Impact of in-row living mulches on tree growth,

soil moisture and weed management in an organic high-intensity apple orchard

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Abstract

The benefits of traditional mulches, such as bark, straw and plastic, are well documented in the literature, as are their issues. In-row management with living mulches (LM) has the potential to deal with many of these issues, enhancing soil management, and being a crucial element for agroecological fruit production. However, optimum agroecological practices are site-specific and require local knowledge. To evaluate the impact of in-row LM on tree growth, soil moisture and weed management in an organic high-intensity apple orchard, a 16-week long experiment was run at the Garden City Lands in Richmond, BC. A randomized complete block design (RCBD) was used to evaluate the effects of three LM types (alyssum, microclover, and nasturtium), as well as an organic mulch (bark) and a control. The effects were evaluated on 60 trees and four apple varieties (Empire, Spartan, Fuji, and Sunrise). The results showed that microclover provided the best performance of all mulches tested by several different measures. Microclover established cover rapidly, and the microclover plots retained significantly more soil moisture than the other plots. The organic mulch (bark) retained less moisture than any of the living mulches or the control. Microclover was also the most successful LM in terms of weed control, although all of the LM provided weed control (with alyssum least successful, but still more effective than the unmulched control). Mulch type did not affect any of the tree growth parameters (trunk girth, shoot length, SPAD meter readings). For the parameters measured, microclover LM delivered the greatest benefits.

Introduction

Organic fruit producers face limited options for agroecological orchard floor management and also face greater challenges as climate change intensifies. There is a need for more research into the efficacy of available floor management options (Sosna and Fudali 2023). More importantly, research is needed about how agroecological practices can effectively deal with the floor management challenges without negatively affecting long-term soil health and production (Neilsen et al. 2014) and at the same time help to reduce inputs and cost (Bałuszyńska et al. 2023). Orchard floor management directly affects fruit production since the overall nutrition of trees is influenced by type of vegetation used in management as much as the agricultural practices for management (Mullinix, K. and Granatstein, D. 2011; Neilsen et al. 2014).

Weed management is one of the main issues for orchard floor management, since weeds compete for available resources, affecting overall tree growth and fruit development (Mia et al. 2020; Sosna and Fudali 2023). One challenge is to manage both weed pressures and pests with agroecological practices in a way that will not have a detrimental effect on tree development and fruit production (Bałuszyńska et al. 2023; Sosna and Fudali 2023). Weed pressure is particularly difficult for high-density organic production, because this type of orchard usually bears fruit early, abundantly, and every year (Sosna and Fudali 2023). Usually planted with dwarf trees having tight in-row spacing, trees in these orchards have a rather weak root system (Sosna and Fudali 2023) and require soil rich in nutrients and water availability (Sosna and Fudali 2023). Moreover, effective options such as mechanical cultivation entail the risk of trunk and surface root damage (Mia et al. 2021), degradation of soil structure, and use of fossil fuel; along with increased costs (Neilsen et al. 2014) and negative impacts on the environment.

The purpose of the proposed research is to evaluate the effects of three in-row annual living mulches as a means of improving soil moisture, with a focus on their impact on tree growth and weed control. This research will be done in an organic, high-density apple orchard, building on past research conducted at this orchard in Richmond BC.

Overview

A long-term goal of organic production is to build soil organic matter and maintain the overall soil health (Neilsen et al. 2014). Orchard floor management plays a crucial role in the overall health and performance of the trees (Mullinix and Granatstein 2011).

An ancient agroecological practice is the use of mulch. The term “mulch” comes originally from the German word “molsch” meaning “easy to decay” (Iqbal et al. 2020), as common mulch materials were organics such as straw, tree cuttings and leaves, that through decay will improve soil health (Iqbal et al. 2020;). However, mulch materials such as clippings, branches and dead leaves have known drawbacks. For example, they tend to attract vermin and host diseases and pest (Sosna and Fudali 2023), to the detriment of the orchard.

Mulching is allowed in organic production for weed suppression and promoting soil health (Golian, Anyszka and Kwiatkowska, 2023; Iqbal et al. 2020; Mia et al. 2020; Qian et al. 2015), and can be an important part of an orchard floor management plan. Soil management is a critical factor that can impact tree development, fruit quality and yield (Golian, Anyszka and Kwiatkowska, 2023; Sosna and Fudali, 2023). For organic production, plastic mulches have emerged as an alternative to organic mulch. However, plastics are a non-renewables resource, are not recyclable, and generate a large amount of microplastic pollution in the environment (Huang et al. 2020).

Living mulches (LM) are suitable for organic farming, and offer a promising alternative. For soil management with LM, the orchard floor is planted with annual or perennial plants for coverage (Golian, Anyszka and Kwiatkowska, 2023; Sosna and Fudali 2023;. Qian et al. 2015), These plants prevent weed emergence by outcompeting weeds for light, nutrient and soil moisture (Mia et al. 2021).

Weed pressure is one of the main problems for organic fruit production due to the difficulty of agroecological weed management. Orchards that are overgrown by weeds can have multiple problems, ranging from reduced pollination that results in poor yields, to creating favourable conditions for pests and disease, to increased risk of frost damage (Golian, Anyszka and Kwiatkowska, 2023). There are few agroecological practices available at small scale that successfully reduce weed competition with the trees. Most practices aim to control weeds by physically removing them (Mia et al. 2021) which requires expensive seasonal inputs for hand labor and mechanical weeding which also requires fossil fuels, or rely on the use of non-renewable resources such a plastic mulch (Neilsen et al. 2014). For example, weed control by regularly tilling the soil has long-term effect on the overall soil health while also damage the tree roots (Mia et al. 2021), particularly of low-vigor rootstocks with shallow root system (Sosna and Fudali, 2023). This in turn directly impacts tree growth, fruit yield, and fruit quality (Mia et al. 2021). Another hybrid solution for weed management is called the sandwich system (SS) which combines partial areas with LM grasses and leguminous areas with tilled strips. This approach has beneficial impact for biodiversity and nutrient cycling (Neilsen et al. 2014; Mia et al. 2021).

Orchard floor management use mainly the Fabaceae and Poaceae family species as LM (Golian, Anyszka and Kwiatkowska, 2023). Generally, valued characteristics for LM species are their suitability to local climate, shallow root system, an appropriate root-to-shoot ratio, high drought tolerance, low competitiveness for nutrients, and overall low maintenance. (Golian, Anyszka and Kwiatkowska, 2023). In contrast, species with high nutrient requirements, or that have the potential to host pests and diseases, or that have long growing season and late flowering that can detract pollinators from the trees, should be carefully considered before introducing them (Golian, Anyszka and Kwiatkowska, 2023).

One of the main benefits of LM is that it promotes agroecological soil management, while reducing inputs, including plastic use and fuel consumption. Another benefit of introducing LM is that its introduction provides proper soil management through the whole season while enhancing soil health and biodiversity in the long term (Bałuszyńska et al. 2023; Mia et al. 2021). For example, one study shows that LM can improve soil microbial communities which are crucial for nutrient cycling and decomposition of organic matter (Qian et al. 2015). Species selection and timing of their introduction can have various impacts on trees in an orchard, depending on several factors such as the age of the orchard, tree cultivar, and orchard floor management systems (Bałuszyńska et al. 2023; Sosna and Fudali, 2023). For example, Mia et al. (2021) found that the suppressive effect of *Alchemilla vulgaris* (lady's mantle) and *Mentha piperita* on weeds was achieved in the second summer season, reaching almost full coverage of the soil and control of the weed development. Additionally, they also found that chlorophyll index and nutrient content of apple leaves were higher when LM *Alchemilla vulgaris* (lady's mantle) (Golian, Anyszka and Kwiatkowska, 2023), and *Mentha piperita* were introduced (Mia et al. 2021). Furthermore, LM had potential to offer farmers a second crop. As researchers are gaining more understanding on the benefits certain species, farmers may be able to choose from various LM species, such as grasses, legumes, other crops or culinary herbs (Mia et al. 2021). For example, second crop benefits may be obtained by using small flower such as *Alchemilla vulgaris* (lady's mantle) and culinary herbs such as *Mentha piperita* (Mia et al. 2021). Another example showed that annual crops such as *Tropaeolum majus* suppressed more weed growth (33.4%) compared with control in-rows of the apple trees (Golian, Anyszka and Kwiatkowska, 2023). Lastly, research is showing the potential cost-effectiveness of LM in comparison with other types of mulches. Research has shown that LM has a lower initial cost than organic re-application of straw or bark in tree rows, and also lower cost than synthetic and plastic mulch. (Bałuszyńska et al. 2023)

Inconsistent Findings

There are inconsistent findings in the literature when it comes to assessing if LM benefits offset the potential drawbacks of different LM species. For example, weed pressure levels on LM changes over time, depending on which species of LM are sown, the types of weed that emerge, and the timing of the interaction between LM and weed species, with that interaction determining the effectiveness of LM at weed suppression (Bałuszyńska et al. 2023). Other findings have shown that perennial weeds can remain dominant whereas annuals may emerge simultaneously (Bałuszyńska et al. 2023). However, the soil cover will depend on the date at which plants are sown, the sowing density, maturity date, (Golian, Anyszka and Kwiatkowska, 2023), and favorable environmental conditions for their germination. Even a single LM species can show inconsistent results. For example, the introduction of white clover (*Trifolium repens*) as LM may positively influence flavour of pears, but other research has found that white clover can be problematic on the long-term due to an increase in weed pressure and its attractiveness to rodents (Sosna and Fudali, 2023). These inconsistent findings also show the need for more research to gain better understanding of interspecies competition, since one of the main drawbacks of LM is nutrient competition (Mia et al. 2021; Sosna and Fudali, 2023), which subsequently impacts tree growth and development (Bałuszyńska et al. 2023; Mullinix and Granatstein 2011;), and fruit size, weight and flavour (Sosna and Fudali, 2023). From an agroecological perspective, the inconclusive results from introducing LM show that an orchard floor management system that does not physically or chemically remove weeds, will inevitably entail trade-offs in the short term. There may also be trade-offs in the long-term, showing that while LM is generally a desirable and sustainable approach to orchard floor management, it is also imperfect, and individual applications should likely have site-specific research.

One important reason for research into LM is that it may help to mitigate the effects of climate change, which is dramatically affecting fruit production. Orchard floor management systems that LM can regulate temperature oscillation and promote soil moisture (Zoppolo et al. 2011), which can help to mitigate the effect of drought and heat. Producers in British Columbia have already faced extreme situations such as drought and off- season extreme high (and low) temperatures. In 2023, extreme and unusual climate conditions killed off fruit production in BC's Okanagan valley, triggering an emergency response for the province to deal with the economic impact (Strachan, 2024). This makes local research into LM especially important.

Locally based research on the use of LM can help to identify suitable and appropriate species for a specific cultivar to improve the overall resilience of orchards, and help to buffer the impacts of some of these extreme events. Simultaneously, identifying species that are resilient can reveal which are the least competitive for the fruit tree cultivar as well as less attractive to pest and diseases (Mia et al. 2021). This can help organic growers to explore LM as a method for pest management and control, by selecting the appropriate species (Neilsen et al. 2014) while minimizing interspecies competition as LM is established (Mia et al. 2021).

Research done abroad may not provide reliable insights to performance under local conditions, even in historically similar bio-geoclimatic zones, as climate change impacts can create impacts with variations even between similar regions. Agroecological practices need to be tailored to the tree cultivar, LM species and local conditions. Consequently, local research is needed to identify which species are best suited to deal with the effects of climate change in our local environmental conditions. For example, water management is a priority in British Columbia and research has shown that LM reduces evaporation compared with bare soil (Qian et al. 2015).

Previous site-specific research into LM has been conducted at the organic, high-density apple orchard that is the subject of the present study. Research conducted by Wu, C. (Harrison) in 2023 evaluated LM weed suppression and the impact on beetle biodiversity, and found that Alyssum and bark mulch can effectively suppress weed growth in the early stages of orchard establishment. The present research has built on this work, expanding on the effect of LM on tree growth, soil moisture and weed management. This present research has been carried out to better understand how LM can be successfully incorporated into the orchard in-row floor management, considering the impacts on different tree types with various LMs.

Material and Methods

Hypotheses

The present study was developed to evaluate three central research hypotheses: (1) identify if LM effects on soil moisture, (2) evaluate if LM affects tree growth, and (3) determine if LM can supress weeds in organic systems. The experimental site, experimental design, data collection methods, and statistical analysis approach used in addressing these research hypotheses are described in the following sections.

Experimental Site

The research was conducted from June to September of 2024 at the high-intensity apple orchard located on the Garden City lands. This land is leased to Kwantlen Polytechnic University in Richmond, British Columbia, ($49^0$10'29.2"N, $123^0$07'13.4"W) Canada. This orchard is part of a 3.3 hectare organically managed farmland. The land is located in a temperate Oceanic Climate, Cfb, in the Köppen-Geiger classification system. The area has an annual mean temperature of 10.2^0 Celsius and annual mean precipitation of 1,952 mm (Climate-data.org, n.d.) with the majority of the precipitation falling in the winter months.

In late April of 2023, the orchard was planted with 60 dwarf apples trees of four varieties of apples (from north to south) *Malus x domestica Borkh* cv. Empire*,* cv. Spartan, cv. Fuji and cv. Sunrise, with dwarf rootstocks Budagovsky 9 (B9). The surface soil layer is imported, and the texture is sandy, clay loam, underlain by peat. The last farm soil analysis taken on February 15, 2024, reported that soil pH was 7.7, with high organic matter content and good EC (0.31). Nutrient analysis report for the soil estimated that potassium was optimum (516 lbs/acre), phosphorous was in slight excess (163 lbs/acre), sulfate-S was marginal (11 lbs/acre) and there was a nitrogen deficiency (47 lbs/acre).

The orchard's layout is a one-row system, with fifteen trees per each variety, spaced at 1.25 meters centers in an 80-meter row. The trees are drip irrigated and trellised on spindle system. No fertilizer is added, only compost which is added at start of the season and then topped up again during the fall. Overall the orchard is managed according to the current organic farming regulation in British Columbia.

Experimental Design

A Randomized Complete Block Design (RCBD) was set up with four blocks per apple variety:

- Block 1 Empire,
- Block 2 Spartan,
- Block 3 Fuji, and
- Block 4 Sunrise.

Each block had a total of 15 trees and within the block, with four replicates and five treatments. The five treatments consisted of three different LM species: Alyssum (*Lobularia maritima*), microclover (*Trifolium repens* var. *Pipolina*), or nasturtium (*Tropaeolum majus*). There was also a treatment with Bark (organic mulch) and the control was bare soil. The LM species were chosen due their valued characteristics as annuals, low growth habit and coverage, and low nutrient requirements.

Important characteristics of the LM species selected are as follows:

- **Alyssum** (*L. maritima*) is from the *Brassicaceae* family. It generally takes 50-60 days to reach maturity, and has a high drought and heat resistance. It may self sow.

- **Microclover** (*T. repens* var. *Pipolina*) is from the *Trifolium* family. It requires moist soil for germination, and germination generally takes 7-14 days. It grows low and dense, crowding out weeds. It is also an organic source of nitrogen, and is characterized by both high drought tolerance, and being cold hardy. It is unattractive to chafer beetles, so eggs would not be laid on Microclover.

- **Nasturtium** (*T. majus*) from the *Tropaeolaceae* family. The optimal soil temperature for its germination is between 12-18° C, and it takes between 55 and 65 days to reach maturity. The species has a compact growth habit, reaching an average height of 40cm (16"). It can thrive in poor to average, slightly acidic, well-drained soil. Edible flowers have the potential to provide a second crop if harvested.

Seed for alyssum (*L. maritima*) and microclover raw seed (*T. repens* var. *Pipolina)* was sourced locally from West Coast Seeds. Seed for the Dwarf Jewel Blend Nasturtium (*T. majus*) was sourced from "High Mowing Organic Seed". Bark was sourced from West Coast Bark Products, in Burnaby.

The experimental layout with RCBD is shown schematically in Figure 1. In the experimental layout, each plot has three trees, and measures approximate 2 m by 4 m, giving a plot area of 8 m^2. Individuals Blocks account for 40m^2 total (5 treatments in each block).

For the initial experimental setup, over two weeks in June 2024, all plots were mowed twice with BSC walk-behind tractor, underwent light cultivation and were hand weeded. Also, in addition to drip irrigation line used in the previous study at this site (Wu, 2023), two other drip lines were added, and 44 micro jet sprinkler (AJ-300 GR 0.050 sourced from watertecna.com) were installed at about 6 feet (183 cm) apart to have an overlap and to guarantee proper irrigation for the living mulch establishment. Then, each Microclover and Alyssum plots were direct seeded (broadcast) on June 22th, the control plot was weeded again and a 10cm layer of bark was placed on the corresponding plots. Nasturtium seeds were pre-soaked for 72hr before direct seeding in four rows

BLOCK 1					BLOCK 2					BLOCK 3					BLOCK 4				
Empire					**Spartan**					**Fuji**					**Sunrise**				
1	2	3	4	5	6	7	8	9	10	10	12	13	14	15	16	17	18	19	20
C	M	N	B	A	A	M	C	N	B	B	N	A	C	M	N	B	M	C	A

Figure 1. *Map of Garden City land farm showing the location of orchard over the purple section with the yellow arrow. Next diagram shows the twenty plots layout , from north to south, and the legend.*

in each nasturtium treatment. Treatments were dense-seeded starting from the tree base to the edge of the treatment area. After seeding, a weekly hand-weeding was performed in all plots for the following five weeks to ensure good establishment of all mulches. The only other intervention during the experimental period was mowing of the drive rows adjacent to the orchard. This was done by farm staff about three times during the growing season.

Data collection

Data collection was initiated June 1, 2024 and site visits were completed at least weekly for the experimental period, concluding September 16, 2024. The following data was collected:

1) **Soil moisture:** was measured weekly with a Fieldscout TDR 300 soil moisture meter, with 12 cm probes, to asses volumetric water content (VWC), which is reported as a percentage. Four measurements were taken per plot as shown in Appendix Figure B-23, starting from the middle point between trees approximated 50 cm away, with two measurements on the east side of the treeline and two measurements on the west side. Measurements during the first three weeks were taken with a 20 cm probe tip, however when one probe broke, measurements transitioned to the 12 cm probes, which proved more durable.

2) **Ground cover :** The Canopeo app was used to assess the percentage of cover on all plots (as shown in Appendix B Figure B-25). Cover was measured weekly for 13 weeks, with each plot divided roughly into quarters, two on the east side, and two on the west. One photo was taken per quarter, and measurements averaged for the east side, west side, and the plot total average.

3) **Weed domination:** Weed domination was estimated for each plot on a weekly basis for 9 weeks, using a photogrammetric method. A tripod with horizontal tube extension was used to hold a camera parallel to the ground approximately 1.2 m above the ground (as shown in Appendix B Figure B-22) and take one photo of a representative 1m by 1m square of the plot (shown within the photo frame). Each photograph was reviewed visually, and the percentage of cover species (versus weed cover) was estimated, to provide a quantitative indication if weeds were dominating or not (as shown in Appendix B Figure B-1 to B-21). The square was divided in quarters and the percentage cover as it follows: >50% cover species, <25% cover species, <15% cover species.

4) **Tree growth:** Three different, non-destructive, quantitative measurement were taken as indicators of tree growth.

   a) Tree trunk diameter was measured for all 60 trees every two weeks for 8 weeks. Measurements were taken at 50 cm above the grafting point, using a caliper with a measurement precision of 0.001 inch (measurements were converted to SI after collection), (as shown in Appendix B Figure B-24).

   b) Shoot length was measured for two branches per tree, one the central lead an the other on a branch selected with moderately horizontal growth. Data collection was every three weeks for 9 weeks, and was taken with a standard meter rule or tape measure.

   c) A one-time measurement was taken with a SPAD-METER to measure chlorophyll leaf content in order to see how much nitrogen is available for the tree. Since nitrogen is a component of chlorophyll, this allows one to indirectly measure the amount of nitrogen in the plant. This measurement was used to assess for differences between the trees/plots/treatments on August 17, 2024, once the growth was well established for all LMs.

Statistical Analysis

Repeated measures data were analyzed by Linear Mixed Model analysis and SPAD data were analyzed by ANOVA. All analyses were conducted using the jamovi interface for the R statistical computing environment.

Results

1) Soil Moisture Results

VWC ranged from 22% to 47.5%, with mean values in all plots in the range of 31.9% (Nasturtium) to 35% (Microclover).

Figure 2 shows the linear regression plot for soil moisture in all plots, separated by mulch type. Microclover performed significantly better in terms of moisture retention over the experimental period. This trend is also clear in Figure 3, which shows that the higher moisture retention in Microclover occurred at a statistically significant level. Figure 3 also shows that the other types of cover, including the control, had similar performance for moisture retention.

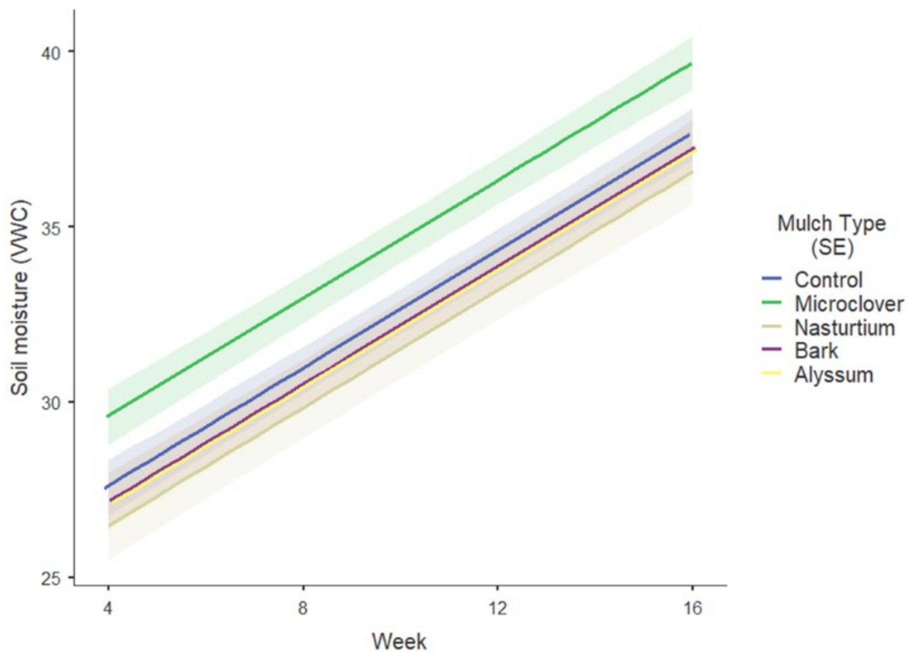

Figure 2. *Linear regression showing the impact of mulch on soil volumetric water content (VWC) over a period for 13 weeks. Shaded zones denote standard error of best-fit regression lines.*

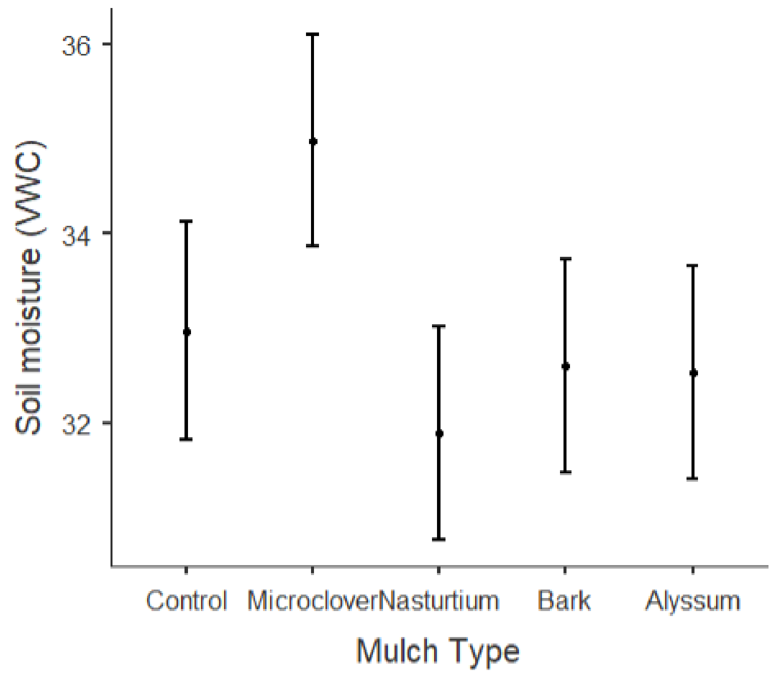

Figure 3. *Soil volumetric water content (VWC) beneath apple trees grown with microclover, nasturtium, or alyssum living mulches, as compared to plots mulched with bark, or no mulch (Control). Error bars denote standard deviation around each mean (n = 4).*

Soil Moisture and Ground Cover

The interaction between soil moisture and ground cover was also evaluated, with the analysis and the corresponding correlation matrix shown in Figure 4. Soil moisture was positively correlated with ground cover ($r = 0.47$, $p < 0.001$).

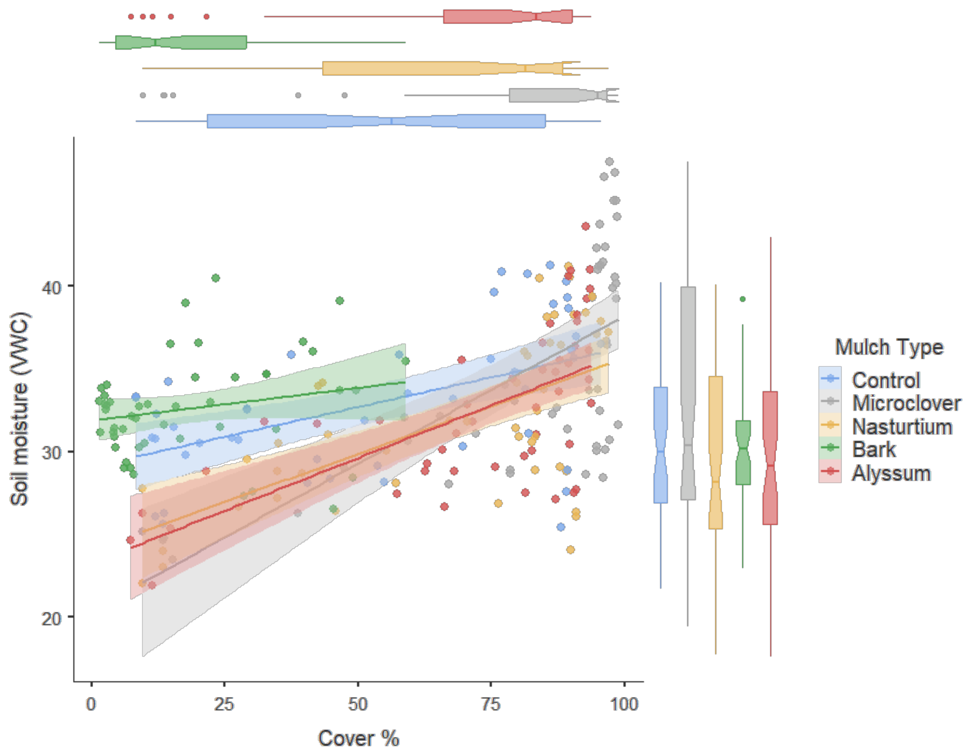

Figure 4. Interaction between effects of mulch treatment and proportion of plot surface covered in foliage (weeds and living mulch) on soil volumetric water content (VWC). Colours of best-fit regression lines vary by treatment. Shaded zones denotes standard error for each regression line.

2) *Ground Cover*

As shown in Figure 5, ground cover increased in all plots over time. Ground cover was least for the bark treatments over the entire experiment, which reflected the ability of bark to supress weed growth (all cover on the bark treatments was observed to be weed species). After bark, the control plot showed the least development of ground cover over time, and like the bark treatments, all cover growth was weed cover.

All three living mulches maintained greater ground cover, with the Microclover plots performing best. By week 16 of the experiment, only the Microclover and Nasturtium plots maintained over 75% groundcover. While a reasonable percentage of ground cover was also maintained on the Alyssum plot, observationally the alyssum was largely overrun with weeds by the end of the experimental period.

Figure 6 provides a more detailed view of the development of ground cover over time. During the first 8 weeks of the experiment, while hand weeding was carried out, all three of the living mulches rapidly began to establish cover. This cover establishment was most rapid for the Microclover plot, which reached roughly 75% cover after 8 weeks, followed by alyssum

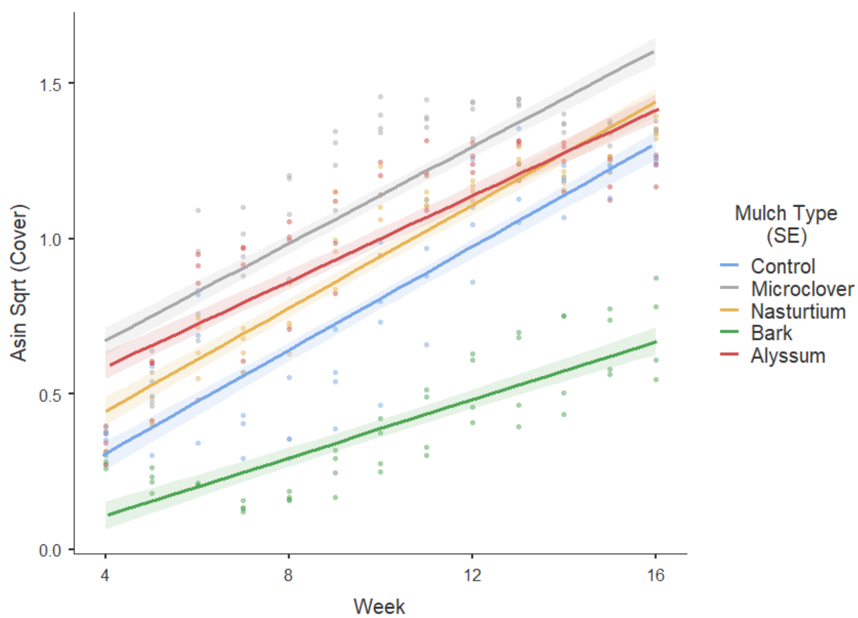

Figure 5. Linear regression of ground cover increase over time by mulch treatment. Ground cover proportion was arcsin square root transformed before regression analysis to better satisfy assumptions of a linear relationship. Shaded zones denote standard error for each regression line.

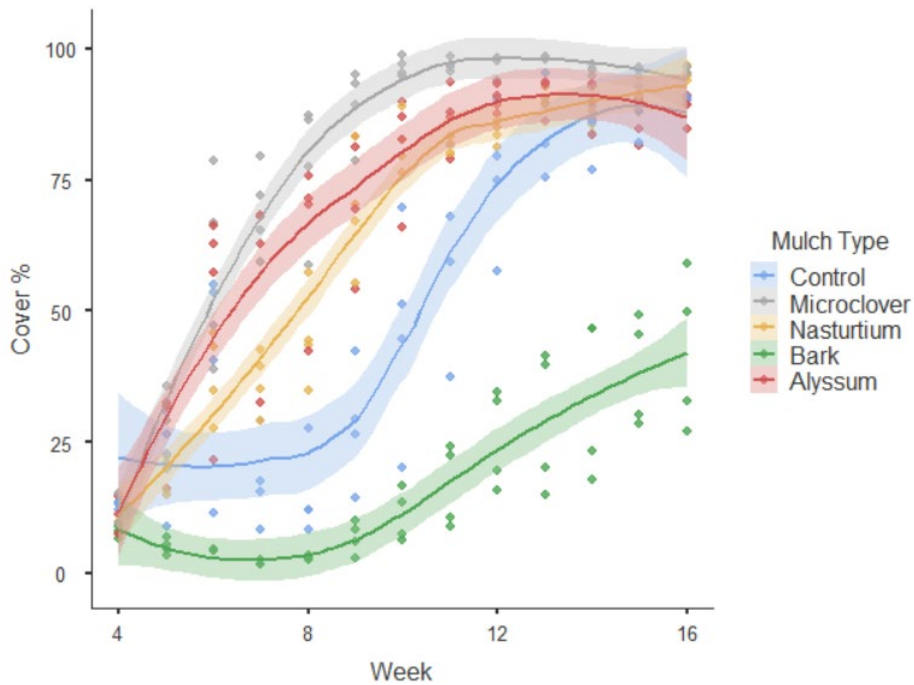

Figure 6. Ground cover development over time. Hand weeding was carried out up to Week 8.

(roughly 60% cover), and nasturtium (roughly 50% cover). By week 10, all living mulches had attained at least 75% cover.

As mentioned previously, the cover development after the weeding period on control treatments was entirely weeds. As can be seen in Figure 6, with the end of the weeding period, weeds established cover rapidly over the control plot, and grew far more slowly on the bark.

3) Weed Domination

Living mulches supressed weeds for part of the growing season, although all plots faced weed pressure. Several recurrent weed species were noted at most plots throughout the growing season. These included lady's thumb (*Polygonum persicaria*), lamb's quarter (*Che-nopodium album*), scentless chamomile (*Matricaria perforata Merat*), chickweed (*Stellaria* *media*), quack grass (*Elymus repens*), Canada thistle (*Cirsium arvense*), and shepherd's purse (*Capsella bursa-pastoris*).

Figure 7 shows the results of quantitative weed pressure measurements made over the course of the experiment. As can be seen in Figure 7, the weed coverage increased most rapidly in the control plots after the hand weeding period ended on week 8. This aligns with the total cover observations made for Figure 6. Figure 7 also corroborates the field observation that the Alyssum treatments were subject to considerable weed pressure and were largely overrun by the end of the experimental period. In contrast, the Microclover and Nasturtium plots were much more successful at weed control.

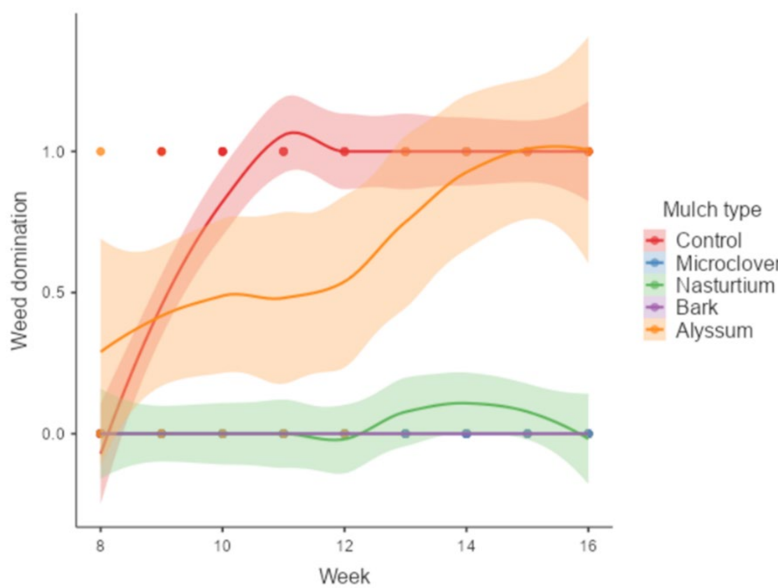

Figure 7. Evolution of weed dominance over time for the various mulch types.

4) Tree Growth Results

Tree growth was measured by three different indicators, including change in tree girth, shoot growth, and plant chlorophyll (as represented by SPAD meter measurements). In general, the results suggested that the selection of mulch type had little or no effect on tree growth over the measurement period. A more detailed presentation of the results for each measurement is provided in the following subsections.

a) **Tree trunk girth** – The impact of the treatments on trunk girth can be considered in terms of both absolute values (i.e., the difference in tree girth between the plots) and also in terms of growth rate. As the trunk diameters were measured biweekly throughout the experimental period, it was also possible to compare differences in the rate of growth.

   In terms of trunk diameters, there were no significant difference in tree diameter between the plots, as shown in Figure 8. The growth rates for each treatment are shown in

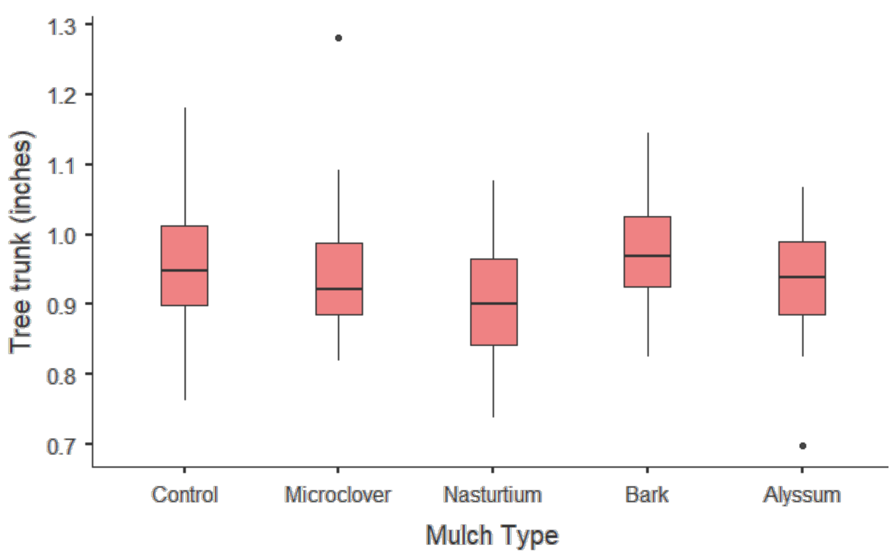

Figure 8. *Impact of mulch type on tree trunk girth*

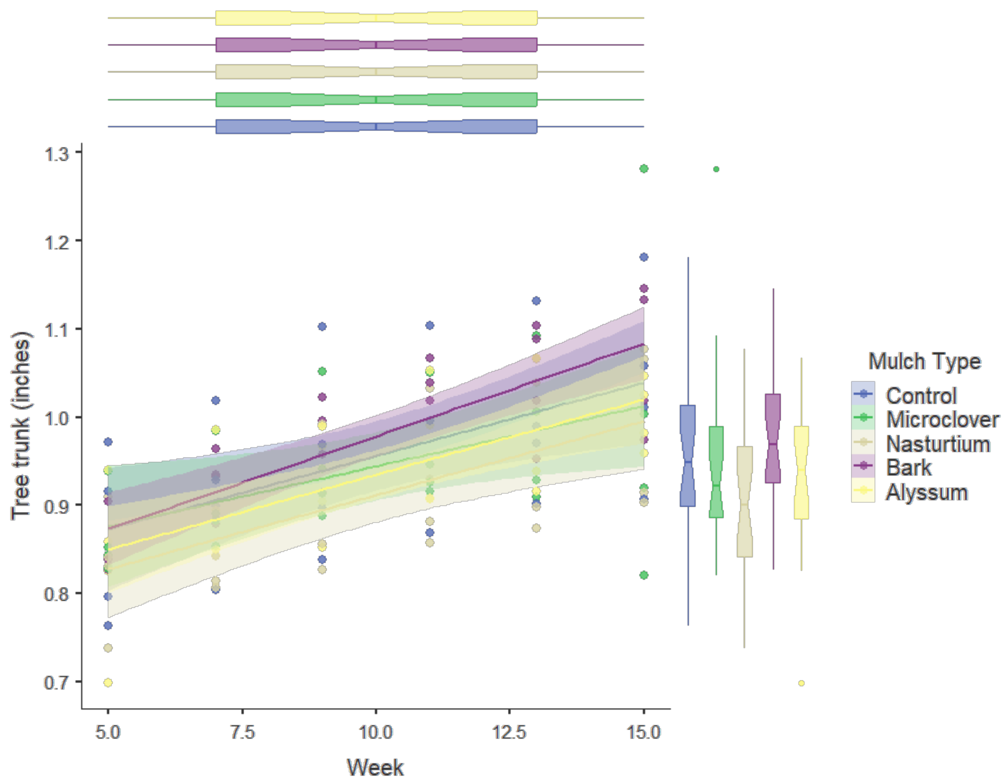

Figure 9. Rate of trunk growth in for all treatments over the experimental period.

Figure 9. While the slopes of the regressions for each treatment are very similar, one can discern a slightly steeper slope for the regression line fit to the tree diameters on the bark treatments.

b) **Shoot length** – The choice of mulch type did not appear to affect tree growth in terms of shoot length. As shown in Figure 10, there was no significant difference in the shoot growth rate between the treatments, although the longest shoots were measured on the plots with the bark treatment.

Similarly, when looking at the shoot length results as a whole for the entire experimental period (Figure 11), there is no significant difference between the treatments.

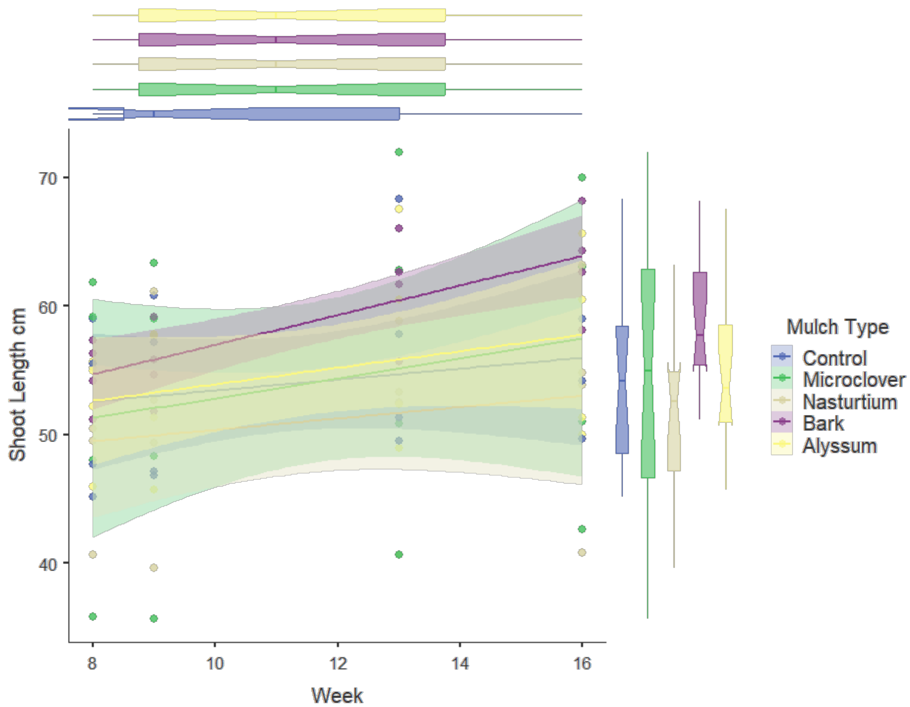

Figure 10. Change in shoot length over time for each of the treatments.

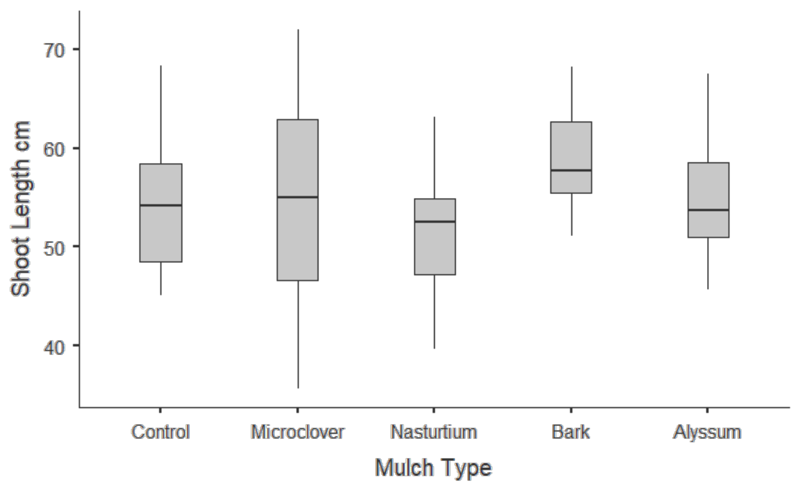

Figure 11. Shoot length by mulch treatment.

c) **SPAD Meter -** Figure 12 shows the differences between the plots for SPAD meter readings, which were used to represent chlorophyll content. The Figure shows that Microclover and Alyssum had no significant difference in chlorophyll content compared to the control or bark treatments. The Nasturtium plot did have a slightly higher chlorophyll content than the other treatments.

5) Additional Observations

All LM have issues trying to cover the area at the tree base. The following is an overview of some of the challenges that were observed during the experimental period:

1. **Alyssum establishment was short-lived.** After hand-weeding stopped, there was an evident rise of weed competition from scentless chamomile, lamb's quarter and lady's thumb. These weeds increased and ultimately weed domination took over the Alyssum plots. For a short period Alyssum achieved total ground cover, for example Plot 20 (as shown in Appendix B-20),

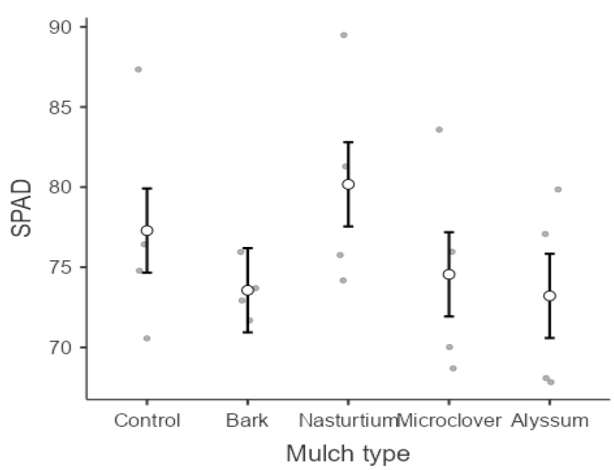

Figure 12. SPAD reading for apple trees grown in plots without in-row mulch (Control); with in-row bark mulch (Bark); or with one of three in-row living mulches (Nasturtium, Microclover, or Alyssum). Error bars denote standard error (n = 4). Grey points show observed values.

but as the season progressed those plots became overcrowded with weeds. E.g. Block 2 Spartan, Plot 6, on July 20, was overrun with Lamb's quarters (as shown in Appendix C Figure C-1, C-2).

2. **Microclover had rapid establishment.** Good clump growth and outcompeting weeds for the longest period as it was able to gain height quickly and rise over the competing weeds.
3. **Nasturtium establishment benefited from hand weeding.** As Nasturtium takes longer to establish a ground cover (as shown in Appendix C-3, C-4) consistent hand weeding secured the slow cover establishment. Once it was achieved, Nasturtium shaded most of the understory weeds, which were slowed down or unsuccessful (E.g., chickweed). Additionally, Nasturtium attracted regularly various pollinators such as hummingbirds, bees and bumblebees to the orchard.

The bark treatment was the only treatment that managed to stay mostly weed-free for much of the season. Towards the end of the experimental period Canadian thistle, grass and lady thumb eventually emerged.

Weed presence varied between plots but seven species were recurrent on almost all plots at the end of the season: Lady's thumb *(Polygonum persicaria)*, lamb's quarter *(Chenopodium album L.)*, scentless chamomile *(Matricaria perforata Merat),* chickweed *(Stellaria media),* quack grass *(Elymus repens)*, Canada thistle (*Cirsium arvense*), and shepherd's purse (*Capsella bursa-pastoris).* Other weeds that were less successful but still visible were: Purslane (*Portulaca oleracea*), pigweed (*Amanranthus retroflexus),* broad-leaved dock (Rumex obtusifolius), sheep sorrel (*Rumex acetosella*), and clover (*Trifolium repens and Trifolium pratense*).

Discussion

This study was developed to evaluate three central research hypotheses: (1) identify if living mulches affect soil moisture, (2) evaluate if they affect tree growth, and (3) determine if they can supress weeds in organic systems.

The experimental results suggest that living mulches retain soil moisture, with the strength of the effect dependent on the type of living mulch. For the species evaluated in this experiment, Microclover outperformed both the control and other living mulches in terms of moisture retention.

The results in terms of the effect of living mulches on tree growth were inconclusive, but suggest that if living mulches do have an effect, it is minor. In terms of changes in tree diameter, the treatments with bark may have experience slightly faster growth rates than either the living mulch treatments, or the control. This could be due to there being less competition for nutrients on the bark plots, which also had the least cover throughout the experiment. However, if this was in fact the case, one would expect this to also be reflected in leaf chlorophyll and higher nutrient content in the leaves of trees on the bark plots. Instead, we observed that chlorophyll content on the bark plots was comparable to the others, with slightly higher nutrient content instead observed on the plot with Nasturtium. In terms of shoot growth, there was no significant difference between the treatments.

The results in terms of weed suppression were favorable for living mulches, although again results for this site were species dependent. Both Nasturtium and Microclover performed very well in terms of weed suppression. In contrast, the Alyssum plot was largely overrun with weeds by the end of the experimental period, like the control.

Sources of Error

The experimental design started with one dead tree in Block 2 Spartan, plot 6 with alyssum (as shown in Appendix D Figure D-1).

During the research period, two issues occurred. First, one tree was chewed and roots were exposed by animal activity in block 2 Spartan, plot 7 microclover (as shown in Appendix D Figure D-2, 3,4 and D-5).

Second, the Control plot 1, in Block 1 Empire, was flooded. The drip tape was broken in several pieces and disconnected for an unknown period of time during week 14 (August 31, 2024) until irrigation was shut off. Due to miscommunication between researcher and the farm staff, this resulted on an entire week of no irrigation during the following week, a week that also had two hot days. This resulted in a significant drop in soil moisture during this period.

Another issue during the summer season was that mowing the paths around the orchard impacted the edges of Nasturtium in three opportunities and damaged the flowers.

Application and further experimentation

The results of this study highlight that Alyssum, Microclover and Nasturtium as LM have potential for water retention and weed control. The current study could be expanded on by investigating the same basic experimental design over two growing seasons, providing data on the longer-term impacts of LM. Local research is important, and the literature review did not identify regionally applicable longer-term studies of LM.

Conclusion

Microclover provided the best performance of all mulches tested by several different measures. Microclover established cover rapidly, and the microclover plots retained significantly more soil moisture than the other plots. The organic mulch (bark) retained less moisture than any of the living mulches or the control. Microclover was also the most successful LM in terms of weed control, although all of the LM provided weed control (with alyssum least successful, but still more effective than the control). Experimental results also showed that the choice of mulch type did not significantly affect any of the tree growth parameters (diameter, shoot length, SPAD meter readings) to a statistically significant degree. The experimental results showed that for the parameters measured, microclover delivered the greatest benefits.

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Appendix A: Photos of set-up and preparation for seeding

Figure A-1 View from Block 1 Empire of the in-row orchard after using the power harrow. June 3, 2024

Figure A-2 Detail shows how close can the BCS approach trees. June 3, 2024.

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Appendix B – Data Collection Methods

Photos from weed percentage cover – August 3, 2024.

Figure B-1 Block 1 Empire, Plot 1 Control

Figure B-2 Block 1 Empire, Plot 2 Microclover

Figure B-3 Block 1 Empire, Plot 3 Bark

Figure B-4 Block 1 Empire, Plot 4 Bark

Figure B-5 Block 1 Empire, Plot 5 Alyssum

Appendix B – Data Collection Methods

Figure B- 6 Block 2 Spartan, Plot 6 Alyssum

Figure B-7 Block 2 Spartan, Plot 7 Microclover

Figure B-8 Block 2 Spartan, Plot 8 Control

Figure B-9 Block 2 Spartan, Plot 9 Nasturtium

Figure B10 Block 2 Spartan, Plot 10 Bark

Appendix B – Data Collection Methods

Figure B-11 Block 3 Fuji, Plot 11 Bark

Figure B-12 Block 3 Fuji, Plot 12 Nasturtium

Figure B-13 Block 3 Fuji, Plot 13 Alyssum

Figure B-14 Block 3 Fuji, Plot 14 Control

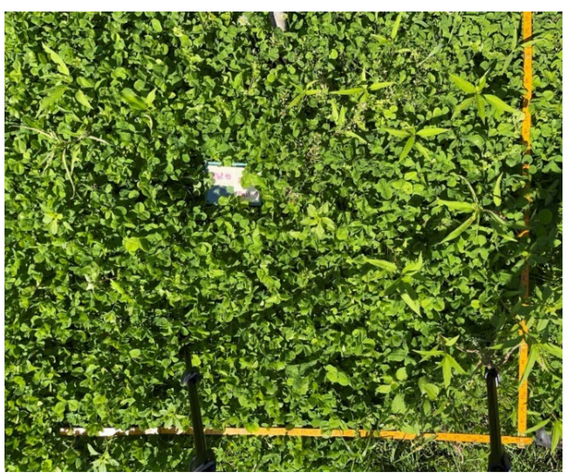

Figure B-15 Block 3 Fuji, Plot 15 Microclover

Appendix B – Data Collection Methods

Figure B-16 Block 4 Sunrise, Plot 16 Nasturtium

Figure B-17 Block 4 Sunrise, Plot 17 Bark

Figure B-18 Block 4 Sunrise, Plot 18 Microclover

Figure B-19 Block Sunrise, Plot 19 Control

Figure B-20 Block 4 Sunrise, Plot 20 Alyssum

Figure B-21 Example weed dominance percentage assessment

Appendix B – Data Collection Methods

Figure B-22 Example of the set-up tripod for photo sampling at Block 1 Empire, Plot 1 Control. August 3, 2024.

Figure B-23 Example of soil moisture content data colleting with Fieldscout. June 1, 2024.

Figure B-24 Example of tree girth data collecting with caliper. June 1, 2024.

Figure B-25 Example of ground cover data collecting with Canopeo app. May 23, 2024.

Appendix C – Discussion/ Observation Weed Dominance

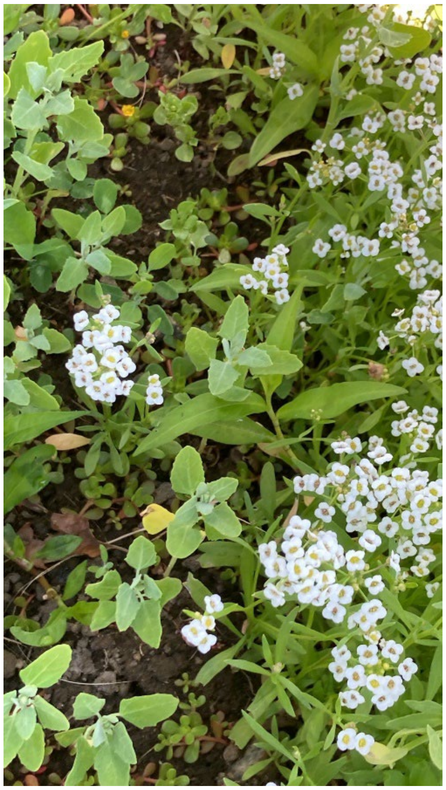

Figure C-1 Detail of Lamb's quarter crowding Alyssum on Block 1 Empire, Plot 6. July 20, 2024.

Figure C-2 Overview of Lamb's quarter crowding Alyssum on Block 1 Empire, Plot 6. July 20, 2024.

Figure C-3 Overview of Alyssum establishment on Block 1 Empire, Plot 20. July 27, 2024.

Appendix C – Discussion/ Observation Weed Dominance

Figure C-4 Overview shows ground cover (west side), Block 3 Fuji, Plot 16 Nasturtium next to a full cover on Plot 15 Microclover, Block 3 Fuji. July 20, 2024.

Figure C-5 Overview of Block 1 Empire, Plot 3 Nasturtium with uneven germination and growth. July 20, 2024.

Appendix D – Sources of Error

Figure D-1 Dead tree(16) on the left side in Block 2 Spartan, Plot 6 Microclover. July 27, 2024

Figure D-2 Overview of Block 2 Spartan, Plot 7Microclover, tree damaged. August 17, 2024

Appendix D – Sources of Error

Figure D-3 Block 2 Spartan, Plot 7 Microclover, tree roots exposed and trunk damaged. August 17, 2024

Figure D-4 Block 2 Spartan, Plot 7 detail of tree trunk. August 17, 2024

Figure D-5 Overview of Block 2 Spartan, Plot 7 Microclover, where tree roots were dug out and trunk damaged. August 17, 2024

Appendix D – Sources of Error

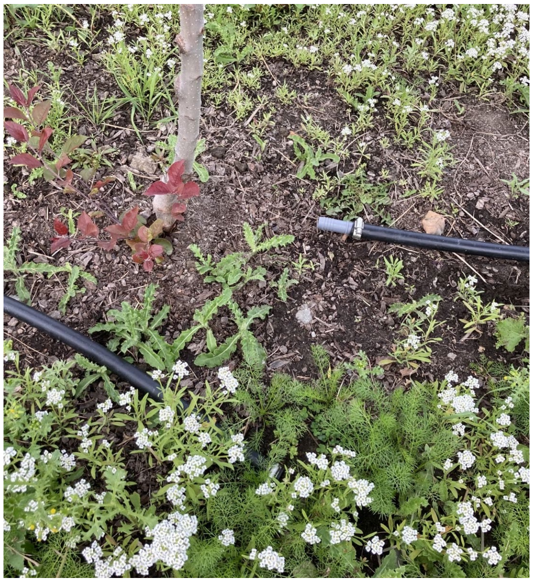

Figure D-6 Detail of irrigation disconnected, Block 1 Empire, Plot 5 Alyssum. July 27, 2024

Figure D-7 Detail of broken irrigation line at the end of the orchard close to Plot 1 Control. August 31, 2024

Figure D-8 Detail of found pirce of broken irrigation line at the end of the orchard. August 31, 2024.

Figure D-9 Detail of broken pieces of the irrigation linefound around the end of the orchard. August 31, 2024

Appendix E - Results

ANOVA - SPAD

	Sum of Squares	df	Mean Square	F	p
Block	228	3	76.0	2.75	0.089
Mulch type	138	4	34.6	1.25	0.341
Residuals	331	12	27.6		