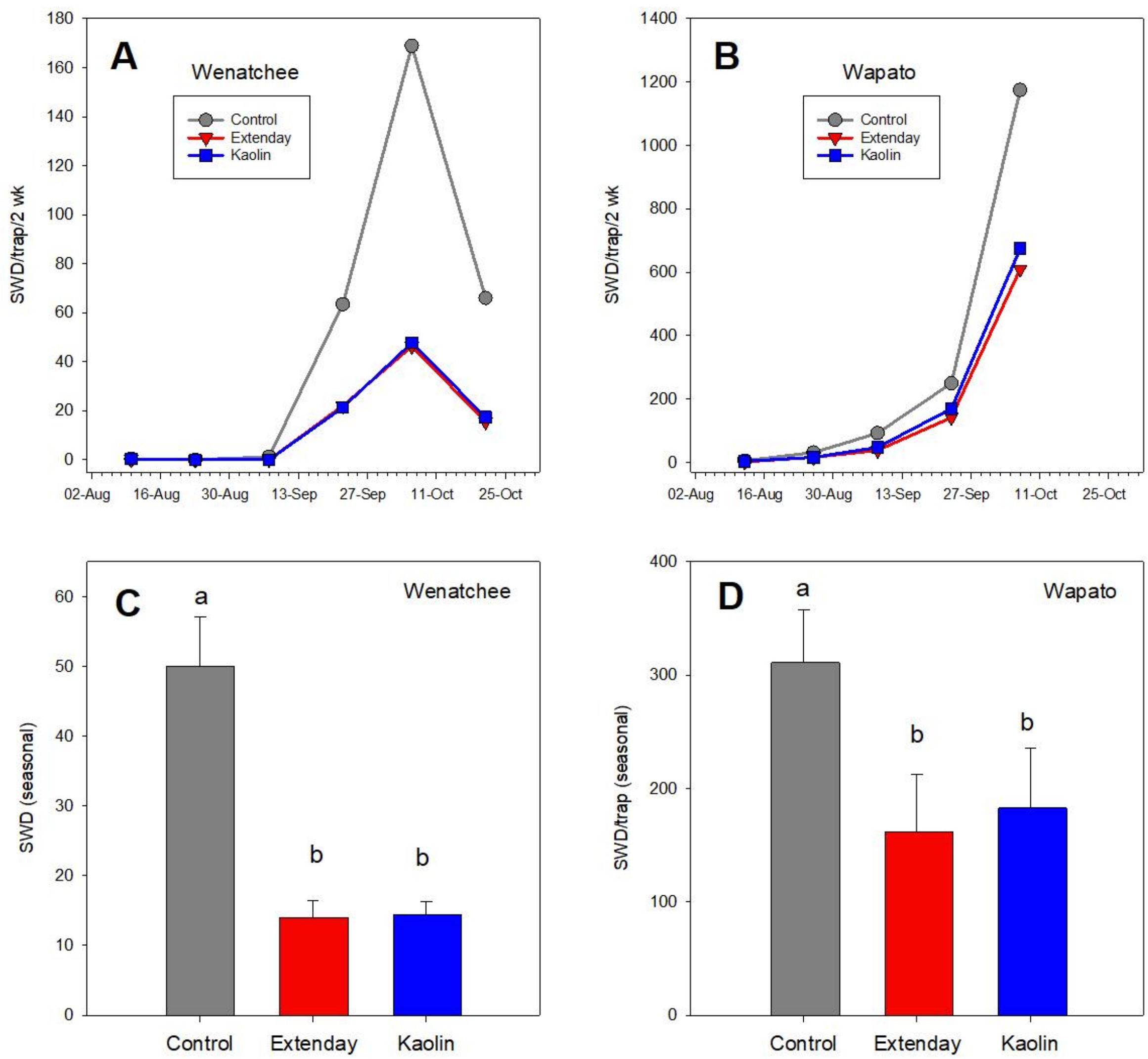

Fig. 9. SWD trap capture over time (A, B) and seasonal means (C, D) in large plot field trials, 2021.

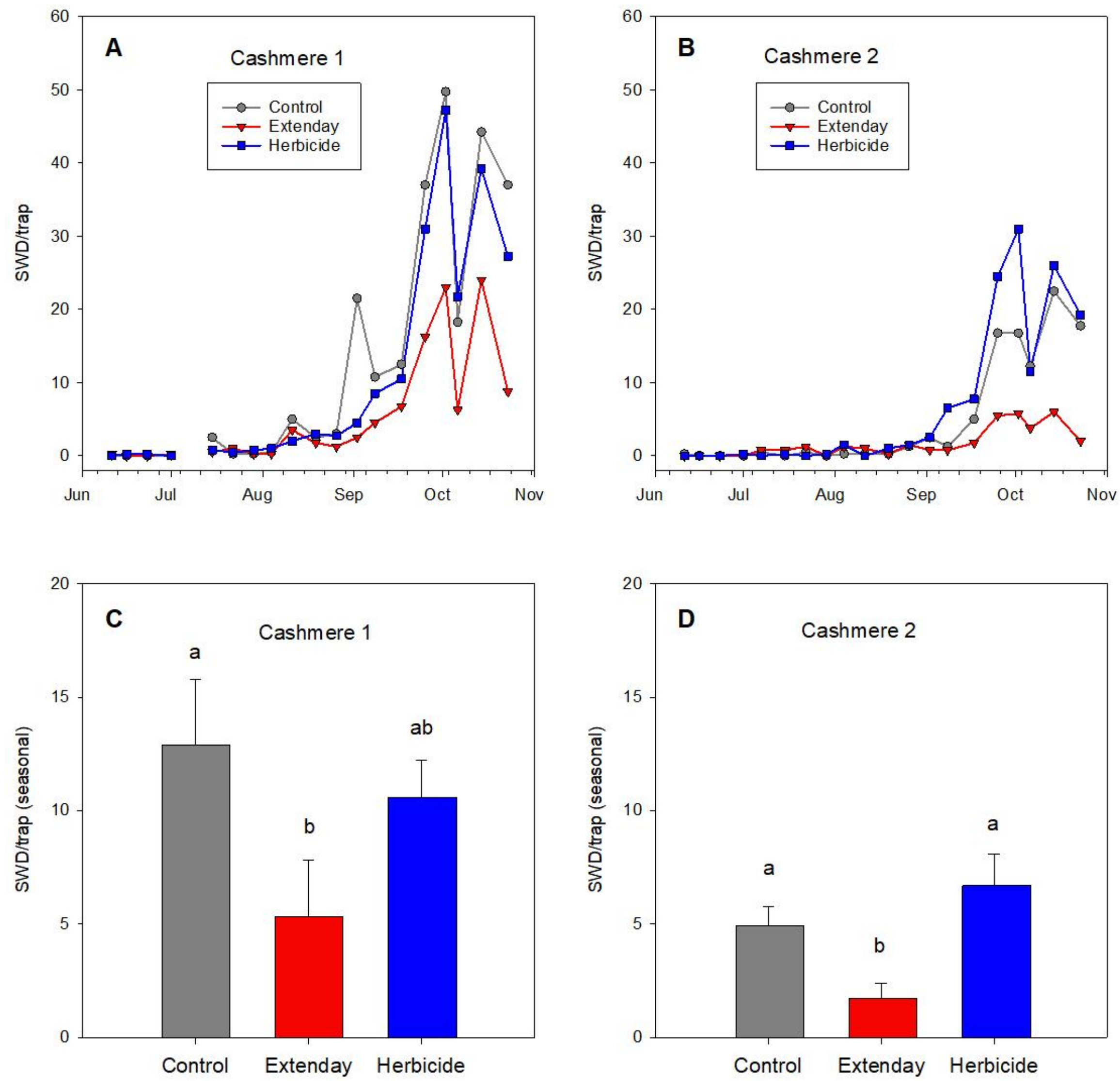

Fig. 10. SWD trap capture over time (A, B) and seasonal means (C, D) in large plot field trials, 2022.

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Executive Summary

Project Title: Coordinating SWD and X Disease Management

Key words: spotted-wing drosophila, *Drosophila suzukii*, X-disease, Kaolin, Extenday

Abstract: The detection of spotted-wing drosophila (SWD) in eastern Washington in 2010 started a new era in insect control in sweet cherry. Up until that point in time, western cherry fruit fly had been the only direct pest of consequence, because of the permanent quarantine restrictions placed on it. Counterbalancing insect pests were lethal diseases caused by viruses or phytoplasmas; the rise of X-disease in the late 2010s shifted the focus to vectors of a disease that, if left unchecked, could kill an orchard (as opposed to destroying the current year's crop). As always, growers were left facing the dilemma of managing their orchard both for the present and the future. This project sought to integrate two of the major concerns of a pest management program, specifically with the use of non-pesticide tactics.

This project examined the use of tactics were more sustainable that prophylactic sprays for SWD and leafhopper vectors which are currently the mainstay of control for these two pests. The work on SWD was done in tandem with the work on leafhoppers, with the idea of finding tactics that were effective for both. This project focused on SWD suppression; work on leafhopper vectors may be found in other projects. The field tests examined the use of a geotextile, Extenday, which was used for horticultural purposes (fruit coloration and maturation); and a postharvest spray whose original use was to reduce doubling of fruit in the subsequent year's crop (Surround, a particle film of kaolin clay). Both tactics were found to suppress trap capture of SWD in the post-harvest period (the period critical for leafhopper vector control). Subsequent tests examined Extenday and herbicides for control of broadleaf weeds in the row middles; the latter was directly more specifically at leafhopper vectors and nymphal development. The continuing theme is that Extenday worked for both pests, while herbicides (effective for leafhoppers) were not helpful in SWD suppression. Regardless, the mechanisms for the various tactics became important to understanding what they would work for, and why.

For the leafhopper vectors, both Extenday and herbicides limited access to the nymphal hosts, and disrupted the life cycle of leafhoppers in the orchard. For SWD, the mechanism was less clear. The reflective properties of Extenday might exert a behavioral influence that prevented correct orientation to the host plant for oviposition; examples of this effect in other crops had been demonstrated. In addition to possible behavioral influences, Extenday functioned as a soil barrier that could limit access to pupation sites. This physical function, however, could also be served by other soil barriers (e.g., black plastic mulch). To this end, we tested the physical effect of soil barriers, but found no effect on the smaller scale of research trials. Drilling down into the underlying biology, it would appear that larvae are most likely to drop directly to the ground (thus potentially influenced by a soil barrier), and are more likely to do it during the daylight hours, when surface temperatures are more likely to be lethal. The studies of mechanism underscore the importance of scale in research experiments. The smaller scale gives more repeatability and precision, but may miss effects that operate at a larger scale.

The effect of kaolin clay sprays remains open to question; its mechanism was not pursued for SWD suppression, in part because preharvest use (the critical period for SWD) is impractical because of the difficulty in removing it from the fruit during packing. Post-harvest, it appear to be a useful, cost-effective method of suppression and for both leafhoppers and SWD. The higher cost of Extenday may be offset by the horticultural benefits, providing an additional incentive for its use.