Ecological Intensification of Oregon Hazelnut Orchards: Restoring Native Plant Communities in Shared Ecosystems

by

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THESIS ABSTRACT

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Master of Science in Environmental Studies

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The rapidly expanding Oregon hazelnut industry offers a unique opportunity for restoring ecosystem services to private lands that were historically oak-prairie-dominated habitats. With typical orchard management consisting of bare-soil orchard floors, ecological intensification through the use of native conservation cover may directly benefit farmers and their operations, saving time and money spent on land management. With the hazelnut industry currently investing resources into young orchards, soil management with cover crops has become a contentious area of research. Looking towards the future, understanding how cover crops can be tailored towards an expanding and aging Oregon hazelnut industry is imperative. Here, I study the feasibility of large-scale native conservation cover implementation in a mature orchard, with measurements of compatibility with orchard management practices and desirable ecosystem services that farmers can directly utilize. My results show that native conservation cover can successfully suppress orchard weeds, align with important pest management timeframes, facilitate hazelnut pickup during wet harvest years, reduce chemical and mechanical inputs, and while not having a significant effect on soil moisture, significantly reducing soil temperature during summer months. This study demonstrates the feasibility and compatibility of native conservation cover to be used in commercial hazelnut systems, and the capacity at which native conservation cover directly benefits the farmer and agroecosystem alike.

ACKNOWLEDGMENTS

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III. INTRODUCTION

Increasing plant cover in intensified agricultural systems is important for soil health, below- and above-ground productivity, and the overall integrity of an ecosystem (Davis et al., 2023; Cárceles Rodríguez et al., 2022; Wittwer et al., 2017). This is true for many nut orchards in the western U.S., as many of these systems utilize bare-ground management to facilitate mechanical nut-pickup during harvest. In Oregon hazelnut systems, this bare-ground management is typically achieved through various quantities of herbicide application, flailing (mowing), and scraping (leveling, dragging, or floating) treatments. This prolonged management style can result in water contamination, degraded soils (e.g., erosion, soil compaction, reduced biological activity), and loss of understory biodiversity, which can ultimately lead to reduced ecosystem services (e.g., water infiltration, nutrient cycling) in orchards and the surrounding landscape (Babcock & Kim, 2020).

Eliminating this need for a bare-soil management regime comes with three steps: (1) reducing the weed seed bank established in orchards, (2) reducing mechanical and chemical inputs, and in place, (3) filling this empty understory space with desirable, low-maintenance, compatible vegetation communities that can complement an array of management strategies used by the majority of Oregon hazelnut farmers. My goal is to harness my knowledge of the system – both historically and present – to develop cover crops that are compatible with day-to-day orchard operations while also providing long-term sustainability and enhanced ecosystem services benefiting the farmer, orchard, and surrounding agroecosystem.

Maintaining cover in bare-ground managed orchards is important for soil health, but finding solutions that meet the needs of orchard management can be difficult. There are a plethora of cover crop types available on the market, though there are pros and cons to implementing any type in the given system. Many farmers worry about the effects cover crops will have on orchard weeds, soil moisture, nut pickup, and the cost to manage (Haring et al., in review). Native conservation cover (NCC), self-sustaining perennial cover crops that are composed of native plant species, may be a good solution for overcoming the precedent of bare-ground management in orchard systems and address these concerns. Native plants may be especially utilitarian in Mediterranean climates where herbaceous vegetation grows in the winter, spring, and early summer, but senesces in the late summer when harvest preparation is needed. In such ecosystems, like western U.S. prairies, native species are adapted to disturbance, and our past work has shown that these species are a viable alternative to many cover crop types currently used. These native species can flourish under farm operations and may enhance certain ecosystem services desirable to hazelnut farmers (Brambila et al., in review). If this type of cover crop can be a viable alternative in commercial-scale hazelnut orchards, it could be worth investing in for many farmers.

Species selection is a key component to refining any type of cover mix for nut orchards. There are key criteria for a species to be viable– they must be adapted to shade conditions on the farm, they must not interfere with farm operations (such as nut pickup and pest management), they must not harm trees (such as competing for water). NCC may fill these gaps due to native species' adaptations to the bioregion. But ideally, these NCC mixes must also enhance on-farm operations – for example, by suppressing weeds and moderating soil temperatures. Suppressing weeds may be a very compelling service offered by these mixes, as an effective conservation cover mix would both reduce mechanical and chemical inputs on the farm, helping the farmer reduce costs associated with labor and expendable inputs like herbicides and diesel, while also facilitating nut pickup during harvest.

Species mix development is a tandem consideration when understanding their combined effect on orchard health and management. For example, many studies in ecology show that diverse plant communities better resist weed invasion by filling all available ecological niches (Halassy et al., 2023). These mixes with greater diversity may be better suited for suppressing weeds, however, these mixtures may also have the capacity to better access all resources, potentially reducing soil water content for hazelnut growth and crop production. Whether this affects water available to the trees in an open question, however, as trees are tapping into a much deeper soil profile. Here I describe key questions and my approach:

IV. HYPOTHESES & EXPECTED RESULTS

Community Composition & Phenology

My first research objective was to develop a self-sustaining, NCC seed mix for a mature hazelnut orchard and evaluate compatibility with orchard management goals. These orchard management goals included compatibility with pesticide treatments and competition with agricultural weeds. Due to cover composition affecting multiple factors in weed exclusion and orchard management function, I tested the individual species that the seed mix was composed of and the community cover mix as a whole, as interspecific competition for resources vs intraspecific competition may result in different varying levels of performance and desirability for each management category. Community mixes may inhibit weed survival and reproduction more than individual species alone due to diversified niche occupation and the associated invasion resistance (Halassy et al., 2023). I hypothesize that (H1.1) NCC communities could suppress weeds effectively enough to see a decline in plot-level weed cover between year one and year two. I also expected, due to diversified niche occupation, diversified growth characteristics, and diversified phenologies, (H1.2) cover community plots would suppress weeds greater than individual species plots. Because each species has various resource acquisition and diversified niches, I hypothesized that (H2.1) certain individual species may suppress weeds better than others. (H2.2) In the first year, I expected to find the annual species, that have similar growth characteristics and phenology to weeds and would suppress weeds better than other individual species. Whereas in year two, I expected that the perennial species would suppress weeds more after a year to establish and develop. Because selected cover species must dually suppress weeds and match key points in the orchard management timeline, it is important to evaluate points of interference. If the cover is flowering at these given points, an ecological trap can occur (Hale & Swearer, 2016) Thus, (H3.1) I expected that species that are in vegetative stages (or flower in a condensed time period) would match orchard management timelines greater in accordance to sucker spraying. I expected that species that could produce viable seed prior to (H3.2) filbertworm moth spraying (which requires flailing beforehand to avoid an ecological trap for pollinators and other beneficial insects) would successfully reseed for the following year.

Harvest Nut Entrapment

My second research objective was to ensure that native cover did not entrap nuts in plant residue or plant regrowth during harvest. Crop pickup is very important to the farmer and it is imperative to design a cover crop that will not interfere with this process. Selecting species based on a variety of factors, including basal rosette shape, leaf structure, and regrowth potential is important when designing seed mixes. My overarching question was whether NCC mixes can be designed, based on vegetative characteristics, to be compatible with standard hazelnut orchard harvesting techniques. When assessing this, it is also important to consider differences in hazelnut pickup and vegetative regrowth in dry vs wet harvest years. (H4.1) I hypothesized that dry harvest years will have equal nut pickup comparing cover plots to control plots and (H4.2) wet harvest years to have slightly less nut pickup in cover plots than in control plots due to increased plant growth from pre-harvest rains.

Input Treatments

My third research objective was to understand if NCC could successfully reduce on-farm mechanical and chemical inputs compared to conventional orchard management practices (i.e. bare-ground). To evaluate this, I selected three management strategies commonly used by hazelnut farmers to measure general input quantities in the form of treatments. Reduction in these three inputs generally means less time, money, labor, diesel, and equipment wear over time. Reduction in these inputs can contribute to a healthier ecosystem and a more sustainable land management regime. I asked if conservation cover can cumulatively reduce the need for broadcast herbicide applications, flailing passes, and scraping passes over a two-year period. Broadcast herbicide applications could be reduced by having a significant amount of conservation cover take the place of weeds, flailing could be reduced by needing to flail weeds less, and scraping could be reduced by the lack of rut creation from herbicide application during spring. (H5.1) I hypothesized that NCC would reduce the need for broadcast herbicide sprays compared to conventional orchard management practices. (H5.2) I also hypothesized that NCC would reduce the cumulative need for flailing passes compared to conventional orchard management practices. Lastly, I expected that (H5.3) NCC would fully reduce the need for scraping passes compared to conventional orchard management practices. To compare these input reductions over time, I elaborated on an expected input cost for implementing and managing each cover type. I hypothesized that (H6.1) conservation cover would reduce overall ground management costs compared to conventional management, but (H6.2) is costlier to implement than conventional management.

Soil Moisture & Temperature Monitoring

My fourth research objective was to evaluate NCC's effects on soil water content and soil temperature by measuring soil moisture and temperature at multiple depths, with and without cover. My overarching questions were to ask whether conservation cover significantly reduces soil water content, and what depths are most affected by cover drawdown, and if conservation cover reduces overall soil temperature, and at which depths are most affected by cover shading. Soil moisture and temperature are important factors for regulating biological and chemical soil processes on various scales (Niu et al., 2024; Dai et al., 2020). Having ample moisture available to trees is important for crop production (Tombesi & Rosati, 1997) and temperature is an important factor influencing soil water content and plant growth (ScienceDirect, 2016). Though it would be hard to directly test whether cover competed with hazelnut trees for plant-available water, some inferences could be made based on assumptions at varying depths. I hypothesized that (H7.1) cover communities would have a negligible to slightly reduced effect on soil moisture compared with conventionally managed soils in the summer. Soil temperature would likely decrease as depth increases due to insulation from the soil profile rather than plants. As depth increases, soil temperature increasingly lags behind daily and seasonal above ground temperatures, though the topmost profile is still generally influenced by plant cover (ScienceDirect, 2016). (H7.2) I expect that conservation cover would have a slight positive effect on soil temperature at every depth.

V. METHODS

Study Area

This study was conducted in the Willamette Valley on a hazelnut farm near Gervais, Oregon. The orchard consists largely of older-stand (~60 years) *Corylus avellana var.* 'Barcelona' (hazelnut) trees intermixed with *C. avellana var.* 'Jefferson' and *C. avellana var.* 'McDonald' planted on a 6.1m x 6.1m grid. Over the course of the study, the orchard went through various levels of canopy structure transformation due to tree replacement and pruning of *Anisogramma anomala* (Eastern filbert blight). Special carefulness and consideration weren taken for plot preservation, though greater disturbance was seen in year two compared to year one of the study. Compared to other orchards in the region, this orchard experienced higher magnitudes of winter and spring disturbance due to this prolonged replacement and pruning of Eastern filbert blight.

Over the course of the two years that the study took place, temperatures at the study site varied from -6°C to 40°C and the site received 1,002.03 mm of precipitation in 2022 and 1,037.08 mm in 2023 (Weatherlink, Davis Instruments). The soil type of the study site is Chehalis silty clay loam.

Study Design

Following the hazelnut harvest in 2021, a four-acre block of plots was established in the northwest corner of the orchard. Plots were established in a checker block pattern, with each plot being separated on every side by a 'management row' for ease of access to orchard equipment. Management rows were managed in accordance with conventional orchard management practices. Out of eighty 6.1m x 6.1m meter plots, twenty plots consisted of a 'community cover' seed mix blend, twenty control plots, and forty 'individual species' plots, with five plots of the eight individual species from the seed mix. Plots were randomized inside of the four-acre block and only established if the plot had 3/4 hazelnut trees of mature status. Each plot corner was marked by a hazelnut tree (appendix figure 1).

Community cover plots were used to assess community composition, weed suppression, soil moisture / temperature, and nut entanglement data. Control plots were used to assess soil moisture / temperature and nut entanglement data. Individual seed mix plots were used to assess phenology, and weed suppression. The entire NCC block of plots was used to assess chemical and mechanical input data. A control block was set up adjacent to the large block of plots to be used to assess chemical and mechanical input data. The control block and control plots were managed in accordance to conventional orchard management practices, with exception to spraying for *Cydia latiferreana* (filbertworm moth) in control plots, which management was instead accomplished through Isomate pheromone dispensers (Miller et al., 2018).

Site Preparation & Management

After the hazelnut harvest in 2021, I prepared the site for the experiment by removing any leaves from the area with a Flory sweeper. I then broadcast sprayed glyphosate over the four-acre block with a 6% concentration to create a baseline vegetation load, utilizing recommended practices from oak-savanna/woodland restoration ecology methodology (Boyer, 2013). I waited fourteen days for the vegetation to die off and the herbicides to break down before seeding. After removing any additional fallen leaves using a leaf blower, the seeds were spread at a rate of 10g/37.16 m^2 (being the size of one plot) using a hand-held broadcast seed spreader, with the seed ratios being calculated by seed weight and mature plant size (Xerces Society and Cruz, 2020).

Mechanical treatments started in January and consisted of winter shredding (mulching pruned branches and winter leaf cover), summer flailing, and scraping (if the farmer determined it was a needed process). After these processes took place, a final flailing pass was performed to crush up any blank nuts that had fallen prior to the majority of nut drop. A month later, after most nuts had fallen, the project sites were harvested using the farmer's personal harvesting equipment (supplement 12).

After harvest, each cover type was rested during the winter, letting the NCC regrow from roots / germinate, and letting the weeds regrow in the conventionally managed plots. In year two, the cover crops filled into the management rows through mechanical dispersal as management rows were deemed unnecessary for workflow.

Cover Crop Selection

Individual species were selected for their functional compatibility traits to hazelnut life-cycle (supplemental figures 2 and 3, supplemental table 4), disturbance tolerance, competitiveness, plant height, price, and commercial availability. Species were actively removed from selection if they had an extended flowering period (to prevent life-cycle mismatch with hazelnut management), had very robust basal leaves or were bunching (to prevent harvest entanglement), or did not meet the required habitat characteristics for growth in hazelnut orchards (i.e. disturbance tolerant, shade tolerant, soil type adaptive, etc.). The perennial (P) species selected were *Camassia leichtlinii, Geum macrophyllum, Lomatium dissectum,* and *Sidalcea campestris.* The biennial (B) species selected were *Phacelia nemoralis* and *Prunella vulgaris.* The annual (A) species selected were *Collinsia grandiflora* and *Collomia grandiflora.* All species selected were local biotypes purchased from Heritage Seedlings & Liners in Salem, Oregon.

Sampling Design

Community Composition and Weed Exclusion

Vegetation cover was surveyed multiple times throughout the spring and summer months, averaging one survey every two weeks. Data was collected by conducting ocular cover percentage estimates across entire plots. Mean cover was evaluated in community cover and individual species plots for target species, weeds (in general), litter cover, and bare ground. During data analysis, peak vegetation data (when plants no longer grow fuller) from June was used to compare 2022 and 2023 results of both community cover and individual species community composition. Target species cover in community cover plots is the mean sum of every seeded plant species. The mean target cover in individual species plots is also the mean sum of that particular plant species. The mean weed cover is a sum of all species cover that was not seeded into the plot, including native and non-native species.

Phenology

Phenology was assessed by visiting each individual species plot and determining what percentage of the population was at which given life stage: germination, vegetation, flowering, seed development, seed maturation, and senescence/death/dormancy. Phenology data was surveyed multiple times throughout the spring and summer months, averaging one survey every two weeks.

Harvest Nut Entrapment

In 2022, nut entrapment was surveyed in ten community composition plots and ten control plots. A $1m^2$ quadrat was set in the middle of the plot where the harvester collected nuts from two hours prior. Inside each quadrat, quality nuts entangled in vegetation or plugged into the soil were collected. Blank and shrivel nuts, nuts attached to husks, and older nuts from previous harvests were removed due to their likelihood of being ejected from the harvester based on weight or surface area. In 2023, the same methods were used, though the survey was expanded to include a sweeper survey. In this survey, a $1m^2$ quadrat was laid in the middle of the tree row, on the North side, where the sweeper paddles extend to, and nuts were collected based on the criteria listed above. In 2023, harvester data was also collected, but expanded to include twenty seed mix plots and 20 control plots.

Input Treatments

Mechanical and chemical treatment inputs were tracked in accordance with how many iterations were performed over the course of the year to the given cover type. Herbicide sprays were accounted for if either cover type received a broadcast herbicide spray. Spot-spraying weeds or hazelnut tree suckers did not count as a broadcast herbicide application. Flailing and scraping passes were accounted for if the cover type received an entire pass, one pass being defined on an axis (i.e. North to South, up and down the row). All three treatment types were determined effective by the land managers, ensuring that the minimum cumulative treatments in each treatment type met the overall expectations for harvest preparation regardless of cover type. Economic data was elaborated and based on the cost to perform each activity, accounting for input costs of herbicides and labor performing each activity. Herbicide cost was based on the average concentration of glyphosate used to spray each cover type (3 quarts per acre) and current market value (~$8/quart). Labor cost was assessed using current the minimum wage for rural areas in counties in the Willamette Valley ($14.20/hr) (Oregon Bureau of Labor and Industries, n.d.). Fuel usage was not accounted for.

Soil Moisture & Temperature

Twelve semi-permanent soil moisture sensors (Sentek Drill & Drop) were installed in six community composition plots and six control plots. The top of each probe was set 5cm below the soil surface to prevent probe destruction from mechanical treatments. Each probe measured temperature and soil moisture at the following depths: 5cm, 15cm, 25cm, 35cm, 45cm, and 55cm, respectively adding 5cm to each depth to account for probe set depth. The probes automatically recorded temperature and moisture data points every 30 minutes from mid-May until flailing in mid-July. Data was stored internally, with data uploads to the server site occurring every two weeks.

VI. DATA ORGANIZATION & ANALYSIS

I used ‘R’ version 4.3.3 to process and manipulate all raw data, visualize all figures, and calculate all statistics. To test Native Conservation Cover’s ability to perform in the orchard system, I fit a linear mixed model with cover type as an explanatory variable. I compared data from each category of the questions section: community composition, phenology, soil moisture and temperature, nut entrapment, and input treatments. Each category is a respective response variable aside from input treatment evaluation, which was not fit to a model.

For the community composition data set, I created two models to evaluate success of target cover compared to weed cover performance. First, I evaluated the abundance of target species (individual target species, community mix target cover, and control) as the explanatory variables. Secondly, I compared the abundance of weed cover with the same explanatory variables (individual target species, community mix target cover, and control). This design showed whether certain target species or the community mix performed better than the other, and which target species or community mix excluded weeds more than the others. When comparing target cover to weed cover for both individual species and the community mix, I calculated statistics using Welch’s two-sample unpaired t-tests. When calculating the mean change of target cover or weed cover year-to-year, I used Welch’s two-sample paired t-tests.

To test nut entrapment, I compared conventional management (bare-ground) to NCC. I calculated these statistics using a Welch’s two-sample unpaired t-tests to compare mean nut loss across cover type by year. I did not compare year-to-year data by cover type due to environmental differences.

To test soil moisture and temperature, I calculated my statistics using a representative interval of the last ten days of data collection (7/7/23 - 7/17/23). I compared conventional management to conservation cover for both data sets, using a two-way ANOVA and then a post-hoc analysis with a Tukey HSD.

Statistics were not calculated for phenology and input treatments due to the nature of the data sets.

VI. RESULTS

Community Composition and Weed Exclusion

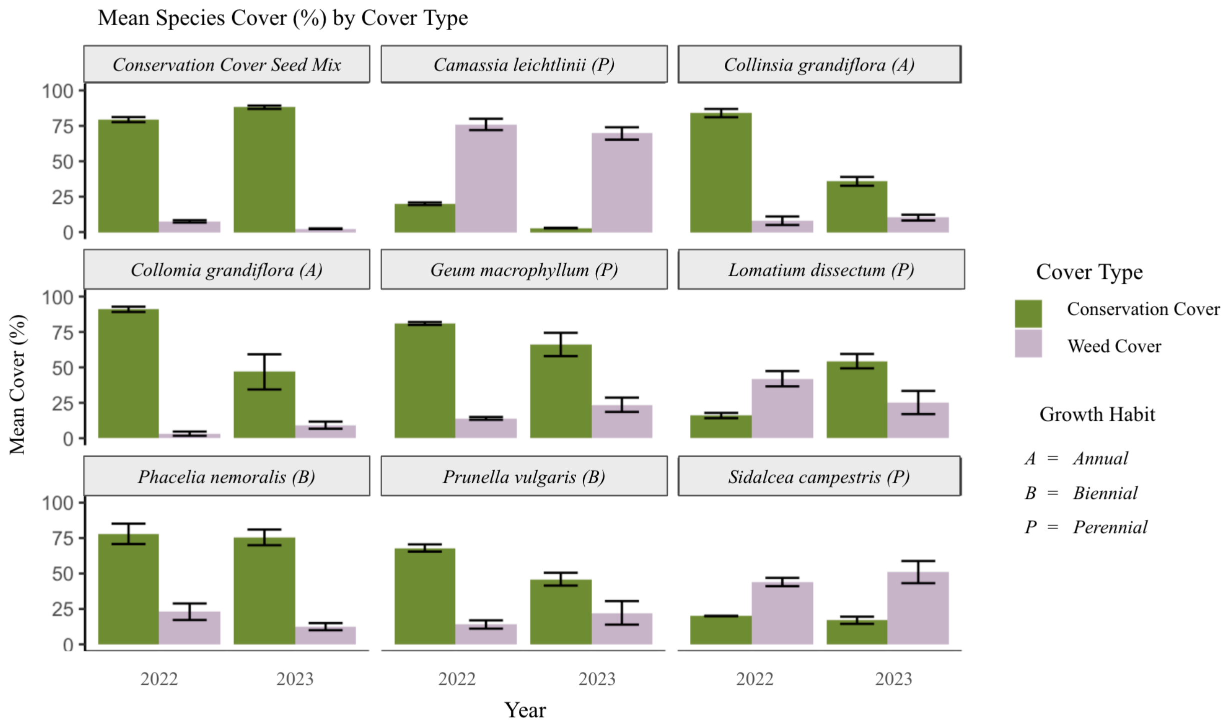


Figure 1 *- Mean percent cover of all plots types comparing target cover to weed cover during 2022 and 2023. The top left panel represents mean conservation cover across community plots. Every other panel represents individual species plots comparing target cover to weed cover. Bare ground cover and litter cover were observed but not included in the figure. A table of p-values can be found in the supplement (table 5).*

Conservation cover in 2022 averaged 82.35% across all twenty community plots, whereas weed cover averaged 6.05%. In 2023, conservation cover increased to a mean of 88.10% ($p = 0.003$) and weed cover decreased to a mean of 2.35% ($p = <0.0001$). These findings support my hypothesis (H1.1), displaying that NCC communities can significantly suppress weeds year to year.

Cover in single-species plots varied from year to year, with a general trend (excluding *L. dissectum* (P), *P. nemoralis* (B), and *S. campestris* (P)) of decreasing conservation cover and increasing weed cover from 2022 to 2023. Mean *L. dissectum* cover significantly increased from 2022 to 2023 and mean *P. nemoralis* (B) and *S. campestris* (P) cover or weed cover did not significantly change from year to year. *C. leichtlinii* (P) and *S. campestris (P)* were planted as bulbs and plugs, respectively, thus they should not be evaluated for weed competition in the same light. These findings support my hypothesis (H1.2), displaying that community plots would suppress weeds greater than all other individual species plots year to year. The only contender to as good of cover maintenance and weed suppression is likely seen in *P. nemoralis* (B) plots, where the general trends are similar. This supports my (H2.1) hypotheses, showing that some species, like *G. macrophyllum* (P) and *P. nemoralis* (B), may suppress weeds better than other species, like *Collinsia grandiflora* (A) and *P. vulgaris* (B), when seeded by themselves. I hypothesized that (H2.2) annual species would suppress weeds better than perennials in year one, and perennials would suppress weeds better in year two, though there is no distinct trend across life habit, and is entirely species reliant.

Phenology

Key management points for each phenologic stage were flowering and sucker spraying, and seed maturation and filbertworm spraying. Management slightly differs between years based on orchard phenology, but events are generally completed within two weeks each year. Results for this component were evaluated categorically. While sucker management was more flexible and largely dependent on farmer discretion (figure 2, blue triangle), filbertworm management was more of a hard deadline (figure 2, red circle), leaving little room for seed maturation to take place on a flexible timescale. In each year, peak flowering phenology happened in between sucker management timepoints and filbertworm management happened roughly about the same time that seed maturation for many species occurred. Flowering phenology for all species categories was largely the same but is most likely this way due to seed selection and filtering criteria. This supports my hypothesis (H3.1) that species that flower in a condensed time period would be best suited for sucker spraying timeline match. In 2022, not as many species went to seed, but seed maturation for annual species was effectively completed prior to filbertworm management, ensuring that the farmer could flail prior to spraying (figure 2, gray dash).

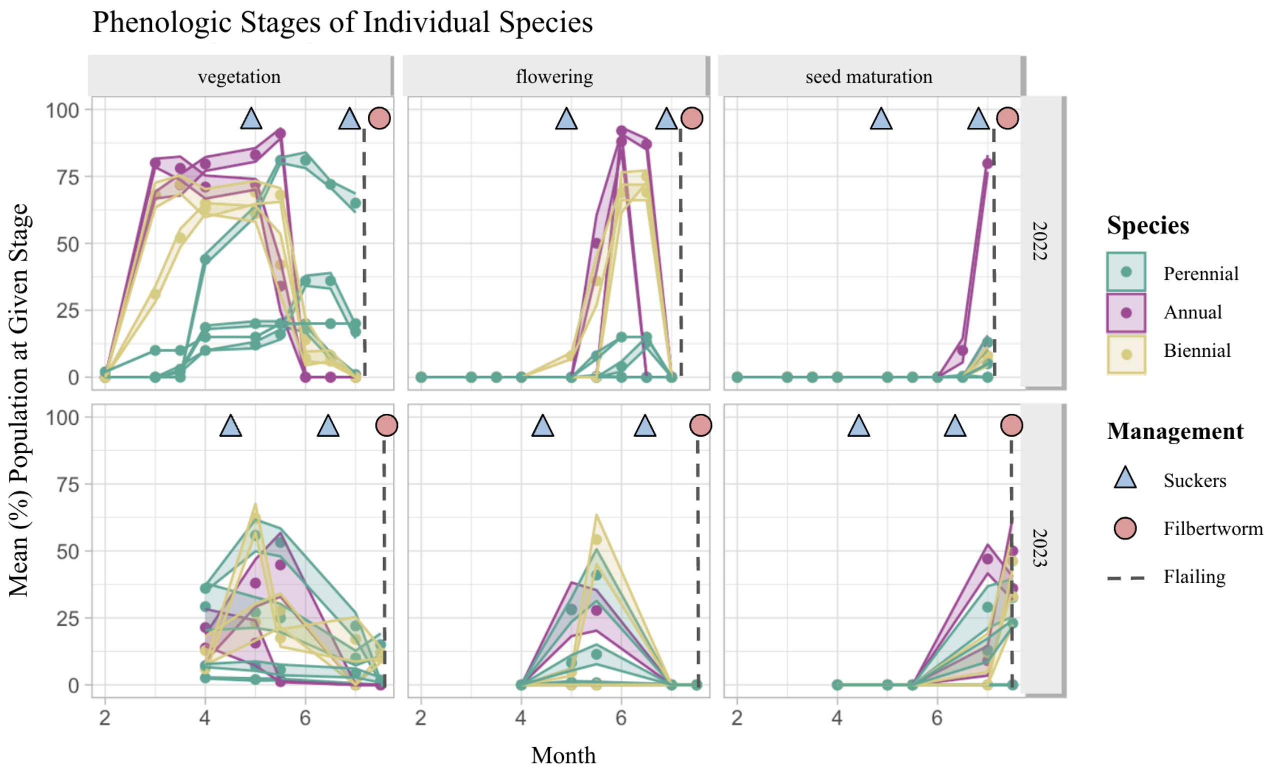


Figure 2 - *Phenological stages of individual species across both 2022 and 2023, broken up into three primary stages: vegetation, flowering, and seed maturation. Individual plant species are colored by annuals (magenta), biennials (yellow), and perennials (teal). Colored shapes indicate time of month in which a management activity took place, with sucker management as a blue triangle and filbertworm management as a red circle. The flailing deadline (gray dash) is also included to indicate when cover was mowed down prior to filbertworm management. Characteristics such as germination, first flower, last flower, and dormancy/death/senescence were evaluated but excluded from this visualization.*

In 2023, annual species effectively went to seed well before this time point, perennial species cut it close but completed seed maturation, and biennial species went to seed last. Some biennial species may not be fit for this rigorous timeline, though given preliminary cover data from 2024, it seems these species did not need to fully mature before being flailed down. This supports my hypothesis (H3.2) suggesting that species that are able to go to seed prior to filbertworm management will have success in reseeding for the following year.

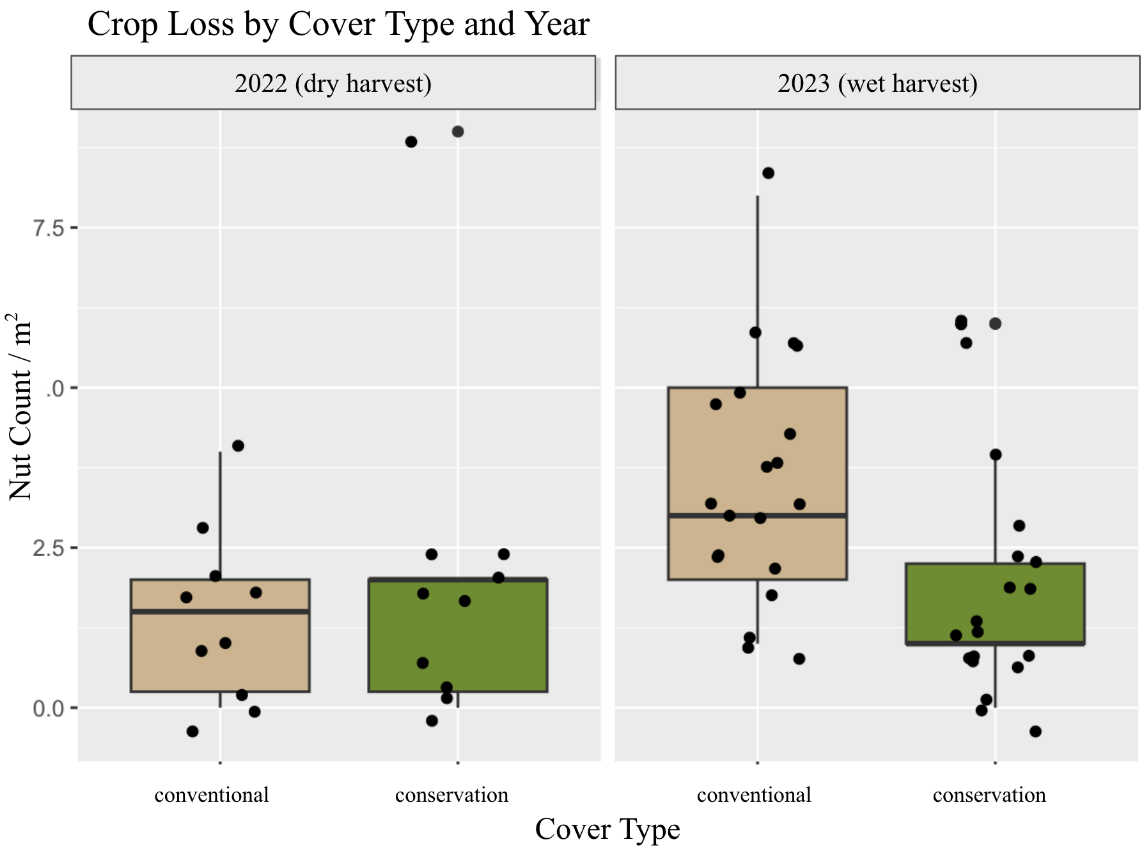


Figure 3 *- Crop loss, counted by nuts leftover after harvest per square meter, by cover type and year. Conventional management is in tan and conservation cover is in green. Data represented is collected in the harvester row. Sweeper data can be found in supplement figure 7.*

Nut entrapment data was collected in the fall of 2022 and 2023, with differing harvest conditions each year. Crop loss in dry years (2022) was comparable, with no significant difference between cover types. In a wet harvest year (2023), crop loss in conservation cover was significantly less than crop loss under conventional management, with a mean reduction in crop loss of 1.5 nuts per m^2 ($p = 0.0204$). This supports my hypothesis that (H4.1) dry harvest years would have equal nut pickup comparing cover plots to control plots, as results from nutpickup between the comparison groups were insignificant. I also hypothesized that (H4.2) wet harvest years would have slightly less nut pickup in cover plots than in control plots due to increased plant growth from pre-harvest rains. These findings do not support my hypothesis, but instead shows that conservation cover can facilitate nut pickup in wet harvest years.

Input Treatments

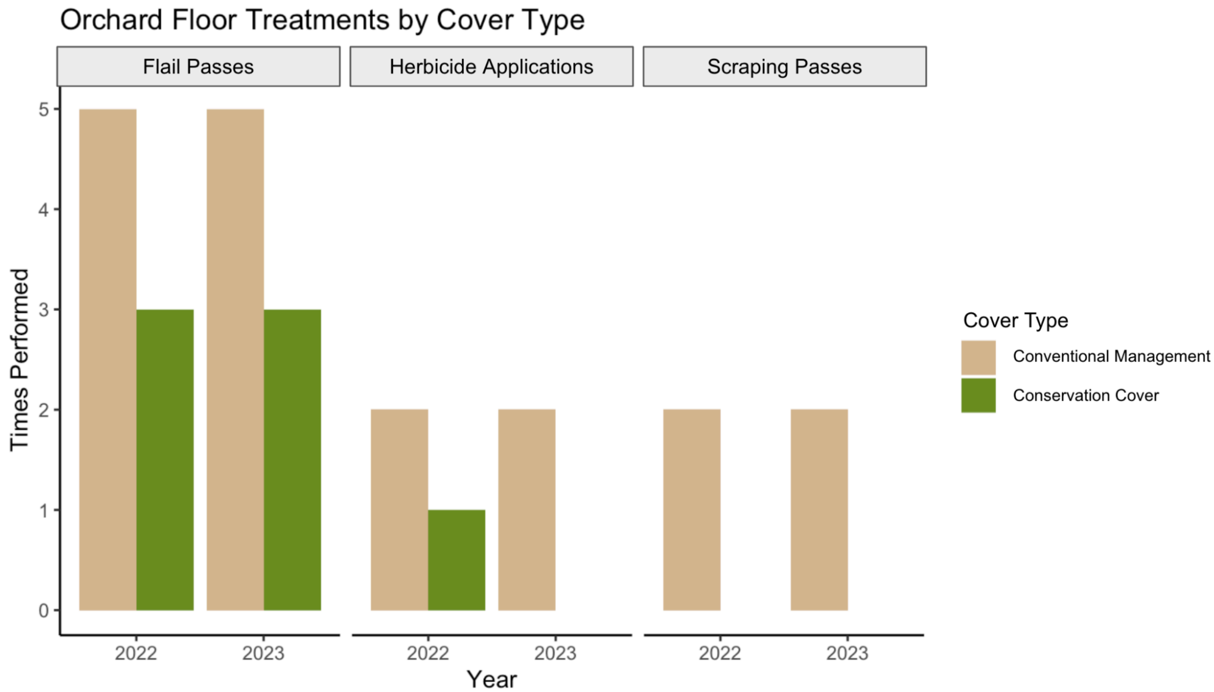


Figure 4a- *Mechanical and chemical orchard floor treatments by cover type. Treatments were measured in the amount of time each activity was performed by cover type in both 2022 and 2023. In tan is conventional management and in green is conservation cover.*

In both years of data collection, conservation cover reduced the overall number of herbicide applications, flail passes, and scraping passes. Herbicide applications were reduced by one in 2022 and two in 2023. In 2022 and 2023, flailing passes were reduced by three in conservation cover compared to conventional management. In both years, scraping in the conservation cover block was also reduced by two passes compared to the conventional management block, with conservation cover negating the overall need to scrape altogether.

I translated this data to a forecasted economic analysis comparing conservation cover and conventional management side-by-side, evaluating cost to implement and manage a ten-acre block over a five year period. For year one, the cumulative total and yearly total for each cover type is the same, with conventional management estimated at $707.10 and conservation cover at $15,673. This high value for conservation cover is due to the price of the seed mix, with an estimated input cost of $1,500 / acre. From years two through five, input costs remain the same for conventional management, accruing an additional $707.10 each year to a cumulative total of $3,535.5 at the end of the five-year period. Input costs for conservation cover are forecasted to reduce in years two through five, accruing an additional $68.10 each year to a cumulative cost of $15,945.4 at the end of the five-year period. This data supports my hypotheses (H6.1) suggesting that conservation cover will reduce overall management input costs, but (H6.2) be costlier to implement.

	Year 1		**Year 2**		**Year 3**		**Year 4**		**Year 5**	
	CM	CC	CM	CC	CM	CC	CM	CC	CM	CC
Seed Cost	$0	$15,000	$0	$0	$0	$0	$0	$0	$0	$0
Herbicide Labor	$56.80	$28.40	$56.80	$0	$56.80	$0	$56.80	$0	$56.80	$0
Herbicide Cost	$480	$240	$480	$0	$480	$0	$480	$0	$480	$0
Flailing Labor	$113.50	$68.10	$113.50	$68.10	$113.50	$68.10	$113.50	$68.10	$113.50	$68.10
Scraping Labor	$56.80	$0	$56.80	$0	$56.80	$0	$56.80	$0	$56.80	$0
Yearly Total	$707.10	$336.50	$707.10	$68.10	$707.10	$68.10	$707.10	$68.10	$707.10	$68.10
Cumulative Total	$707.10	$15,673	$1,141.2	$15,741.1	$2,121.3	$15,809.2	$2,828.4	$15,877.3	**$3,535.5**	**$15,945.4**

Table 4b *- Forecasted operational cost for cover type management over a five-year period. Conventional management (CM) is displayed in tan columns and conservation cover (CC) is displayed in green columns. Cost estimate accounts for seed cost, broadcast herbicide application labor, flailing labor, scraping labor, and the cost of general herbicide inputs on a ten-acre scale. Unaccounted for are fuel costs and the potential for price inflation for each activity.*

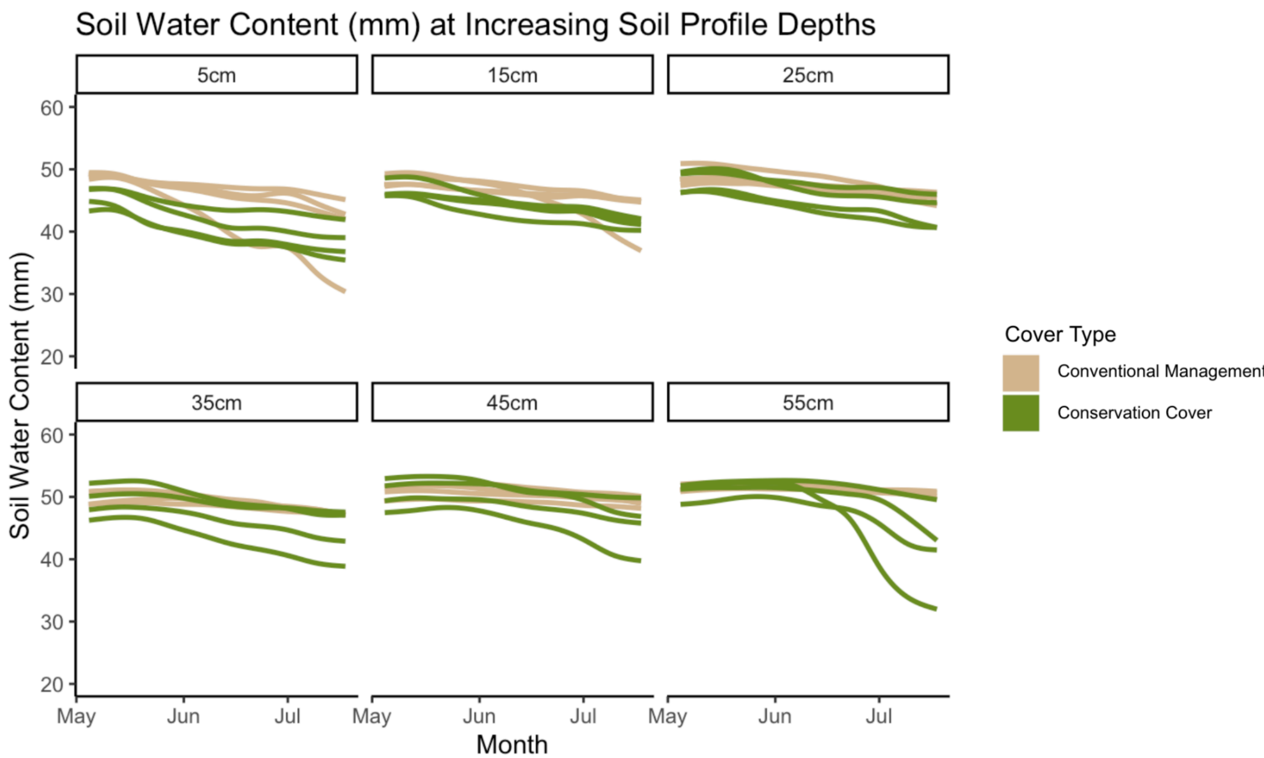


Figure 5a - *2023 mean soil water content (mm) data at different depths in the soil profile starting at 5cm and progressing in increments of 10cm. Conservation cover is displayed in green and conventional management is displayed in tan.*

Mean soil water content progressively decreased as months went by, with a greater difference in soil water content between cover types occurring at shallower depths in the soil profile. At any given depth, soil water content was significantly impacted by cover type ($p = 0.000988$). This data supports my hypothesis (H7.1) that cover communities would have a negligible to slightly reduced effect on soil moisture compared with conventionally managed soils in the summer. Depth also impacted soil moisture significantly ($p = 0.000603$), though there is no significant interaction between the two ($p = 0.635432$) (table 5b).

Temperature in the soil profile steadily increased over time regardless of cover type, with more variance happening at shallower depths compared to deeper depths of the soil profile. At any given depth, soil temperature was significantly impacted by cover, with conservation cover plots lowering soil temperature overall ($p = 8.41e-11$). As depth increased, mean temperature differences between cover types also decreased significantly ($p = 2.90e-08$), though there is not a significant interaction between cover type and depth ($p = 0.953$). This data does not support my hypothesis (H7.2) that conservation cover would slightly cool soil temperatures at every depth. Conservation cover significantly decreased soil temperature at every depth at every temporal period represented.

Cover Type + Depth (cm)	Difference	Lower / Upper	P-Value
NC / CM: 5cm	-2.9049805	-11.23 / 5.42	0.9839281
NC / CM: 15cm	-1.9982243	-10.32 / 6.33	0.9993291
NC / CM: 25cm	-2.1842963	-10.51 / 6.14	0.9984949
NC / CM: 35cm	-3.2012400	-11.53 / 5.12	0.9672628
NC / CM: 45cm	-3.2870498	-11.61 / 5.04	0.9606539
NC / CM: 55cm	-7.3890852	-15.71 / 0.94	0.1227823

Table 5b - *Soil moisture statistics comparing differences in soil moisture content at various depths across cover type. Data is pulled from the representative interval of declining soil moisture, from July 7th, 2023 to July 17th, 2023. Native Conservation Cover is displayed first as NC and conventional management is displayed second as CM.*

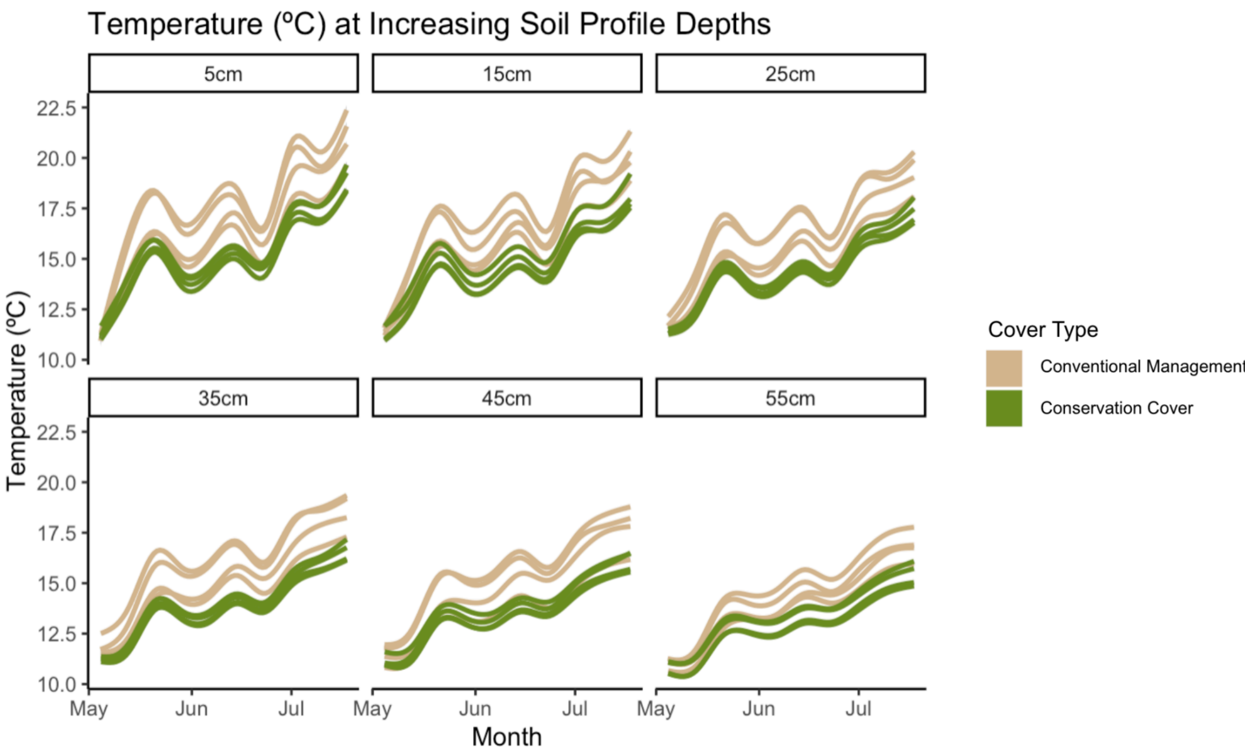


Figure 6a - *2023 mean soil temperature data (°C) at differing depths in the soil profile starting at 5cm and progressing in increments of 10cm. Conservation cover is displayed in green and conventional management is displayed in tan.*

Cover Type + Depth (cm)	Difference	Lower / Upper	P-Value
NC / CM: 5cm	-2.0445	-3.86 / -0.22	0.0168042
NC / CM: 15cm	-2.0465	-3.86 / -0.22	0.0166350
NC / CM: 25cm	-2.1425	-3.96 / -0.32	0.0101595
NC / CM: 35cm	-2.0513	-3.87 / -0.23	0.0162326
NC / CM: 45cm	-1.7666	-3.58 / 0.05	0.0637745
NC / CM: 55cm	-1.5033	-3.32 / 0.31	0.1897940

Table 6b - *Soil temperature statistics comparing differences in soil temperature (°C) at various depths across cover type. Data is pulled from the representative interval of declining soil moisture, from July 7th, 2023 to July 17th, 2023. Native Conservation Cover is displayed first as NC and conventional management is displayed second as CM.*

VII. DISCUSSION

Community Composition & Weed Exclusion

The NCC community selected for this study effectively demonstrated an ability to suppress weeds over a two year period (figure 1). Inside of these community plots, *Collomia grandiflora* cover dominated in both years, with varying levels of cover from all of the other species (supplementary figure 6). In both community cover plots and individual species plots, *Collomia grandiflora* suppressed weeds effectively, though mean *Collomia grandiflora* cover in individual species plots declined in year two (figure 1). Other individual species that competed well with weeds, in both years, were *Collinsia grandiflora*, *G. macrophyllum*, *P. nemoralis*, and *P. vulgaris* (figure 1). *Collinsia grandiflora* may have had an individual advantage due to its early germination start, which usually takes place in the early fall, and like *Collomia grandiflora*, is an annual that tends to be somewhat weedy. *G. macrophyllum* and *P. nemoralis* may have had individual advantages due to their basal leaves forming rosette patterns, which compete well for space. With *P. vulgaris* acting as a biennial “boom or bust” species in this system, this species may have solely done well in both years due to this nature.

It is likely that this native plant community can suppress weeds much greater than individual native plant species alone (figure 1) due to diversified niche occupation (Holmes et al., 2017), though additional evidence suggests that biomass production plays a key role in weed suppression (MacLaren et al., 2019). Many of the species selected for the tested seed mix had multiple traits desirable in competition against weeds, having characteristics such as rhizomes, tap roots, prolonged seed dormancy and associated germination strategies, seed appendages and coatings, etc. (Emery 2021; Russell 2011; Corvallis Plant Materials Center, n.d.).

While both annual species and most of the perennial species did well in competition with weeds in individual species plots, some decline in individual species plot mean cover may be due to mechanical seed dispersal (from flailing, sweeping, and harvesting) to outside of the plot area. Notably, the spread of *Collomia grandiflora*, *P. nemoralis,* and *P. vulgaris* was wide, with the largest span of distance between a plot and outside area to be observed at 12m, with 6m spread being regularly observed. This may be due to seed shape and weight, as all three species have relatively heavy, rounded seeds that may have the ability to disperse better via equipment ejection during harvest (LaForgia (in preparation)). Spread of *G. macrophyllum* was also observed widely, and this may be due to seed shape and weight, and/or due to seed burrs. The 'weedy' quality of the highest performing species is very desirable in an orchard setting as competition with weeds will likely be an ever persisting challenge due to the weed seed bank in orchards, annual disturbance patterns (Brambila et al., 2022), and sink-source dynamics from neighboring lands (Petit et al., 2012). Overall, diverse mixes of native plants that display persistent colonization habits and have the ability to spread easily should be used in conservation cover mixes to achieve maximum weed suppression and mean cover, as they compete better against weeds compared to individual species.

Phenology

When considering individual species to select for NCC seed mixes, it is important to consider the phenology of each species in accordance with the mechanical and chemical treatments that are required on-farm to prepare for a quality hazelnut harvest (supplementary figure 3). Two key management steps that take place in order to satisfy a quality harvest are sucker management and filbertworm management, which both often take form in a pesticide application. With regards to the phenology data, it is important to note the time of management activities in relation to the associated stage of cover crop development. For sucker spraying, it is important to avoid the flowering time period as much as possible so floral resources for pollinators are not compromised. For this phenology stage, most individual species fall within a safe window between sucker spraying (figure 2). *G. macrophyllum* and *P. vulgaris* first flowers come close to this window in differing years, but would likely not inhibit a safe sucker spraying window. Given that many farmers spray their orchard suckers differently, this inherently has pros and cons to how timing of sucker spray happens and whether or not farmers feel comfortable with the seed mix phenology. If farmers have the correct equipment for spot spraying suckers, and are more comfortable taking sucker spraying at a slower and more careful pace, suckers may be able to be sprayed when cover crops are coming into peak flower or exiting peak flower, as most species do not grow directly at the base of trees (within a 0.5 m radius of the trunk) due to the increased shade, canopy drip during rain events, and lesser amount of available rooting space. Some farmers strip spray the tree line to burn back suckers and kill vegetation in the tree line, which if also using NCC, would be an important time period to avoid for flowering as this could end up directly coating flowering plants with herbicides, potentially creating an ecological trap for pollinators (Hale & Swearer, 2016). Increasing research into non-suckering trees, diversified seed mix phenologies (so peak bloom does not happen at once), diversified seed mix pollination strategies (wind pollinated, etc.), and new sucker management technologies will help in this regard.

For filbert worm management, most farmers spray one or more insecticides to mitigate life-cycle completion for the filbertworm (Wiman et al., 2014). In regards to phenology, and if a farmer is using insecticides to manage filbertworms, it is important that species produce viable seed prior to spraying for filbertworm (~early to mid-July) so the cover can be flailed down in time to spray for filbertworm but avoid creating an ecological trap for pollinators and beneficial species (figure 2). Every individual species selected for the seed mix develops its seeds to either the hard-dough or mature stage (Young & Young, 1986) by the time flailing needs to happen in preparation for filbertworm insecticide application. Species that have seeds reaching maturation before flailing are *C. leichtlinii, Collinsia grandiflora, Collomia grandiflora, G. macrophyllum,* and partially *S. campestris.* Species that have seeds reaching hard-dough stage prior to flailing are *P. vulgaris, P. nemoralis,* and partially *S. campestris.* Seeds only reaching hard-dough stage by the flailing timeframe likely mature on the ground after being separated from the desiccated plant material (Young & Young, 1986). *L. dissectum* did not flower in 2022 or 2023, but will likely reach a hard-dough stage by the time flailing occurs as well.

In this study, the plot area was not sprayed with any insecticides, but instead used isomate filbertworm rings (Miller et al., 2018) to hang in the trees to prevent filbertworm mating from occurring. I managed filbertworm this way in order to minimize any possible disruption to insect life present in the cover cropped area. The ismoate filbertworm rings effectively deterred filbertworm mating inside of the cover cropped area, with threshold traps recording zero filbertworm catches over the two years of the study, compared to zero in the control in 2022 and one in the control in 2023. The enhanced trophic-web in the cover cropped area may have also increased filbertworm predation, combining in effect with the isomate rings to disrupt mating efforts. Some species included in the seed mix may have acted as host plants for parasitoid wasps (Russell, 2015; Stephens et al., 2006) that prey on filbertworm, especially members of the Apiaceae (*L. dissectum*), Boraginaceae (*P. nemoralis*), and Rosaceae (*G. macrophyllum*).

Harvest Nut Entrapment

One of the biggest factors playing into the use of cover crops in Oregon hazelnut orchards is the entrapment of hazelnuts in cover crops when mechanically harvesting. With conventional orchard management, the orchard floor is typically bare from weeds and debris, allowing the harvester to pass through each row of trees to pick up the nuts easily. With conservation cover matching the phenology of the hazelnuts rather well (figure 2), conservation cover can be flailed down just in time for mechanical harvest (supplementary figure 3, supplementary figure 8). Mechanical harvest consists of sweeping the nuts into windrows and then picking them up with the mechanical harvester. Through analysis of the data, it is determined that the most amount of nuts are typically lost in the sweeping portion of the harvesting process (supplementary figure 7). Though, this is significantly reduced when sweeping over conservation cover. The harvester loses less nuts overall, but crop loss is also significantly reduced by conservation cover in wet harvest years. Cover type has no significant impact on crop loss during dry harvest years (figure 3), and this is likely due to conservation cover and conventional management cover types creating similar orchard floor textures. In wet harvest years, crop loss may be significantly less in conservation cover plots due to the improved root structure in the topsoil (Hudek et al., 2021), preventing nuts from being plugged in the soil as seen in conventionally managed plots. In 2023 (wet harvest), some species in the conservation cover mix regrew from their roots prior to harvest , though this seemed to have a negligible impact on crop loss given these findings. Given this information, basal leaf structure is a very important factor when designing NCC seed mixes, as certain perennials with fine leaf patterns or bunching basal leaves may inhibit hazelnut pick-up (ex. *Achillea millefolium*) (Brambila et al., (in review)).

Input Treatments

Harvest preparation typically happens over the duration of the spring and summer, and usually consists of herbicide application, flailing, and scraping the orchard floor to get a smooth, vegetation-free surface for mechanical harvest in the fall (supplementary figure 2, supplementary figure 3, supplementary figure 8). Conventional orchard floor preparation usually consists of 1-2 broadcast herbicide applications a year (or one burndown application mixed with a preemergent), 4-6 flail passes, and 1-3 scraping passes, depending on the condition of the orchard floor due to debris load and ruts, and the desired floor texture of the farmer. The earliest time frame for flailing is during initial soil drydown in the late spring, and the latest time frame for flailing can be condensed right during blank drop in the late summer (Olsen & Peachy, 2013). With such a large allowable time frame for harvest preparation to occur, it is important that seed maturation has occurred prior to flailing so that the cover crop can self-seed for the following year. Given that native seeds are so expensive (table 4b), self-seeding is the most economical way to prepare for next year's cover crop and hazelnut harvest. Building up a native seed bank in an orchard will help suppress weeds long-term, support an ecological community that facilitates many ecosystem services, and can help keep costs low year to year. One of the most acclaimed reasons for using cover crops is the lure of reducing chemical and mechanical inputs in orchards, reducing the costs for labor, time, and expendable products like diesel, pesticides and surfactants, flail teeth, and grease. Based on the findings from this study, it can be concluded that conservation cover can reduce the need for broadcast herbicide sprays after initial cover establishment. This initial broadcast application to reduce the weed seed bank should not be dismissed, though, as it is imperative to the success and establishment of these native plants. In this study, both mechanical inputs (flailing and scraping) were also reduced (figure 4a). Flailing was reduced in part by reducing the need to mow down weeds, whereas scraping was fully reduced by the lack of need to scrape out ruts in the soil from traversing equipment. Scraping may be reduced in part due to less cumulative rutt-creating activity happening in the plot area from flailing and herbicide spraying, and in part due to the conservation cover root structure preventing soil displacement (Hudek et al., 2021; Balkcom et al., n.d.).

Conservation cover management also largely reduces overall orchard floor management costs year to year compared to conventional orchard floor management (table 4b). While these preliminary results show a great opportunity for economic sustainability, seed prices solely make conservation cover implementation out of economic reach for many farmers. Generally, native seed prices can range anywhere from $90 - $350 per pound, meaning that a NCC seed mix *alone* can outprice conventional orchard floor management on a ten acre scale over a five year period. In order for these mixes to be adopted by the majority of hazelnut farmers, price will need to be reduced. If a cost share program could be implemented, this cover type may be very valuable for farmers for long term management.

A downfall of this dataset is that labor costs are largely based on tractor speed. Regardless of tractor speed, the ratio between flailing passes and labor used should largely be the same. Herbicide expense data is largely based on market price for pesticides, which fluctuates year to year. Fuel estimates were not calculated into this analysis due to variations between tractor type, implement type, and fuel consumption from farm to farm. Overall, this data set fits well within the range expressed amongst Willamette Valley hazelnut farmers (Murray et al., 2022), though should be investigated further to parse out variations in year-to-year and farm-to-farm data.

Soil Moisture & Temperature

Cover crops are notoriously criticized for their water consumption, as they tend to use more water in perennial systems than perennial systems without cover (Kaspar 2006). Because studies are limited to evaluating conventional cover crops and not native cover, it is important to understand what water usage looks like at differing depths inside orchards and if cover actively competes for water with hazelnuts. Given the findings from this study, NCC may have little effect on soil water content (table 5b). As depth increased, soil water content also increased (figure 5a), but still without significant difference between cover types. In terms of this data set, this was not statistically significant, though the number of probes were limited to six per treatment, limiting the power of these statistics. A lot of literature discusses the minimal water usage of native plants, referencing the adaptations to climate and environment these species have developed over time (McMahan, 2018). For future research, it would be beneficial to have side by side comparison of water usage in native cover to non-native cover to see if these adaptations truly come into play in agricultural systems. In the context of understanding competition for water, this study is unable to answer that question directly, but may give some insight to how this could be approached in the future. With hazelnut rooting patterns consisting of roots mostly developing in the top 60cm of soil, depending on the soil profile and water table of an individual orchard, hazelnuts can have roots reaching depths beyond the majority of the cover crop root system, reaching depths of 600 - 1000 cm (Olsen, 2014). Given these findings, competition for water might happen in the upper soil profile in which juvenile trees are rooted, but likely does not see much direct competition in the lower soil profile (>35cm) where mature trees have more roots and the conservation cover has less roots. Many of the species in the seed mix have very small, fine roots, but some, like *S. campestris* and *L. dissectum* may have roots reaching depths of 15 - 35cm (University of Washington, 2024). Roots may have impacted the results seen in this study as some soil moisture probes had readings consisting of large errors that rebounded quickly. NCC roots may have encapsulated probe nodes and removed plant-available water from around the probes quicker than in the rest of the soil profile due to the increased pore space around the probes from insertion. These large errors were removed, though the impacted probes consistently read lower than non-affected probes.

In perennial systems, cover crops are also used to prevent evapotranspiration by shading the ground (Blanco-Canqui et al., 2015). In younger hazelnut orchards, it is especially important to cover the orchard floor to prevent problems associated with heated soils, like limited soil microbial activity, which can lead to limited decomposition, nitrogen mineralization, root growth, etc. (ScienceDirect, 2016.). In more mature orchards with a denser canopy, the orchard floor is decently shaded, though a cooler soil temperature throughout the summer months can still improve conditions for biological activity, enhancing all of these listed factors. In this study, even given the mature status and shading of the orchard floor, temperature in all profile segments measured had significantly decreased temperatures (table 6b) and stabilized amplitude fluctuations in soil when under NCC (figure 6a). In other hazelnut orchards with less canopy cover, this temperature difference may be larger (Brambila et al., (in review)). If conservation cover can stabilize soil temperature throughout the winter months as well, hazelnut root growth can continue to be active when temperatures reach 4.5 ℃ or higher (Olsen, 2014).

Other Considerations

Some limitations to this study may be in the factors that couldn't have been unaccounted for, such as seed dispersal, mechanical seed scarification, pollinator-plant relationships, etc., but are hard to determine and may well be worth researching in the future. Throughout the study, it became apparent that seed dispersal in hazelnut systems likely happens largely due to mechanical treatments (flailing, scraping, sweeping, harvesting, etc.). These treatments can spread any type of seed and could be used to their advantage and/or disadvantage in this system. With these mechanical treatments, some may act to unintentionally treat seed coats (scarification, etc.) to give them a germination advantage or accidentally terminate the seeds. Species in the selected seed mix, like *S. campestris,* germinate better with scarification (Corvallis Plant Materials Center USDA, n.d.) whereas other seeds in the seed mix do not require any treatment (Emery, 2021). This could be changing the persistence of conservation cover and weed cover and should be evaluated in the future to determine species' seed responses to these mechanical treatments. Another factor that could influence success of individual target cover and weed competition is certain plant growth preferences, like the preference for growing in a monoculture or polyculture. *C. leichtlinii* species are known for their performance in monocultures from their adaptations to indigenous cultivation over time (Carney et al., 2021), so competition with weeds may not be demonstrated when not tightly packed. In the hazelnut orchard context, *C. leichtlinii* did not compete well with weeds in a sparse monoculture, but had an easier time in the polyculture (community plots). *L.*

dissectum did well as a monoculture, growing from year one to year two significantly, but did not do as well in the polyculture. *Collomia grandiflora* did not do well in monocultures, significantly declining from year one to year two, but dominated polyculture cover increasing from year one to year two (figure 2a), almost creating a monoculture in the polyculture itself. These phenomena should be more thoroughly investigated as they could be very interesting to study and have a large effect on which plants are selected for conservation cover seed mixes.

Another outside factor that may have implications on the success of NCC is habitat type and connectivity to wildland habitat. These qualities may have an effect on wildflower seed development and year-to-year cover performance, especially if a plant species has a specialist pollinator(s) that may not have suitable habitat in close proximity to the hazelnut orchard. Another factor in pollination and seed production success may be in the management of the cover itself. Mulching cover crops annually may contribute to insect decline in intensified agricultural settings as habitat is significantly altered and reduced every year (Ganser et al., 2019). Other studies indicate that even in these ecosystems, pollinator populations increase over time (Schmied et al., 2022), thus more research should be done for this specific system.

With this study being limited to the native forbs that are commercially available, it is important to note the wide array of species that may be compatible with the management and function of these orchards that are not yet commercially available. In the Willamette Valley, native seed production is steadily growing, but restoration efforts far outpace the quantity and availability for practitioners, researchers, tribes, and the public (International Network for Seed-Based Restoration, 2023). Many more native species have desirable functional traits that would be optimal for use in differing types of orchards for light/shade tolerance, differing management practices, soil quality, etc., but do not exist in bulk quantities. Going forward, investing more research into which species are compatible with the majority of orchards may be able to improve native seed production goals if NCC becomes widely adopted.

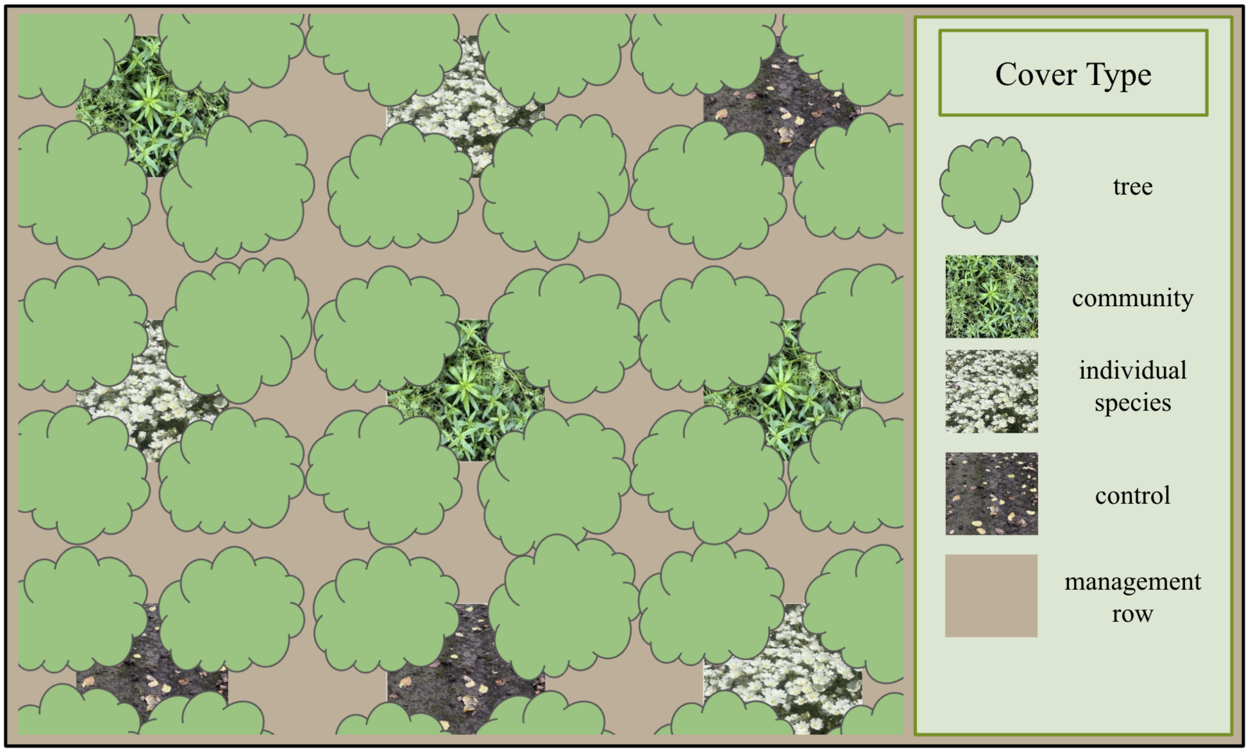
VIII. CONCLUSION

Native conservation cover (NCC) may be a great cover crop option for Oregon hazelnut farmers to adopt as the practice aligns with key orchard management goals studied. From this research, conservation cover communities demonstrated effective weed suppression capabilities and alignment with key orchard management activities, like sucker spraying, filbertworm management, and the ability to increase hazelnut pickup during wet harvests. Conservation cover also demonstrated the ability to reduce chemical and mechanical inputs, likely saving farmers input costs, time, and energy spent controlling orchard weeds and maintaining smooth ground for harvest. While NCC may reduce soil available water at the soil surface and down to 35cm consistently, it did not significantly impact soil water content at these depths or lower than this. In orchard floor areas covered by NCC, temperature was significantly reduced in the summer months while also stabilizing temperature fluctuations over time. Given the ecosystem services that this type of cover has the capability to provide orchard systems and farmers alike, broader seed mix design and scaled-up implementation could further enhance services targeted towards farms, the surrounding communities, adjacent wildland habitats, and the greater bioregion as a whole. With the current price of native seed, a cost share program would likely be needed in order for affordability by the majority of farmers. Given the economic services that NCC has the capability to provide, further investigation and investment into these practices could help agricultural sustainability efforts, stimulate the economy, and reduce time and money spent on pest and orchard floor management.

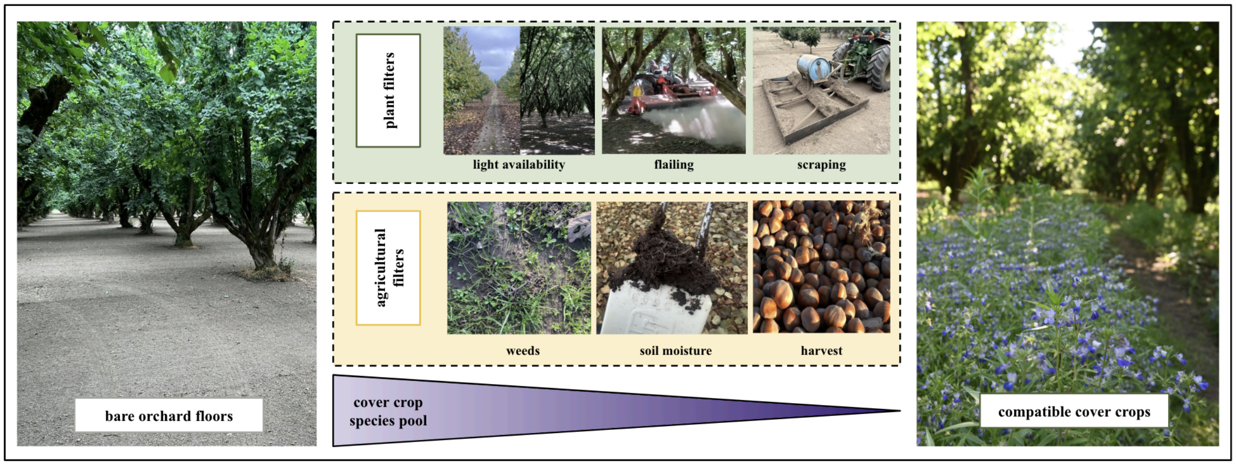
IX. CONFLICT OF INTEREST STATEMENT

I would like to acknowledge that this study site is located on my family's hazelnut farm.

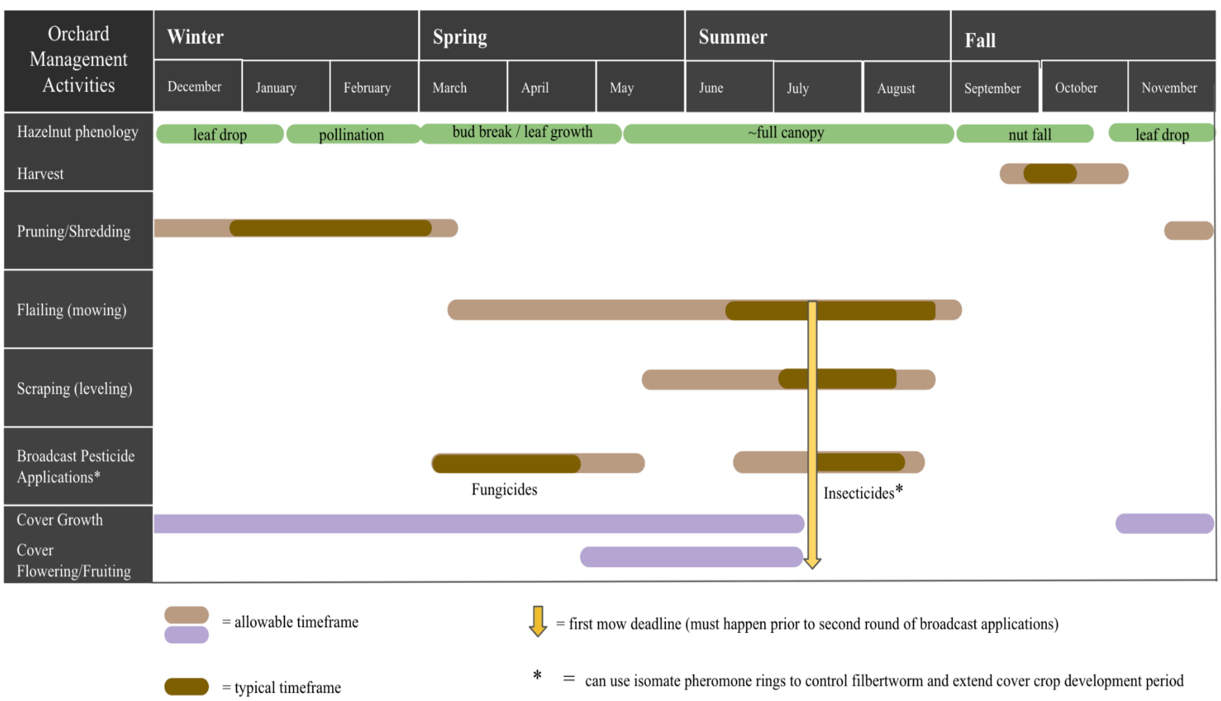
X. APPENDIX



Supplemental Figure 1 - *Site Design. On the left is the 'checkerboard' pattern represented from an aerial view and on the right is the cover type key.*



Supplemental Figure 2 - *Cover crop filtering methodology (physical). Species selection criteria was based on plant (light availability, flailing, and scraping) and agricultural filters (soil moisture, weed suppression, and harvest compatibility). A list of compatible cover crops were then selected through the filtering criteria. Figure adapted from Brambila et al. (in review).*



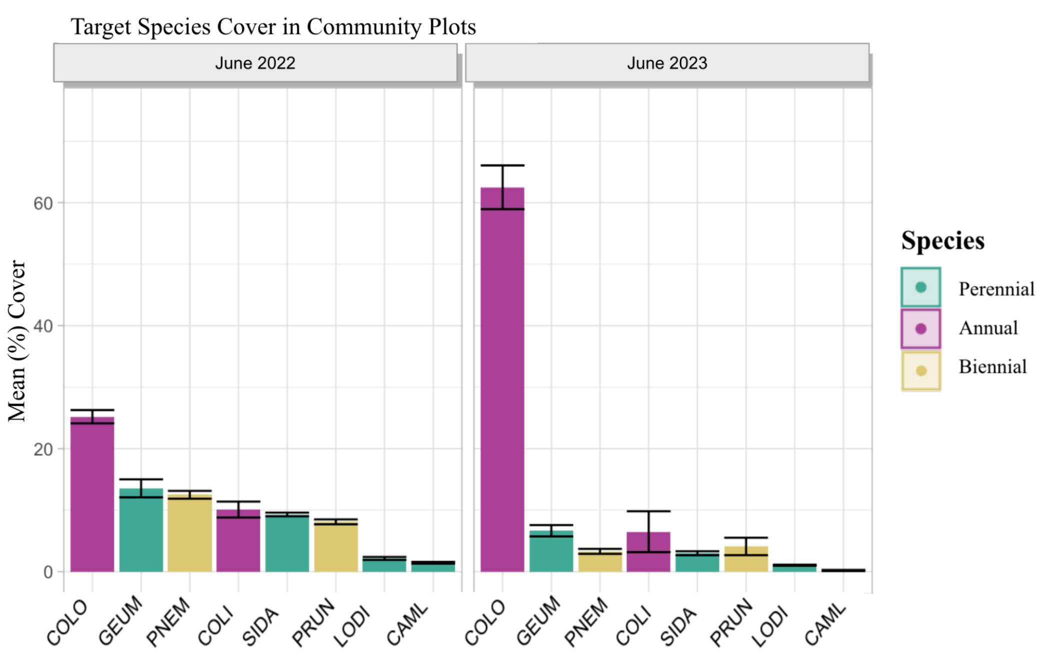
Supplemental Figure 3 - *Cover crop filtering methodology (temporal) – orchard management activities timeframes. This figure shows the basis for the temporal cover crop pool species filter. Along the bottom are keys indicating key time points or management frames to align cover crop species pool with.*

Species	**Plant Code**	**Plant Growth Habit**	**Listed Height**	**Listed Flowering Phenology**	**Target Traits**	**Demonstrated**
Camassia leichtlinii spp. suksdorfii	CAML	Perennial	20 - 130 cm	March - July	Disturbance tolerant, shade tolerant, bulb forming	Disturbance tolerant, semi-shade tolerant, weed intolerant
Collinsia grandiflora	COLI	Annual	6 - 40 cm	April - August	Semi-shade tolerant, short in stature	Semi-shade tolerant, phenology match, short in stature
Collomia grandiflora	COLO	Annual	10 - 90 cm	April - July	Disturbance tolerant, semi-shade tolerant, drought tolerant	Disturbance tolerant, semi-shade tolerant, drought tolerant, weedy, tall
Geum macrophyllum	GEUM	Perennial	20 - 110 cm	April - August	Disturbance resistant, shade tolerant, rhizomatous	Disturbance resistant, shade tolerant, rhizomatous, spreading
Lomatium dissectum var. dissectum	LODI	Perennial	30 - 200 cm	March - July	Disturbance resistant, shade tolerant, drought tolerant	Disturbance resistant, very shade tolerant, drought tolerant, does well in monocrops, flowering stalks very tall
Phacelia nemoralis ssp. oregonensis	PNEM	Biennial	20 - 120 cm	May - August	Disturbance resistant, shade tolerant, drought tolerant	Disturbance resistant, very shade tolerant, drought tolerant, spreading
Prunella vulgaris	PRUN	Biennial	10 - 60 cm	May - September	Disturbance resistant, shade tolerant, short in stature	Disturbance resistant, semi-shade tolerant, short in stature
Sidalcea malviflora campestris	SIDA	Perennial	50 - 200 cm	May - August	Disturbance resistant, semi-shade tolerant, rhizomatous	Disturbance resistant, semi-shade tolerant, persistent, very tall, rhizomatous

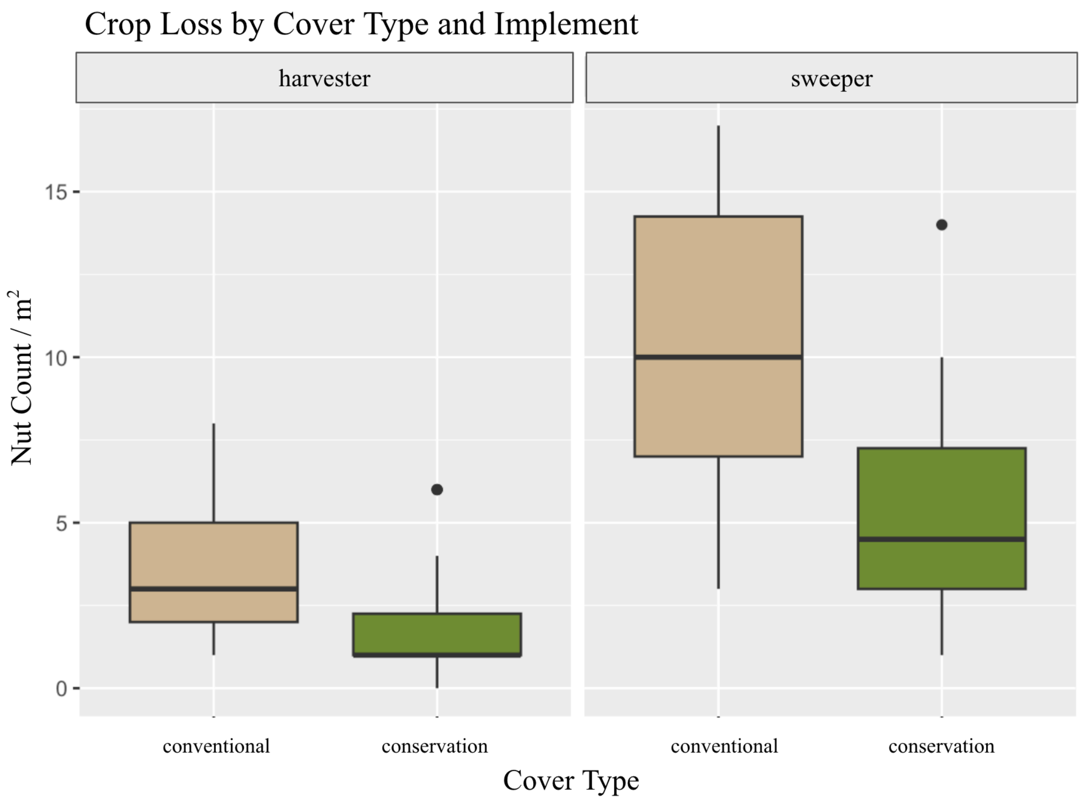
Supplemental Table 4 - *Selected seed mix species and associated target traits*
Sources: Oregon Flora, Washington Native Plant Society, CalFlora

Species	2022 target vs weeds cover	2023 target vs weeds cover	2022 vs 2023 target cover	2022 vs 2023 weeds cover
C. leichtlinii	<0.0001* (-)	<0.0001* (-)	<0.0001* (-)	0.3811
Collinsia grandiflora	<0.0001* (+)	<0.0001* (+)	0.0004* (-)	0.4177
Collomia grandiflora	<0.0001* (+)	0.0178* (+)	0.0262* (-)	0.0192* (+)
G. macrophyllum	<0.0001* (+)	0.0022* (+)	0.1497	0.1052
L. dissectum	0.0018* (-)	0.0164* (+)	0.0003* (+)	0.0157* (-)
P. nemoralis	0.0003* (+)	<0.0001* (+)	0.8559	0.3910
P. vulgaris	<0.0001* (+)	0.0359* (+)	0.0116* (-)	0.4346
S. campestris	<0.0001* (-)	0.0033* (-)	0.3046	0.3508

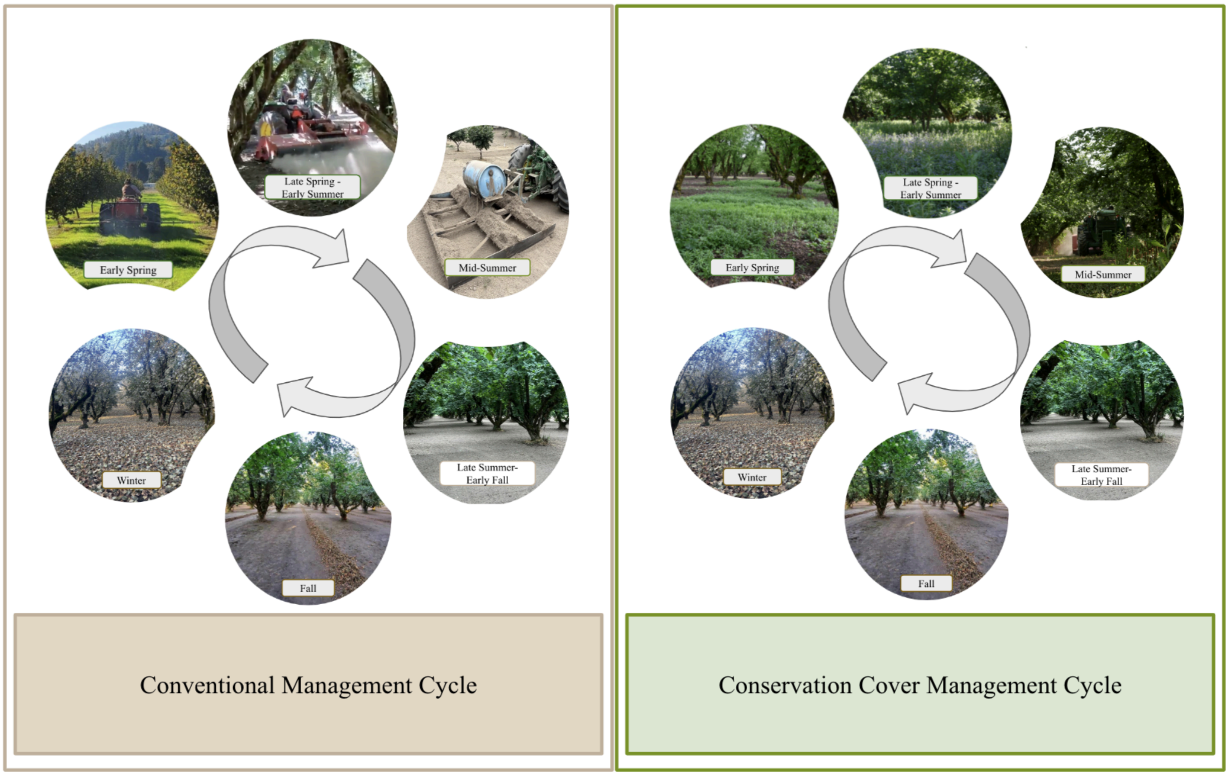
Supplemental Table 5 - *Individual species' and weed plot p-values by year, comparing mean conservation cover (by species) to general weed cover per plot and significant changes by cover type. Mean conservation cover and mean weed cover was also compared against itself, Denoted by the p-value is a (+/-) indicating whether the change in target cover was significantly positive or negative compared to mean weed cover, or whether the change was significantly positive or negative comparing cover type across years. All p-values were calculated with a confidence interval of 95%, with designation being acknowledged with the symbol: *.*



Supplemental Figure 6 - *Community plot composition by species type in both trial years.*



***Supplemental Figure** 7 - 2023 data comparing implement type and cover type crop loss. Harvester crop loss is reduced in conservation cover, compared to conventional management, by a mean of 1.5 nuts per m^2, with a p-value of 0.0204. Sweeper crop loss is also reduced by conservation cover, compared to conventional management, by a mean of 4.85 nuts per m^2 , with a p-value of 0.0003. In both cases, conservation cover significantly reduces crop loss compared to conventional orchard floor management.*



Supplemental Figure 8 - *Conventional vs Conservation Cover Management Cycle in Oregon Hazelnut Systems. On the left in tan is the standard, bare-ground, conventional management style used in the majority of Oregon hazelnut orchards. In early spring, weeds are sprayed, followed by flailing in late spring-early summer. After flailing, scraping takes place in mid-summer to create a smooth orchard floor in late summer-early fall. The ground in then flailed again and harvest proceeds after nutfall in fall. Leaves fall on the ground in winter and the cycle then continues. Conservation cover management is identical from late summer-early fall through winter, with spring and summer being replaced by growing cover. Flailing is shifted to mid-summer to achieve a bare-ground orchard floor for nut pickup in the fall.*

XI. LITERATURE CITED

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