IMPROVING SOIL MOISTURE RETENTION IN HAZELNUT ORCHARDS THROUGH THE USE OF NATIVE COVER CROPS AND CONVENTIONAL MECHANICAL TREATMENTS

BY

MARISSA LANE-MASSEE

A THESIS

Presented to the Environmental Studies Program of the University of Oregon
In partial fulfillment of the requirements
For the degree of
Bachelor of Science
University of Oregon
December, 2020

An Abstract of the Thesis of
Marissa Lane-Massee for the degree of Bachelor of Science
In the Environmental Studies Program to be taken December, 2020

IMPROVING SOIL MOISTURE RETENTION IN HAZELNUT ORCHARDS THROUGH THE USE OF NATIVE COVER CROPS AND CONVENTIONAL MECHANICAL TREATMENTS

Approved: [redacted]

The purpose of this study is to understand how hazelnut orchards in the Willamette Valley, Oregon retain soil moisture throughout the spring and summer months, and how orchard floor treatments can be used to improve soil moisture retention in various ages of hazelnut orchards. The two orchard floor treatments studied looked at how the conventional mechanical processes of flailing and scraping impact soil moisture retention, and how the use of native herbaceous understory cover can be used as a way to increase soil moisture retention. The mechanical methods of treatment include irrigation, flailing, scraping, and many harvesting processes, and the vegetation treatment methods includes seeding mixes of native herbaceous and agricultural cover. The methods of data collection in the study consist of soil moisture monitoring and vegetation community analysis. The results determined in this study conclude that both mechanical and vegetative treatments have a wide variety of impact on soil moisture retention in hazelnut orchards in the Willamette Valley. Results vary depending on orchard canopy cover, orchard age, and vegetative community composition. Canopy cover had the largest impact on soil moisture retention and flower development in vegetative communities. Orchards with less canopy cover saw a greater portion of native cover survive to maturity and/or produce seeds, but retained less soil moisture than orchards with more canopy cover. These orchards saw a greater survival rate of all native seed mixes, especially the growth and flowering of the annual communities. Orchards with more canopy cover did not see large portions of surviving vegetation, but retained soil moisture more than orchards with canopy openings. In these orchards, most annuals did not survive, but the perennial communities saw successful rates of survivorship from sunlight availability and repeated mechanical disturbance. Overall, the vegetative communities that were composed of native plants, combined with less intensive mechanical treatments, retained the highest amount of soil moisture throughout the study period. The moisture retention rate in these plots averaged a 3-5% increase compared to those plots in which vegetation was non-native or non-seeded, or the scraping mechanical treatment. This study has the possibility to impact how Willamette Valley hazelnut farmers prepare their orchard floors for harvest, how agricultural systems in the Willamette Valley can reintroduce important ecosystem services like biodiversity, wildlife habitat, and soil moisture retention, and increase the potential to alleviate the impacts of anthropogenic climate change on agricultural crops like hazelnuts.

Improving Soil Moisture Retention in Hazelnut Orchards Through the Use of Native Cover Crops and Conventional Mechanical Treatments

Environmental Studies Honors Thesis
Marissa Lane-Massee, Spring 2020

Introduction

Background

The European hazelnut (*Corylus avellana)* is an economically important crop grown in abundance in the Willamette Valley. Throughout the valley, nearly 1,000 families grow hazelnuts on approximately 80,000 acres of farmland (Oregon Hazelnuts, 2020), representing 4.7% of the 1.7 million acres of Willamette Valley farmland (Oregon Board of Agriculture). Because of the growing increase in price of nuts per pound since 2010, many new hazelnut orchards have been planted in the Willamette Valley (International Nut and Dried Fruit Council, 2018). Oregon is the third largest producer of hazelnuts worldwide, following only Turkey (67%) and Italy (13%) (Food and Agriculture Organization, 2019). Unlike some countries which harvest their hazelnut crops by hand, Willamette Valley hazelnut farmers harvest their crop by machine. Preparation for the process of mechanical harvest involves much attention to the orchard floor. Flailing, which is the use of a large tractor-mounted mower to pulverize organic pruning debris, weeds, and dirt clods, reduces the amount of debris entering and being processed by the harvester. Flailing is usually completed right after the rainy season ends, and continues until right before harvest to crush up any remaining organic material laid on the orchard floor, and all of the “blanks” (nuts without kernels that the trees release before harvest). The other standard method of orchard floor maintenance is the process of scraping, which is the use of a large, tractor-mounted, three-bladed box scraper that is pulled behind a tractor to level out the orchard floor. Scraping usually takes place after flailing has been completed one to three times, and is used to even-out divots and ruts in the orchard floor. When the scraper is in motion, the scraped dirt builds up inside of the different blades waiting for a less-level section of dirt to be driven over, then releasing dirt. Dirt often pools up and spills over the blades, slowly dispersing organic material and dirt throughout the orchard. This act of dispersing the soil and organic material is a crucial step in soil moisture preservation-- many farmers scrape most of the topsoil off of their orchards, leaving the ground bare and unable to absorb and retain moisture (DuPont et al, 2020). Both mechanical treatments act to keep the orchard floor clear of vegetation and debris in order to prepare for harvest, but often result in an orchard with an inability to retain high amounts of moisture into the dry season, and complications like erosion in the wet season.

Bare ground in orchard floors absorb more heat during the day and release more heat during the night compared to orchard floors covered in vegetation (Washington State University, 2017). Previous studies have shown that desertification and modern agricultural processes deplete water soil moisture content, but planted cover vegetation can help reduce the hazards of desertification (Yang et al, 2018). Nearly all of the hazelnut farmers in the Willamette Valley keep their orchards bare during the Willamette Valley’s dry season, which can stress trees because of the lack of water. The Willamette Valley’s climate is classified as a warm-summer mediterranean climate (Koppen-Geiger), and while hazelnuts are adapted to withstand some degree of water stress, more extreme summers from the changing climate are posing severe drought stress on hazelnut orchards in the Willamette Valley. Climate change may impact the dry season of the Willamette Valley by making the summer month's average temperature rise by 2℉ to 7℉ (1℃ to 13℃) (Oregon State University, 2015). *Corylus avellana* is considered a sensitive species to water stress due to the plant's low capacity for stomatal regulation. In this crop, water stress affects fruit quality and production, as well as juvenile tree development (Catoni et al, 2017). Studies have shown that drought can reduce growth in mature trees by 80% and reduce nut production by 20% (Mingeau, 1994).

The two options for mitigating orchard drought stress are adding more water to the system and conserving existing water resources. The two respective corresponding strategies are usually irrigation and cover cropping. Oregon State University, the leading university in hazelnut research in the United States, has been experimenting with new irrigation technology to monitor and irrigate hazelnut orchards using a digital monitoring system designed to apply only the necessary amount of water to each tree through a dripline irrigation system (Baldwin, 2015). Unfortunately, many farmers do not have the means of funding or time to install this, so usually farmers may lay irrigation pipes in young orchards to apply a broad spectrum sprinkler system, or temporarily situate buckets at the base of each tree to fill with water from a mobile source. Irrigation can often be expensive, time consuming, and require water rights and a pump. Cover cropping may be preferable to irrigation (or used with irrigation) to conserve water that is already present in the soil. Many farmers choose cover cropping or alley cropping as techniques in younger orchards, where they often grow alfalfa, clover, strawberries, and sometimes winter grains. These cover crops can provide some revenue for farmers with younger, less productive orchards. Specific cover crops can also aid in nitrogen fixation and can potentially save money typically spent on fertilizer (Wiman 2019). Many cover crop systems planted in different types of farm settings can aid in moisture and nutrient holding capacity due to the increased root system biomass in underlying soil profiles. These root systems help soil retain water and nutrients cycle, through increased infiltration and percolation. (United States Department of Agriculture, 2020) Oregon State University (OSU) and the United States Department of Agriculture (USDA) have developed recommended cover crop mixes based on industrial seed mixes and agricultural alley crops that can bring in revenue to farmers with younger orchards or reduce monetary input towards nutrient amendments.

Using any vegetation as a means of cover cropping is beneficial to soil, hazelnut, and climate health, though some non-native plants may be less adept at surviving as an understory community in a Willamette Valley hazelnut orchard without additional nutrients or water. Native plants that have adapted to live in the Willamette Valley may have a competitive edge on industry and agricultural cover due to their ability to survive cold, wet winters and warm, dry summers (Withrow-Robinson et al, 2006). Native plants may also be more efficient at water and nutrient use, ability to create broad cover, and have greater shade-tolerance due to their unique local adaptations (Oregon Conservation Strategy, 2020). In this study, the native seed mix that was selected will likely mimic the plant communities found in Oregon White Oak (*Quercus garryana*) woodlands, one of the Willamette Valley's historically foremost ecosystems. With hazelnut orchards occupying a similar ecological role as Oregon White Oak lowland woodlands (Gucker, 2007), in an agricultural setting, these seed mixes will likely thrive and reproduce similar to those communities.

Hypotheses/Thesis Statements

My thesis takes a broad view on how orchard floor management affects soil moisture in Willamette Valley hazelnut orchards. My broad goal is to provide a resource for Willamette Valley hazelnut farmers to conserve soil moisture as means of adaptive management. I consider the effects of traditional mechanical treatment on soil moisture and how these are moderated by reintroduction of understory cover across orchards of various ages.

I hypothesize that (H1) both flailing (F) and scraping mechanical (FS) treatments reduce soil moisture retention compared to unmanaged (C) plots. I predict that orchard canopy cover will interact with mechanical treatments, with (H2) more open canopy orchards retaining the least amount of soil moisture because of increased exposure to direct sunlight. For the cover cropping treatments, I expect that (H3) cover crops will increase soil moisture retention over non-cropped controls, and that (H4) native seed mixes will enhance soil moisture retention relative to the industry mix.

Methods

Plot Establishment and Management

To test my hypotheses, I installed an orchard floor management experiment across three farms for a duration of two years. All three orchards vary in age and canopy cover. The youngest orchard, being 15 years old, represents the open canopy found in young, newly planted orchards. The second orchard, being 40 years old, represents a closed canopy, or the desired canopy cover of an orchard in prime production. The third orchard, being 60 years old, represents a patchy canopy that is partially open due to pruning from Eastern Filbert Blight (*Anisogramma anomala*), a fungus that infects and kills hazelnut trees. Six blocks of management plots were established in every orchard. Each block consisted of three plots arranged next to each other in an orchard row. Each plot had one mechanical treatment applied: control (C), flailed (F), or flailed and scraped (FS). The control plot did not have any mechanical treatments applied to it and whatever seed bank or standing vegetation existed was not tampered with. Because all three orchards are planted on a 6.096m x 6.096m grid, each plot is the area of one orchard grid block bounded by four trees.

In mid-August 2020, the (F) and (FS) treatment types were applied to the respective plots once each. In late-September 2020, the harvesting process took place. Whatever remaining vegetation was left over right before harvest in the unmanaged plots, I cut to four to six inches using a line trimmer to facilitate harvest. Prior to the harvester harvesting nuts, a machine designed to pile the nuts into rows drives through each plot twice. The machine, called a sweeper, applies rubber paddles to the ground in combination with a fan and circular brush. After this process happens, the harvester drives through the plots to collect the nuts onto a conveyor belt. The harvester also uses rubber paddles to push nuts into a tighter row and up onto the belt. The belt is designed to be weighted for a whole nut, and blows lighter organic material out through a series of fans. These fans redistribute non-harvestable organic litter back throughout the orchard while each consecutive row of hazelnuts are being harvested.

Measuring Soil Moisture

During the summer of 2019 (before seeding cover crops), I sampled baseline soil moisture at all three different orchards using a mechanical soil moisture sampling device. This device had a hand-held moisture monitor that gave outputs of each sample when the two, three inch long, box-mounted probes were stuck in the ground. In each plot, I sampled the four corners of the plot to get four different soil moisture readings and then averaged them out during the statistical processing portion of my thesis. I proceeded to continue taking soil moisture readings every week, for the next four weeks at each orchard. At every orchard, the (F) treatment was applied four times, and the (FS) treatment type had been flailed four times and scraped once, with about an inch of topsoil churned in total. After raining 0.10 inches in mid-July at the youngest orchard, I replicated that rain event across all plots at each site using a Rear's Powerblast Sprayer. I calibrated the sprayer to produce 0.10" of "rain"that was evenly distributed across all plots.

Starting in late April 2020, I started taking soil moisture readings within each seeding subplot with a new HydroSense II Soil Moisture Probe and Meter. In addition to this new meter, I used a different method of data collection called the Nail Method (Grinath et al, 2019). This method consists of driving two nails, roughly the distance between each probe, into the center of each subplot. By replacing the original probes with bolts that were shaved down to ¼" nubs, the new nubs could be held onto the nails and a moisture reading could be taken. This new method allowed for a more consistent depth of moisture reading over time and to ensure that each reading would be taken in the same place. In mid-May of 2020, cover crop data collection started.

Measuring Vegetation Cover

In Fall October-November 2019, plots were divided into four subplots for cover crop planting. These subplots were seeded with seed mixes of either annuals, perennials, a megamix (annuals and perennials), an industrial agricultural mix, and a control. Inside of the unmanaged plots, the four subplots were seeded with an annual mix, a perennial mix, a megamix, and a control (see figure 1.1). Inside of the flailed and scraped plots, subplots were seeded with an annual mix, a perennial mix, the industry mix, and a control . Each seed mix has all included species listed under 'Figure 1.3'. In late December of 2019, I blew all of the fallen leaves off of every plot to ensure germination.

We collected cover crop results by visually estimating percent cover of each subplot for percent weeds (volunteer plants), percent bare ground, percent target cover (annuals/perennial as a whole community), and each individual species percent cover.

Results

Soil Moisture Results, Hypothesis H1 & H2

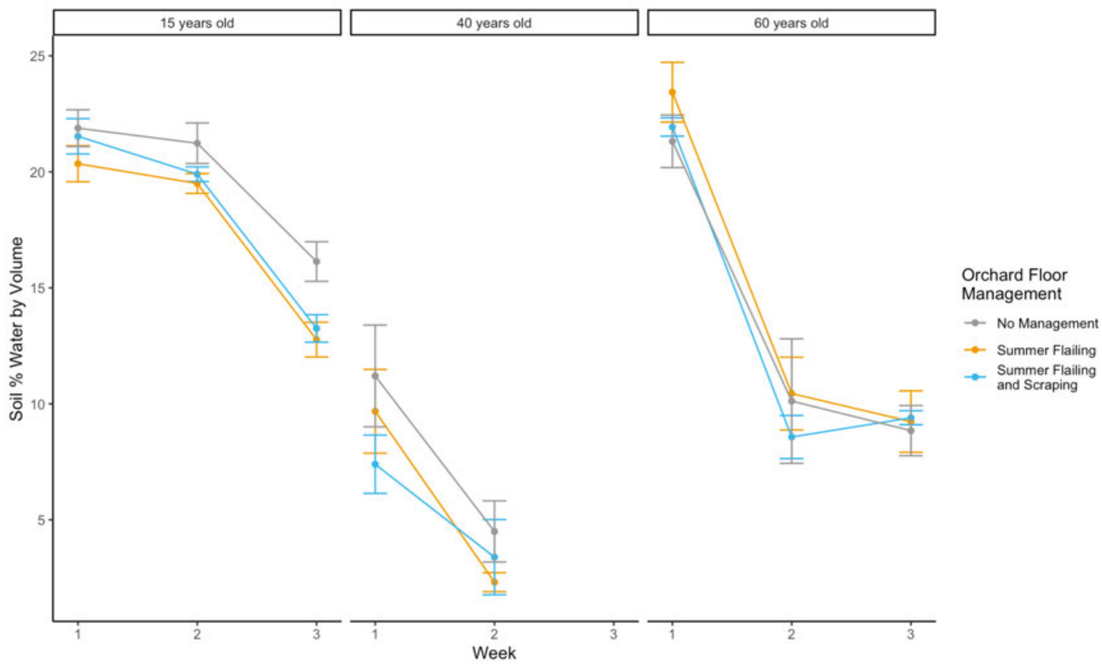

Figure 1.0 *Baseline (2019) soil percent water by volume across orchards and management types before seeding in 2019. Soils were all irrigated at the same rates during the summer and monitored for three weeks.*

In 2019, soil water percent by volume decreased at different rates, and from different starting levels across all three orchards following irrigation. Overall, (FS) plots had the most amount of soil moisture loss in open canopies (15 and 60 years old), but had the least amount of soil moisture loss in the closed canopy (40 years old). The (C) and (F) plots had nearly the same amount of moisture loss in all orchard ages. And generally, older orchards lost more soil moisture than younger orchards. Over the first two weeks of data collection, unmanaged plots had higher soil moisture percent than the flailed and scraped plots in the forty year and fifteen year old orchards. In the sixty year old orchard, the flailed plots had higher moisture percentage the first two weeks, followed by the scraped plots in week three.

In the forty year old orchard, unmanaged plots had higher soil moisture by volume than flailed plots (P=0.001) and scraped plots (P=0.029), but not in the fifteen and sixty year old orchards (P>0.05). In the fifteen year old orchard, the adjusted p-value for the (FS) plots compared to (F) plots is (P= 0.477). The (C) plots had retained more moisture than the (F) plots (P=0.0541), and the (C) plots also retained more moisture than the (FS) plots (P= 0.434). In the forty year old orchard, the (FS) plots retained more moisture than the (F) plots (P= 0.461), and the (C) plots retained more moisture than the (F) plots (P= 0.00101). The (C) plots also retained more moisture than the (FS) plots (P= 0.0291). In the sixty year old orchard the (FS) plots retained less soil moisture compared to the (F) plots (P= 0.338), the (C) plots retained more moisture than the (F) plots (P=0.868), and the (F) plots retained more moisture than the (C) plots (P= 0.177) By the third week of data collection, the (C) plots in the fifteen year old orchard had higher moisture by volume percent than both the (FS) (P=0.0368) and (F) (P=0.0149) plots.

In the first two weeks of soil moisture sampling in 2019, the forty year old orchard absorbed/evaporated less moisture compared to the fifteen year old orchard (P=<0.001), the sixty year old orchard lost less moisture compared to the fifteen year old orchard (P=0.0019), and the sixty year old orchard absorbed more moisture compared to the the forty year old orchard (P=<0.001). This data shows that the more open canopy an orchard has, the more moisture the soil beneath the canopy will lose.

From moisture sampling week one to week two, comparisons between orchard age soil moisture losses were not significant. The forty year old orchard loss moisture faster than the fifteen year old orchard (P=2.83e-05), the sixty year old orchard loss moisture faster than the fifteen year old orchard (P=0.00e+00), and the sixty year old orchard loss moisture less fast than the forty year old orchard (P=9.10e-06). These results were consistent across management practices and starting level of moisture retention.

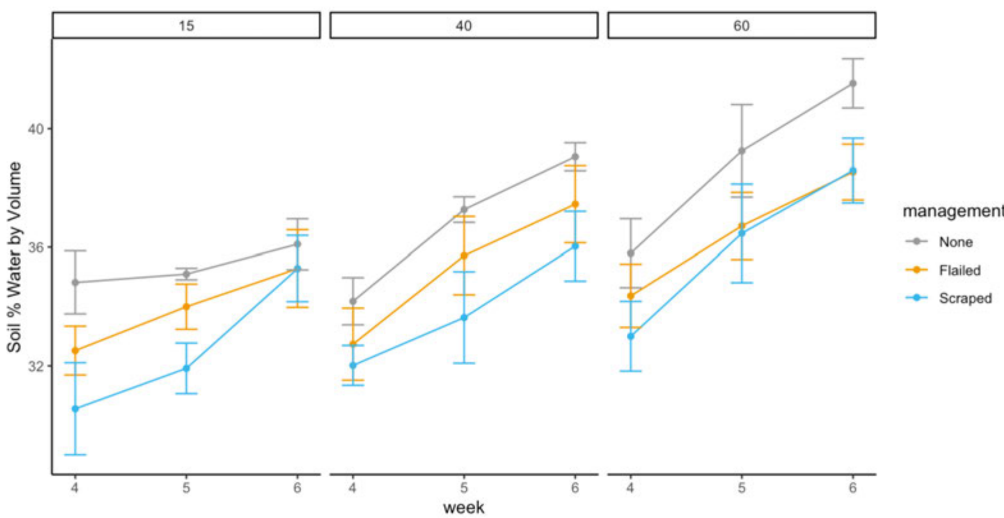

Figure 2.0 *- Soil Water Content (%) by Volume, 2020 Data (Cover Crop Control subplots), by age and management type.Over three weeks in the spring in 2020, soil moisture increased in control plots, but at different rates across management treatments.*

During the 2020 sampling period, which was earlier than 2019, the orchard canopy leafed out, and cover crops started to grow. The percent of soil moisture increased across all plot treatment types. Overall, the data shows that older orchards retain more moisture than younger orchards, and that the unmanaged treatment type ((C) or (none)) retained the most moisture over all ages of orchard.

For the fifteen year old orchard, in comparison to the (C) plots, the (F) (P=0.0010285) and (FS) (P=0.0001048) plots absorbed and retained less moisture, but were not greatly different than each other in their retention abilities (P=0.8431). For the forty year old orchard, compared to the (C) plots, the (F) (P=0.00042) and (FS) (P=<0.001) plots absorbed and retained less moisture. In this orchard, the (F) plots retained more moisture throughout the sampling period than the (FS) plots (P=0.0001). For the sixty year old orchard, compared to the (C) plots, the (F) (P=0.0000294) and (FS) (P=<0.001) plots also retained less moisture. In this orchard, the (FS) and (F) plots resembled each other more closely in their moisture retention measurements, but the (F) plots still retained more moisture than the (FS) plots. (P=0.3216492). For all three orchard age groups, all of the statistical contrasts are significant, and in all three, the (C) plots absorbed and retained more moisture than the (F) plots, which absorbed and retained more moisture than the (FS) plots.

For the 2020 moisture sampling data, the moisture retention samples showed that the oldest orchards lost the least amount of soil moisture over time, with the forty year old orchard losing less moisture than the fifteen year old orchard (P=1e-07), the sixty year old orchard losing less moisture than the fifteen year old orchard (0e+00), and the sixty year old orchard losing less moisture than the forty year old orchard (0e+00).

Cover Crop Data Soil Moisture Data in Relation to Cover Crop Results, Hypothesis H3

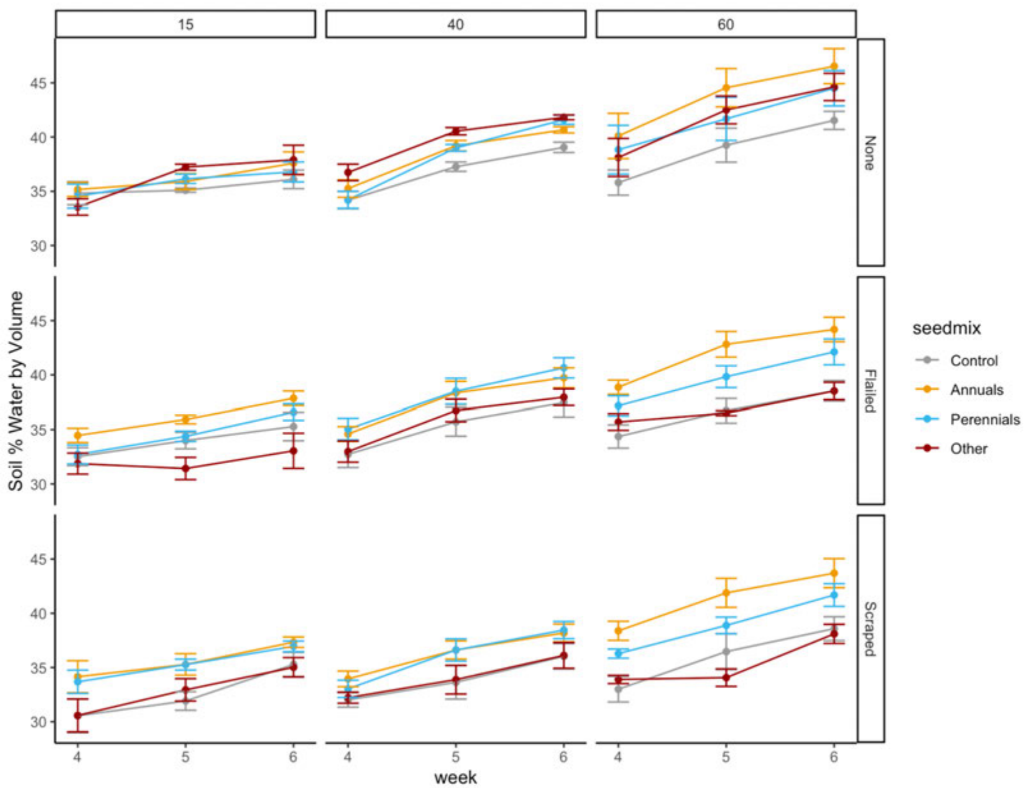

Figure 3.0 - *Soil Moisture (%) by Soil Volume, 2020* This figure shows soil moisture percent by volume with weeks on the bottom, orchard age on the top, and mechanical treatment type on the right side

Overall, the planted vegetation increased the soil moisture retention in every orchard. The native seed mixes did much better than the industry mix, and depending on orchard age, annuals or perennials outperformed both the industry mix and megamix. In the fifteen and forty year old orchards, the megamix retained the most moisture in the unmanaged plots. In the mechanically treated plots, the annuals retained the most amount of moisture. In the 40 year old orchard, the megamix retained the most moisture in the megamix, and the perennials retained the most moisture in the mechanically treated plots. In the 60 year old orchard, the annuals did the best overall in all plot types, and megamix came in second in the unmanaged plots.

In managed plots (F, FS) the annual and perennial subplots always have higher soil moisture by volume than the industry and control subplots, which are almost always indistinguishable in results. The annual subplots do significantly (P=0.00045) better than the perennial subplots in the sixty year old orchard, and the perennial subplots are nearly indistinguishable in the fifteen and forty year old orchards. In the fifteen year old orchard, the annuals (P=0.000016) and perennials (P=0.0095) retain more moisture than the control, the industry and control retain nearly the same amount of moisture (P=0.566), the perennials and annuals are comparable (P=0.3180551), and the annuals (P= 0.0000002) and perennials (P=0.0002353) both retain more moisture than the industry mix. In the forty year old orchard, the exact same pattern persists. The annual (P=0.00084) and perennial (P=0.00084) subplots retain more moisture by volume than the control, the industry mix retains nearly the same amount moisture than the control (P=0.914), the perennials and annuals are nearly indistinguishable in moisture retention (P= 0.994), and the annual (P=0.007) and perennials (P=0.003) subplots retain more moisture than the industry mix. In the sixty year old orchard, the annuals (P=<0.001) and perennials (P<0.001) retain more moisture by volume than the control, the industry mix and control are indistinguishable in moisture retention (P=0.994), the annuals retain more moisture than the perennials (P<0.001), and the industry mix retained more moisture by volume than both the annuals (P=<0.001) and perennials (P<0.001).

Combining the annuals and perennials into a megamix only helped statistically in the forty year old orchard (P<0.001), where it provided better moisture retention than both the annuals (P=0.006) and perennials (P=0.011) on their own. In this orchard, the perennial and annual subplots retained nearly the same amount of moisture (P=0.996). Compared to the megamix, the annuals (P=0.032) and perennials (P=0.018) retained less moisture by volume in this orchard. The megamix was indistinguishable in moisture retention from the annual and perennial mixes in both the fifteen (annuals, P=0.999; perennials, P=0.949) and sixty year (annuals, P=0.418; perennials, P=0.999) old orchards. In the fifteen year old orchard, none of the other subplot cover types significantly retained more moisture than the control subplot type. The annual (P=0.548) and perennials (P=0.8800) retained less moisture than the control, while the industry mix (P=0.628) retained less moisture compared to the control as well. In the sixty year old orchard, the annual (P=0.0018) and perennial (P=0.1374) subplots both retained significantly more soil moisture than the control subplot. The industry mix subplot (P=0.122) also retained more moisture than the control subplot. In this orchard, the perennials retained more soil moisture by volume than the annuals (P=0.386).

Vegetation Cover Data, Hypothesis H4

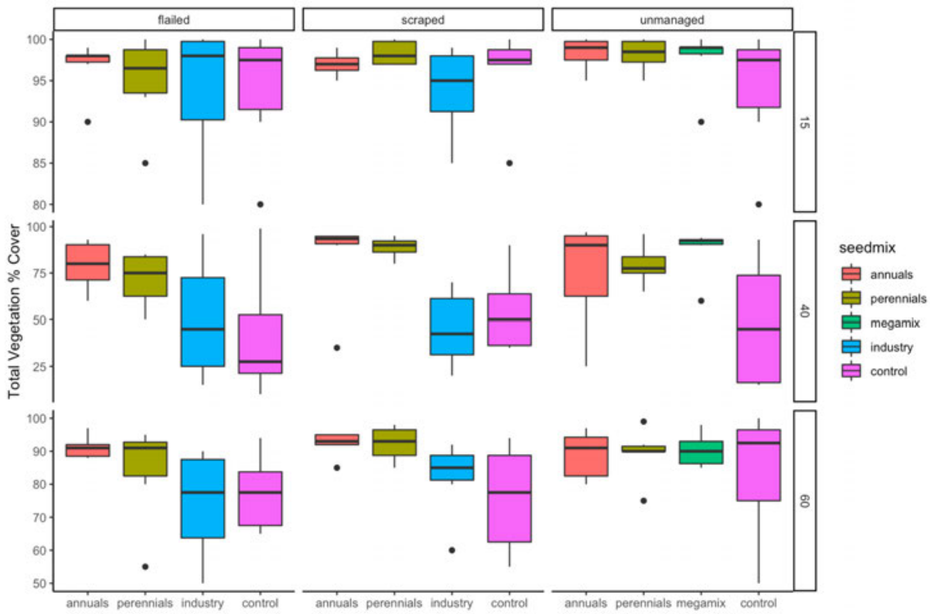

Figure 4.0 *- Total Vegetation Cover by cover crop treatment, orchard age, and mechanical treatment (%), 2020 Cover Crop Data*

This figure shows how mechanical treatments and orchard age affected total percent vegetation cover by subplot. In all orchards, the native mixes (annuals, perennials, and megamix) had highest percent cover compared to the industry mix and the control. For total vegetation cover in each subplot, each boxplot contains only information about total vegetation cover-- this includes weeds and the targeted species. In the 15 year old orchard, the highest concentration of weeds was seen across all mechanical treatment types. In the 40 year old orchard, the annuals and perennials had high cover, though the industry mix only had high cover in the unmanaged plots. Vegetation did not usually grow well inside of the control subplot, which acts as a good comparison for the amount of weeds that grew in the other control plots in the two other orchards. In the 60 year old orchard, every target cover mix grew well, and many of these target crops excluded weeds from the subplots, although many weeds germinated in the control subplot.

Discussion

Soil Moisture and Mechanical Treatments

For my hypothesis on mechanical treatments, I initially said that (C) plots would retain the most amount of soil moisture in every orchard, that (C) plots would lose the least amount of moisture over time, and that plots with a less disturbed organic material layer ((C) and (F)) would preserve soil moisture better than those plots with an intensely disturbed organic layer (FS). Organic material in soil acts as a sponge to moisture and nutrients, slowly releasing these vital resources over time (DuPont, 2020). Without the intact layer of topsoil to absorb and retain water, i.e. the (FS) plots, orchards with floor management strategies similar to the (FS) treatment type may suffer more extreme drought conditions and require more irrigation and fertilizer. For the mechanical treatments, my hypothesis was mostly supported, aside from the (C) plots maintaining the most amount of soil moisture in every single orchard. This may be because of the top soil remaining intact, undisturbed, and the additional organic layer being preserved (Sambeek, 2017). Inside of the 60 year orchard, the (F) plots retained the most amount of soil moisture, and in the 40 year old orchard, the (FS) plots lost the least amount of soil moisture.

Overall, the strongest correlation seen amongst all of the data is the relation of mechanical treatment type and cover crop treatment type with the age and the canopy cover of the orchards. It seems that the most crucial factor determining the retention of water in orchards is the amount of sunlight that reaches the orchard floor. This being said, this data does show that mechanical treatment types and cover cropping treatment types have differing effects on the amount of moisture retained. As seen in the results, the general trend by orchard age shows that orchards with more open canopies will lose more soil moisture than those with more closed canopies. As orchards progress with age, the general trend shows that older orchards will lose more soil moisture than the younger orchards. This is probably due to the older orchards having to combat Eastern Filbert Blight for a longer period of time, resulting in more orchard pruning, and consequently, more sunlight directly heating the orchard floor. These older orchards have larger temperature differences between nighttime lows and daily highs seen in when comparing the different orchards' canopy cover, and by the amount of water used by the different ages of trees. The younger orchards have a lot of sun exposure to the floor because of their open canopies, but do not experience this drastic temperature difference between day and night due to the constant exposure to the sun. (Washington State University, 2017). Older tree stands that are closer to their prime productive age use more water than young trees, and old, dying trees. This is due to the water requirements to keep larger trees alive, produce a substantial and healthy crop, and have effective means of transpiration (Grant et al, 1999).

Because of the patchy canopy cover seen in older orchards, the 60 year old orchard is a good example of this because of its patchy canopy combined with old tree age; the shade versus direct sunlight inside the orchard changes throughout the day while the trees consume more water than younger orchards, whereas the fifteen year old orchard has constant direct sun upon its floor and the trees require less water throughout the season. The (C) and (F) plots have a layer of organic litter, either crushed up by the flail mower, or in its original state in the (C) plots. This creates a buffer from warm, direct sunlight, enabling more soil moisture retention because of the added surface area and absorptive material, as compared to the (FS) plots that lack this organic material (Yang et al, 2018). Because the 40 year old orchard has a completely closed canopy, the (FS) plots likely did not see that added element of evaporation due to direct sunlight. These plots likely absorbed and retained most of water that penetrated the canopy during the rain events, but saw less evaporation because of the closed canopy.

Vegetation Cover and Mechanical Treatments

While I did not have a hypothesis about vegetation cover and mechanical treatments, I would like to acknowledge that the mechanical treatment types across orchard age did not vary greatly in terms of vegetation cover ability (see figure 4.0). In the fifteen year old orchard, all three mechanical treatments had consistent vegetation cover in all subplots, aside from the industry mix in the (FS) plots. I think this may be due to the lack of organic material for the grasses to germinate and root on top of. The native mixes seemed very fine germinating in the (FS) plots, and this may be due to their adaptive ability to grow in poorer nutrient and soil conditions. In the forty year old orchard, the results regarding vegetation and mechanical treatments are a little more varied than the fifteen year old orchard. While the (F) and (FS) plots closely resemble each other in results, the (C) plots suited the annuals and megamix seed mixes much better than the perennial seed mixes. The same trend between vegetation cover and mechanical treatments happened in the sixty year old orchard, with the cover crops closely resembling the same growth patterns in (F) and (FS) plots. In this orchard, the cover crops also responded differently to the (C) plots. For these patterns to closely resemble each other in both orchards, I think that this issue may come from the disturbance of the organic material layer on the top soil. With this layer not being disturbed one year prior to cover crop germination, these plots absorb and retain more water than plots with mechanical disturbance (see figures 2.0 and 3.0). I think that this ability to absorb and retain more water in the soil, and also have a viable gemination bed, is the key to why these plots saw higher vegetation cover from all target and non-target species and mixes (see figure 4.0).

After all of the mechanical treatments had taken place, including flailing, scraping, sweeping, and harvesting, many of the dominant perennial species survived. Most of these individuals also survived well enough to grow more leaves, many even surviving the early winter frosts that have coated the Willamette Valley. Many of these individuals are also outcompeting the invasive grasses and forbs that have germinated or retained their leaves since last growing season. This is the case for the three plots in the fifteen year old orchard that were overrun by *Poaceae, Brassica, and Equisetum* species. The planted, native species that are currently dominating those plots over the invasives are *Prunella vulgaris, Achillea millefolium, Eriophyllum lanatum,* and *Geum macrophyllum.* In the other orchards, in the mechanically treated plots, the species that have survived to grow more or have noticeably reseeded thus far are *Achillea millefolium, Geum macrophyllum, Prunella vulgaris, Eriopyllum lanatum, Potentilla gracilis,* and the members of the industry mix, *Avena sativa, Hordeum vulgare,* and *Trifolium repens* (see figure 6.1).

Vegetation Cover and Moisture

For the hypothesis regarding the cover crop treatments, it was said that in every age of orchard, the megamix would result in the highest amount of water retention and would have the highest total vegetation cover. It was also predicted that the native seed mixes would result in higher rates of soil moisture retention and be more productive than the industry mix. Although my hypothesis was not supported, the megamix does seem like a promising seed mix when cover cropping in an orchard with a patchy/partially closed canopy. Overall, the annuals did the best in open canopies and the perennials did the best in the closed canopies, with the patchy canopy suiting best for both mixes. In all orchards, the megamix did decently, but usually somewhere in between the productivity and moisture retention levels of the perennials and annuals, depending on the canopy cover of the orchard (see figure 3.0). This is likely due to the megamix being a nearly exact combination of both the annual and perennial seed mixes.

Additional Points of Discussion

The canopy cover density factor was the most prominent factor determining which cover crop mixes did best in which orchards. The orchards with less dense canopies often saw a general greater success of annual and megamix subplots thriving better than perennials, whereas the orchards with the greater percent canopy cover had better success with the perennial seed mix. Inside many of the open canopies, a lot of the perennial mixes flowered and went to seed because of the access to ample sunlight. This will improve the ability to have long-term cover cropping in hazelnut orchards without the need to reseed every year. Unfortunately, not many subplots in the 40 year old orchard had perennial or annuals plants flower or go to seed. In this orchard, the only plants that made it to the flowering stage before they started to decompose were individual *Plectritis congesta, Amsinckia menziesii,* and a very small number of *Gilia capitata* individuals. The perennial forbs did much better in the closed canopy orchards due to their adaptive ability to put all of one years worth of energy into energy production and storage. Next year, this saved energy will aid in the production of flowers, and hopefully, the reproduction of the perennial plant communities. The annuals did not perform well in these shady environments due to their inability to flower in one season without ample energy for reproduction (Friedman et al, 2015).

As the dry season progressed, almost all of the perennials flowered in the fifteen and sixty year old orchards. Of the perennials that did not flower, the largest reason was competition for sunlight, water, and nutrients amongst many of the other great perennial competitors. The perennials that did not make a significant appearance were *Viola praemorsa, Lomatium nudicaule,* and *Agoseris grandiflora* (see figure 6.1 and 6.2). Similar growth patterns appear in these plants, like basal leaves, shallow roots, and shade intolerance. None of the perennials flowered in the forty year old orchard, but because of their vigorous growth and survival of the mechanical treatments, they may produce flowers next season.

In the 60 year old orchard, all seed mixes did very well, and I predict that both annuals and perennials will return next year if they can adequately compete with the non-native seed bank already present inside of the orchard. Many of the flowers in this orchard produced very full blooms and almost every species went to seed, excluding those species that did not compete well with the other cover crops (see figures 6.1 and 6.2) . Inside of the 15 year old orchard, the first three plots in this orchard mass produced blooms in both the annual and perennial subplots, but the last three plots did not do well at all. These last three plots had a south facing exposure blocked by forty-foot tall pine trees and had a very difficult time competing with *Equisetum, Poa,* and *Brassica* species that dominated this area.

For the industry seed mix, the 60 year old orchard tended to have the better success with this cover crop. Because this seed mix is specifically recommended for orchards that are young and have open canopies, I would have expected this seed mix to do much better in the 15 year old orchard, but the general pressure from the weeds and deer herbivory made this mix hard to grow in this orchard. In the 60 year old orchard, the lack of weed seed bank and ample access to light likely made it easier to grow in this orchard. The industry mix did not do well inside of the 40 year old orchard. This is likely due to the lack of sunlight during late spring and into the summer, when this seed mix really started to grow in the other two orchards, and to the herbivory, which occurred at all orchards, but primarily the 40 year old orchard. For this mix, both the oats and barley went to seed, where the seeds have now germinated and started to re-colonize the plots in the sixty and fifteen year old orchards. The vetch and clover did not produce many seeds, and whether or not the complete seed mix community will return, this mix may not be a great cover community for most farmers, as these cover crops do not retain much soil moisture (see figure 3.0), compete with weeds very well (see figure 4.0), or withstand pressure from herbivory.

Cover Crop Suggestions

With general conclusion, this study suggests that cover crops can be utilized by hazelnut farmers as a way to retain moisture in their orchard floor, especially a mix of diverse, native species that are adapted to similar ecosystems as these specific agricultural settings. Overall, native cover crops performed much better than industry crops and the non-seeded control. While industrial and agricultural crops are useful to some farmers in certain contexts, these crops may not provide many ecosystem services to farmers or wildlife. Native cover crops may readily suit native fauna that are specialists in their ecosystem role, all while contributing to the genetic diversity of wild populations of these forb species which are in decline. As seen from this study, native cover can also facilitate many important ecosystem services that farmers and wildlife may benefit from.

Because of the data produced by this experiment, I would like to suggest a few cover crop mixes for different ages of hazelnut orchards (see figure 6.2). For young orchards with open canopies, ranging from ages 0-20, or until the canopy closes, I would recommend using an native annual seed mix or a megamix of annuals and perennials. These mixes compete with weeds better and retain more moisture because of the amount of ground cover they provide. For orchards with closed canopies, I would recommend a native mix of perennials that thrive well in shade. The perennials provide nice, low ground cover that retains soil moisture, but also does not decompose when the orchard interior gets too moist. For older orchards with a patchy canopy, I recommend any of the native mixes, depending on what the orchard manager is interested in. All three native mixes did very well inside of the 60 year old orchard, all of them providing a good amount of ground cover that aided in soil moisture retention. The perennials act as a lower-lying ground cover compared to the megamix and the annuals, which will likely get to be about three feet tall. Many other great ecosystem services can also come from planting native cover crops. Services such as pollinator foraging, habitat for insects, small mammals, and birds, nutrient cycling and soil formation, as well as the service tested in this study: soil moisture retention. Many farmers can also alter the list of seed mixes provided (figure 6.1) to suit their specific needs, like nitrogen fixation and erosion control.

Next Steps

With the advancing research possibilities in agroforestry, restoration ecology, and hazelnut orchard management, I would like to continue working on this project by researching and testing different variations of annual and perennial seed mixes, introducing new species combinations, and expanding the vegetation cover crop plots to see if these cover crops can work inside of a large scale orchard setting. If these new tests become better possibilities for future farming practices, I would someday like to explore different mechanical treatment types and advance this project in more explorative ways that can help farmers, like soil remediation, erosion control, and native cover nitrogen fixation. Overall, there is a lot more research to be done in this field, and specifically within the boundaries of reintroducing more ecosystem services back into agricultural settings in the Willamette Valley.

Appendix

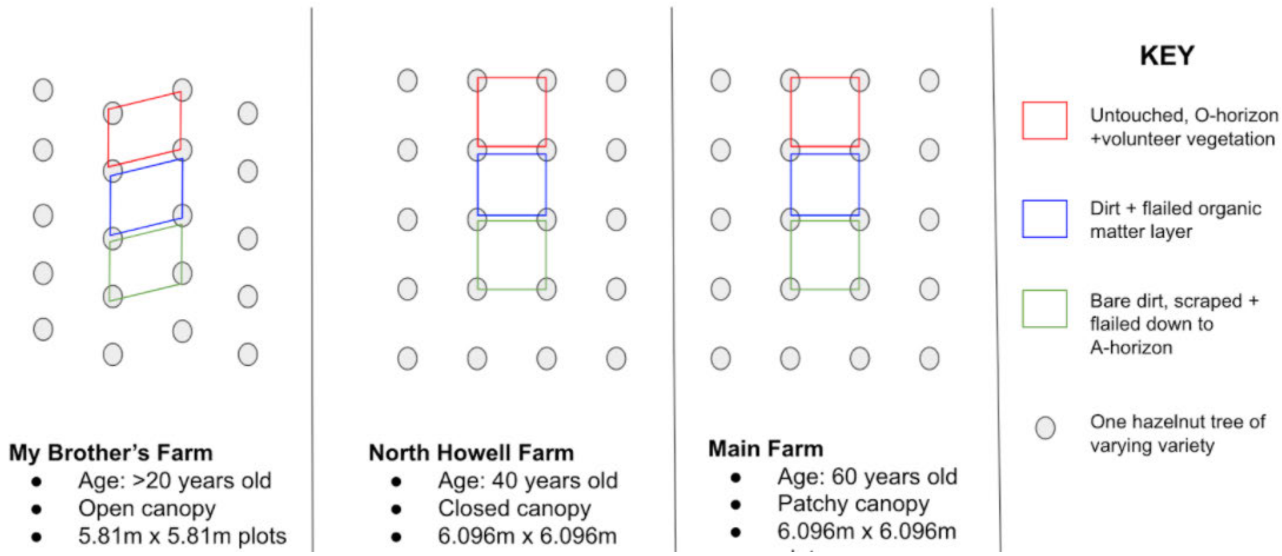

Figure 5.0 *- Mechanical Treatment Experimental Design by farm age*

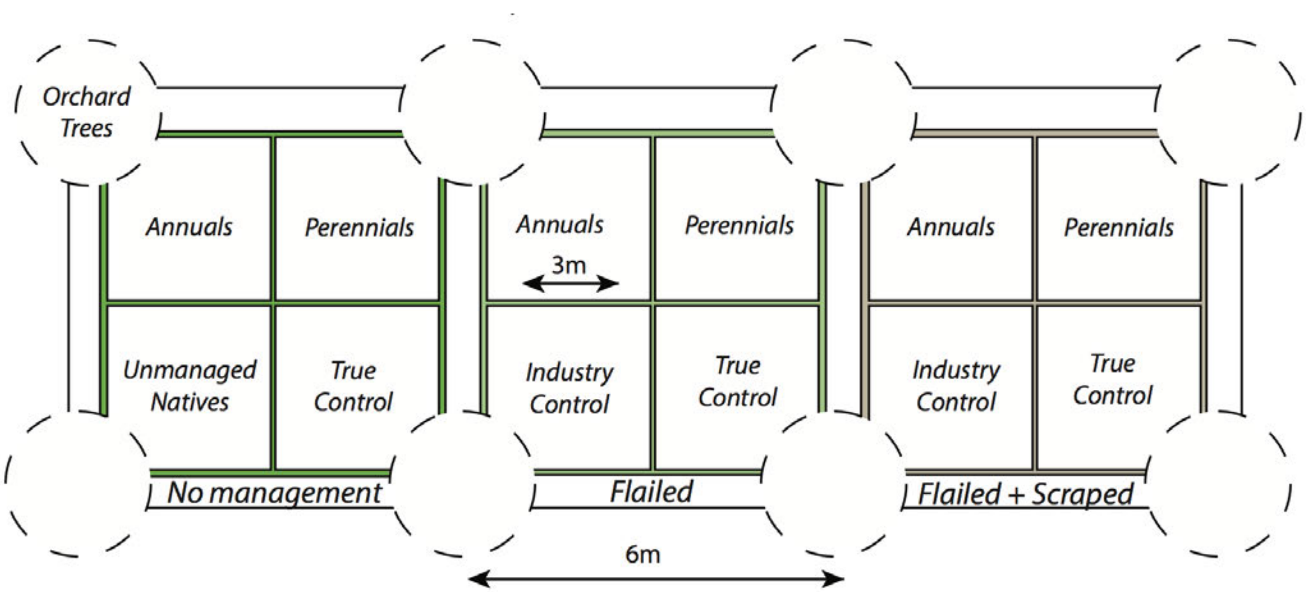

*Figure **6.0** - Cover Crop Experimental Design*

Annuals	*Amsinckia menziesii, Clarkia purpurea, Collomia grandiflora, Gilia capitata, Epilobium densiflorum, Lotus purshianus, Plectritis congesta,* and *Sanguisorba annua.*
Perennials	*Achillea millefolium, Agoseris grandiflora, Geum macrophyllum, Eriophyllum lanatum, Lomatium nudicaule, Potentilla gracilis, Prunella vulgaris,* and *Viola praemorsa.*
Megamix	Everything listed in the annuals and perennials as well as *Carex tumulicola*, *Danthonia californica*, and *Festuca roemeri*.
Industry Mix	Common vetch, Dutch white clover, Oats, and Winter barley.

Figure 6.1 *- List of Cover Crop Species by Cover Crop Experimental Design Treatment*

Orchard Age	**Cover Crop Recommendation** (in order of viability)	**Specific Plants that Performed the Best**
0-20	1. Annuals 2. Megamix 3. Perennials 4. Industry Mix	*Amsinckia, Clarkia, Gilia, Plectritis, Collomia*
20-50 or 50-100+ (with a closed canopy)	1. Perennials 2. Megamix 3. Annuals 4. Industry Mix	*Geum, Achillea, Eriophyllum, Potentilla, Prunella, Epilobium, Clarkia,* and occasionally *Lomatium*
50-100+ (with an opening/open canopy)	1. Annuals 2. Megamix 3. Perennials 4. Industry Mix	Everything did decently well besides *Agoseris* and Dutch clover

Figure 6.2 *- Cover Crop Recommendations by Orchard Age*

Sources

American Journal of Botany. (2015, April). Retrieved December 3, 2020, from https://bsapubs.onlinelibrary.wiley.com/doi/10.3732/ajb.1500062

Baldwin, B. (2015, July). THE GROWTH AND PRODUCTIVITY OF HAZELNUT CULTIVARS. Retrieved December 02, 2020, from https://core.ac.uk/download/pdf/41240273.pdf

Climate Change. Retrieved June 12, 2020, from https://www.oregonconservationstrategy.org/key-conservation-issue/climate-change/

DuPont, T., Granatstein, D., & Sallato, B. (2020, November). SOIL HEALTH IN ORCHARDS. Retrieved December 02, 2020, from http://s3-us-west-2.amazonaws.com/treefruit.wsu.edu/wp-content/uploads/2020/11/23134102/EM120E_Soil-Health-in-Orchards.pdf

Future Climate. (2018, July 24). Retrieved December 03, 2020, from https://inr.oregonstate.edu/ww2100/analysis-topic/future-climate

Grant, R., Black, T., Hartog, G., Berry, J., Neumann, H., Blanken, P., . . . Nalder, I. (1999, November 01). Diurnal and annual exchanges of mass and energy between an aspen‐hazelnut forest and the atmosphere: Testing the mathematical model Ecosys with data from the BOREAS experiment. Retrieved December 03, 2020, from https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/1998JD200117

Grinath, J., Larios, L., Prugh, L., Brashares, J., & Suding, K. (2019, January 29). Environmental gradients determine the potential for ecosystem engineering effects. Retrieved June 2020, from http://www.oikosjournal.org/appendix/oik-05768

Gucker, C. (2007). Quercus garryana. Retrieved December 03, 2020, from https://www.fs.fed.us/database/feis/plants/tree/quegar/all.html

Hazelnut production. Retrieved June 12, 2020, from http://www.fao.org/3/x4484e/x4484e03.htm

Jiles, K., Houston, L., Rupp, D., Wiman, N., & Mote, P. (2016). Climate Zones for Hazelnut Production. Retrieved May 30, 2020, from https://www.reacchpna.org/sites/default/files/Kirstie_Jiles.pdf

Mingeau, M., Ameglio, T., Pons, B. and Rousseau, P. (1994). EFFECTS OF WATER STRESS ON DEVELOPMENT GROWTH AND YIELD OF HAZELNUT TREES. Acta Hortic. 351, 305-314 DOI: 10.17660/ActaHortic.1994.351.33
https://doi.org/10.17660/ActaHortic.1994.351.33

Natural Resources Conservation Service. (n.d.). Retrieved December 03, 2020, from https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ny/technical/?cid=nrcs144p2_027252

Observed and projected climate shifts 1901-2100. (n.d.). Retrieved December 03, 2020, from http://koeppen-geiger.vu-wien.ac.at/shifts.htm

Orchard Floor Management. Retrieved June 12, 2020, from http://treefruit.wsu.edu/orchard-management/orchard-floor-management/

Oregon Conservation Strategy. The Willamette Valley Landowner's Guide to Creating Habitat for Grassland Birds. Retrieved December 02, 2020, from https://www.dfw.state.or.us/conservationstrategy/docs/grassland_bird_habitat/grasslands.pdf

Oregon Hazelnuts . Retrieved June 2020, from http://oregonhazelnuts.org/

R. Catoni, L. Gratani, F. Bracco, M.U. Granata,
How water supply during leaf development drives water stress response in Corylus avellana saplings, Scientia Horticulturae, Volume 214, 2017, Pages 122-132, ISSN 0304-4238, https://doi.org/10.1016/j.scienta.2016.11.022.
http://www.sciencedirect.com/science/article/pii/S0304423816305805)

Sambeek, J. J. (2017). Orchard Management using Cover Crops to Improve Soil Health and Pollinator Habitat. Retrieved December 02, 2020, from https://www.fs.fed.us/nrs/pubs/jrnl/2017/nrs_2017_vansambeek_006.pdf

Ustaoglu, B. (2014, August). The effects of climate change on spatiotemporal changes of hazelnut (Corylus Avellana) cultivation areas in the Black Sea Region, Turkey. Retrieved June 2020, from https://www.researchgate.net/publication/270407818_The_effects_of_climate_change_on_spatiotemporal_changes_of_hazelnut_Corylus_Avellana_cultivation_areas_in_the_Black_Sea_Region_Turkey

Valness, K. (2019, January). Report from the State Board of Agriculture. Retrieved June 2020, from https://www.oregon.gov/ODA/shared/Documents/Publications/Administration/BoardReport.pdf

Wiman, N. (2019, January 15). Evaluating cover crops for mature hazelnut orchards in the Willamette Valley, Oregon. Retrieved June 12, 2020, from https://projects.sare.org/project-reports/ow16-028/

Withrow-Robinson, B., & Johnson, R. (2006, November). Selecting Native Plant Materials for Restoration Projects. Retrieved December 02, 2020, from https://catalog.extension.oregonstate.edu/em8885

Yang, T., Ala, M., Zhang, Y., Wu, J., Wang, A., & Guan, D. (2018, June 21). Characteristics of soil moisture under different vegetation coverage in Horqin Sandy Land, northern China. Retrieved December 03, 2020, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6013216/