Integrating living mulches into annual strawberry production systems.

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Introduction

Locally grown strawberries are a high value crop in Minnesota, and the potential for a longer production season is now possible with new day-neutral cultivars grown in an annual system. The system can be incorporated into an annual horticultural crop rotation, which boosts biodiversity and economic diversity on local farms. However, even in varied production systems, weed control remains a constant battle for fruit and vegetable farmers. In our recent survey of over 200 farmers, weed control was ranked as the top concern. Many farmers fall back on herbicides or tillage to manage weeds, which reduces environmental sustainability and profit potential.

We have been refining a reduced-input annual strawberry production system in Minnesota since 2014. This research has taken place at the University of Minnesota (U of MN) West Central Research and Outreach Center (WCROC), as well as several farmer-cooperator sites. Our past research has focused on optimizing a system for day-neutral strawberry production in the Upper Midwest. This research has resulted in recommendations for planting layout, plastic mulches for in-row weed control, low tunnel construction, and fertility in systems that produce marketable fruit from July through October (Petran et al., 2017). We have used landscape fabric for weed control between the rows which effectively controls weeds but doesn’t benefit the soil and results in excessive waste.

In 2019, we set out to make the system more sustainable by demonstrating a between-row living mulch in order to suppress early-season weeds without competing with the strawberry plants, as well as to contribute to soil health (Brennan, E.B. & Smith, R.F., 2018). Research has been conducted using various living mulch species in different horticultural crops with mixed results. Recent research on winter genotypes of camelina, canola, and rye show these plants have the qualities that might work well as living mulch for weed suppression (Brown, J., et al. 2008). At the end of the season, when the living mulches are tilled under, they will add valuable organic matter to the soil (Univer, T., Põrk, K. and Univer, N., 2009).

Description of the Experimental Design, Education and Outreach

In the spring of 2019, we established two experimental trials working with a farmer-cooperator, Twin Cities Berry Company and another trial at WCROC. The WCROC site was planted/trialed inside a deer fence exclosure on silty clay loam soil where the previous cropping history is fallow ground. The Twin Cities Berry Company is located in Farmington, MN, has a sandy loam soil, fallow ground and is certified organic. We used our existing equipment to shape raised beds, lay drip irrigation tape, and secure white-on-black plastic mulch over the beds. We planted dormant, day-neutral strawberry transplants through the plastic mulch and connect the drip irrigation tape to existing irrigation systems on the planting sites.

At each location, we established annual strawberry rows with the day-neutral cultivar Albion and Cabrillo with 4 between-row treatments: (1) winter camelina, (2) winter canola, (3) winter
rye, and (4) landscape fabric. Each treatment was replicated 4 times. The plots were maintained with organic production methodologies. We performed an analysis of variance to determine if there are significant differences among treatments. Soil test data was taken at the beginning and end of the growing season which will indicate the effect of the living mulches on soil organic matter percentages.

This project also included education and outreach activities. Education and outreach for this project included online and face-to-face components. To reach a wide audience, we posted project updates and findings on the Minnesota Fruit Research website (fruit.umn.edu), on the UMN Department of Horticultural Science Facebook page (facebook.com/UMNHorticulture), and the UMN Extension Fruit and Vegetable Farming Facebook page (facebook.com/UMNFruitandVegetable).

Steve Poppe and Andy Petran, our farmer cooperator demonstrated the project at the WCROC Horticulture Night on July 25, 2019. We shared our experiences and impressions of the system. This event had 1,500 people in attendance, making it one of the most well attended educational events in the U of MN College of Food, Agricultural and Natural Resource Sciences. The farmer cooperator also spoke about the project to customers at their booth at Mill City Farmers Market. The customers expressed excitement that their fruit was coming from farms that endeavored to increase environmental sustainability and were also glad to learn more about day-neutral fruit production in general.

**Summary of Results and Conclusions**

The two locations (WCROC, Morris and Twin City Berry Company, Farmington) had very different outcomes in terms of how well the living mulch germinated and became established.

At Farmington, germination was poor, so the mulches never became fully established and therefore did not offer any weed control. At Morris, germination and establishment were good for all the living mulches.

The weather around the time of seeding is critical in establishment. Heavy rain and cold temperatures in spring delayed seeding and made the soil difficult to work. These poor conditions likely contributed to low germination rates at Farmington.
Living mulches and weed suppression

Here is a breakdown of how each of the living mulches performed over the growing season at the WCROC in terms of establishment and weed control. All crops were planted by hand broadcasting at the same time in early summer after the strawberry rows had been planted and only watered twice to aid in germination and promote establishment.

By early summer, all three living mulch crops at Morris were well-established and successfully suppressing weeds. Photos by WCROC/Department of Horticultural Science.

Winter camelina

Winter camelina is a crop that is typically planted in the fall where it then germinates and forms a small rosette and then lies dormant in the soil over the winter before it grows and flowers. With this information, we believed that over the summer camelina would remain in the rosette stage. The camelina seed was provided by the USDA North Central Research Lab in Morris, MN and was recommended for this particular study by weed Scientist Dr. Frank Forcella.

In late July, the camelina had grown tall, flowered, and began to die. It was no longer beneficial for suppressing weeds. Photos by WCROC/Department of Horticultural Science.
We seeded the camelina at 10lb/acre and had very good germination at WCROC, which led to good establishment. Weed suppression was successful for the first month while the plant remained a rosette. However, likely due to the cool, wet June, the camelina started to flower by early July which caused a decline in weed suppression. The rosette leaves started to deteriorate which exposed soil, allowing weed seeds to germinate. By the end of August, the camelina plants had very little biomass left. Overall, camelina was unsuccessful at controlling weeds throughout the season.

**Winter canola**

Winter Canola is similar to camelina in its growth and development stages in the way that it requires a dormancy period in order to flower. The variety we used for this project was Torrington Winter Canola. Again, it was seeded at 10lb/acre and there was very good germination and establishment.

The canola grew quickly into large rosettes, which led to excellent weed control. In fact, the rosettes grew so large that they had to be mowed back four times throughout the whole season to keep them from growing up and over the strawberry rows. This made the canola a relatively high maintenance mulch compared to the others. However, it provided excellent weed control over the entire growing season since its large rosettes left no exposed soil for weeds to grow.

*By late July, the canola (look for the broad, kale-like leaf) had grown dense, tall rosettes that suppressed many but not all weeds. Because of the height, we had to mow down the canola four times during the growing season. Photo by WCROC/Department of Horticultural Science.*

**Winter rye**

Winter Rye, (*Secale cereale*) was the final mulch we experimented with, which also needs a dormancy period. Ryman rye was seeded at 60lbs/acre and had good germination and establishment at WCROC. As a grass, winter rye doesn’t have a rosette stage like broadleaf plants, but it does stay relatively short. It too is a biennial and requires a period of cold temperatures before flowering. It grows quickly meaning it would likely choke out most weeds. Its height is easily managed by mowing, and it makes a good surface for walking. Plus, the seed is readily available and inexpensive.
Rye (bottom) and canola (top) plants at the end of the season in October. The rye formed dense stands while staying low to the ground. No mowing required.

At the farmer cooperator site in Farmington, each plot replication was seeded twice, but for the most part all cover crops failed to properly germinate or provide adequate weed coverage throughout the season. The fabric treatments provided superior weed suppression and appeared to have slightly higher quality fruit.

The farmer cooperator provided the following thoughts on the trial at their farm:

“I seeded at the density according to recommendations and also right before rain events, so I am not positive as to why germination was poor. It is possible that since most soils are not as fertile as what they have at WCROC that germination and/or growth was worse, making the cover crops not as able to compete against the native seedbed. Also, it is possible that not even the native rain events were enough for proper germination, but as a commercial operation it would become more difficult to manually water every walkway in every acre of land.

“As a scientist and a farmer I’d say we need more data before making a regional recommendation on walkway cover crops for annual strawberry production. What I can say is that for my specific plot, I do not think that the crops have potential for weed control and I will not be using them in the future. However, if you are a farmer who lives in a particularly fertile area, such as the rich prairie mollisols found near Morris/central Minnesota, it is worth trying for yourself and then making a more permanent decision based on what you observe on your own farm.

“I will not be using living mulches categorically in the near future and will be switching exclusively to landscape fabric in between the rows. I am doing this because:

1. The effectiveness of fabric at weed suppression compared to anything else.
2. The increased quality of fruit in the fabric treatments, combined with the quantitative increases in yield observed at WCROC. Increased yields may be due to better ‘nutrition competition’ from the lack of cover crops that otherwise may be competing with strawberry plants for nitrogen.
3. The reduced labor involved with fabric. This is a big one. I calculated that an acre of fabric in the walkways results in a savings of approx. 150 labor hours over the course of the season since I don’t have to mow, weed whack, etc., and can use that time instead for harvesting, cutting runners, field maintenance, etc. I can also use my plastic lifter/wrapper machine to properly roll and reuse the fabric for multiple years of reuse incredibly quickly: [https://www.youtube.com/watch?v=ihjw-agKyyk](https://www.youtube.com/watch?v=ihjw-agKyyk)

“In general, using fabric just makes more sense for me as someone managing the strawberries on a growing commercial scale. I realize that it also means less ‘soil health’ in theory, but I’m trying to make up for that by using cover crops on the plots when they are not in production in my annual rotation system.”

**Living Mulch in Strawberries Soil Results Summary**

Initial soils samples before treatment application had oxidizable carbon levels at 623ppm, extractable nitrate at 5.8ppm, extractable ammonium at 1.5ppm, mineralizable ammonium at 2.0ppm and total ammonium at 3.5ppm. Oxidizable carbon indicates how much organic matter is in the soil that is easily degradable within 2-5 years depending on soil conditions. Both plant and microbial carbon is detected, so typically over a growing season the levels increase due to increased microbial activity. Extractable nitrate is the amount of nitrate present in the soil at the time of sampling. Nitrate is the form of nitrogen typically preferred by plants but is very volatile and easily released into the atmosphere or leached out via water. Extractable ammonium is the amount of ammonium present in the soil at the time of sampling. Ammonium is a form of nitrogen that plants are able to use and is more stable in the soil than nitrate but still subject to leaching. Mineralizable ammonium is the measured amount of organic matter present in the soil that can be broken down and used by a plant within one growing season. The ammonium is not readily available for the plant at the time of soil sampling but will be in the near future. Total ammonium is the combination of the extractable and mineralizable ammonium levels to get a better look at what is happening in the soil over the whole growing season.

In comparison to the initial soil samples before treatments were applied, the fabric treatment increased the oxidizable carbon levels and mineralizable ammonium by 211ppm and 0.9ppm respectively. Fabric decreased extractable nitrate, 3.2ppm, and ammonium, 1.4ppm, levels of the soil throughout the growing season which caused a decrease in total ammonium by 0.5ppm. Therefore, this treatment is depleting the soil of nutrients that will be available for the following year’s strawberry crop meaning more fertilizer will be required to achieve peak production. Strawberries are a heavy nitrogen user and reduced ammonium and nitrate levels will lead to deprived plants.

The rye treatment showed similar results to the fabric; an increase in oxidizable carbon, 206ppm, and mineralizable ammonium, 0.7ppm, but a decrease in extractable nitrate, 3.8ppm, and ammonium, 1.3ppm, levels leading to a decrease in total ammonium by 0.6ppm. This
shows that this particular living mulch is using up the available nutrients in the soil but not releasing them back into the soil within one growing season. Since the nitrogen is tied up in the biomass of the rye, it will likely not be readily available for the following year’s strawberry crop and more fertilizer will be required to maintain plant health.

Camelina increased the oxidizable carbon, 206ppm, mineralizable ammonium, 1.5ppm, and total ammonium, 0.3ppm, levels but decreased the extractable nitrate, 2.0ppm, and ammonium, 1.1ppm, indicating that this mulch has the potential to increase soil nitrogen levels. Even though extractable ammonium was decreased, it is possible that the decomposing biomass readily decomposes and releases the ammonium that the plant used while growing, especially since camelina senesced early in the growing season. However, the decrease in soil nitrate could be problematic for the next strawberry crop.

Finally, the canola treatment showed an increase in oxidizable carbon, 240ppm, extractable nitrate, 1.1ppm, mineralizable ammonium, 1.4ppm, and overall ammonium, 1.2ppm. The only decrease was in extractable ammonium, 0.3ppm. These results indicate that this living mulch does indeed create a more nutrient rich soil within just one growing season. By increasing the nitrogen levels, the next strawberry crop should benefit from this and possibly require less fertilizer over the season.
The tables below display yield summary statistics separated by cultivar and by mulch treatment. We observe that Cabrillo produced higher average yields per plant than Albion, and that fruit produced with landscape fabric walkways was higher than any other treatment, followed by rye, camelina and then canola. We have also included projected average yields per acre based on our plot findings. However, we advise that these acreage projections not be taken as conclusive due to the small sizes of our research plots.

<table>
<thead>
<tr>
<th></th>
<th>Yield (lb/plant)</th>
<th>Yield (lb/acre)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Albion Cabrillo</td>
<td>Albion Cabrillo</td>
</tr>
<tr>
<td>Valid</td>
<td>176 176</td>
<td>176 176</td>
</tr>
<tr>
<td>Missing</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>Mean</td>
<td>0.752 1.179</td>
<td>11280 17685</td>
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<td>Std. Deviation</td>
<td>0.435 0.596</td>
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<tr>
<td>Minimum</td>
<td>0 0.02</td>
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<tr>
<td>Maximum</td>
<td>2.185 2.366</td>
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<th>Yield (lb/plant)</th>
<th>Yield (lb/acre)</th>
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<tr>
<td></td>
<td>Camelina Canola</td>
<td>Camelina Canola</td>
</tr>
<tr>
<td>Valid</td>
<td>88 88</td>
<td>88 88</td>
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<tr>
<td>Missing</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>Mean</td>
<td>0.889 0.815</td>
<td>1.125 1.033</td>
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<tr>
<td>Std. Deviation</td>
<td>0.512 0.5</td>
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</table>

![Total Ammonium (ppm)](image)
The following figures display the average yield per plant information.
We also performed several analyses of variance and subsequent post-hoc pairwise comparisons to determine the presence of statistical significance in our 2019 yield results. In our first ANOVA we see that our observed yield differences between cultivars was highly significant (p < 0.001). This allows us to more confidently advise that Cabrillo produced significantly more fruit than Albion in our trial.

### ANOVA - Yield (lb)

<table>
<thead>
<tr>
<th>Cases</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivar</td>
<td>15.994</td>
<td>1.00</td>
<td>15.994</td>
<td>58.728</td>
<td>&lt; .001</td>
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<tr>
<td>Residual</td>
<td>95.318</td>
<td>350.00</td>
<td>0.272</td>
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</tbody>
</table>

*Note. Type III Sum of Squares*

The ANOVA for walkway treatments also revealed statistical significance (p < 0.001).

### ANOVA - Yield (lb)

<table>
<thead>
<tr>
<th>Cases</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>5.141</td>
<td>3.00</td>
<td>1.714</td>
<td>5.617</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>
Because of our significant ANOVA findings, we performed a pairwise comparison using Tukey’s Honest Significant Difference test. This test revealed that strawberry plants placed next to landscape fabric produced significantly more fruit than plants placed within camelina and canola cover crops, but not rye. Plants within rye cover crops also produced significantly more fruit than canola, but unlike fabric did not achieve statistical separation from camelina.

**Post Hoc Comparisons - Treatment**

<table>
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<th>Mean Difference</th>
<th>SE</th>
<th>t</th>
<th>p tukey</th>
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<td>Camelina Canola</td>
<td>0.073</td>
<td>0.083</td>
<td>0.881 0.815</td>
</tr>
<tr>
<td>Fabric</td>
<td>-0.236</td>
<td>0.083</td>
<td>-2.837 0.025</td>
</tr>
<tr>
<td>Rye</td>
<td>-0.144</td>
<td>0.083</td>
<td>-1.732 0.309</td>
</tr>
<tr>
<td>Canola Fabric</td>
<td>-0.310</td>
<td>0.083</td>
<td>-3.718 0.001</td>
</tr>
<tr>
<td>Rye</td>
<td>-0.218</td>
<td>0.083</td>
<td>-2.613 0.046</td>
</tr>
<tr>
<td>Fabric Rye</td>
<td>0.092</td>
<td>0.083</td>
<td>1.105 0.686</td>
</tr>
</tbody>
</table>

Finally, we performed a 2-way ANOVA including both cultivar and treatment and discovered a distinct lack of significant interaction effect (p = 0.443). This means that Cabrillo plants produced significantly more fruit than Albion regardless of walkway treatment. This effect is further visualized in the final figure, where we can see distinctly higher yields for Cabrillo even when separated by walkway treatment; the lowest yielding Cabrillo treatment was still higher than the best performing Albion treatment.

**ANOVA - Yield (lb)**

<table>
<thead>
<tr>
<th>Cases</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivar</td>
<td>15.994</td>
<td>1.000</td>
<td>15.994</td>
<td>61.490</td>
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<tr>
<td>Treatment</td>
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<td>3.000</td>
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<td>&lt; .001</td>
</tr>
<tr>
<td>Cultivar ✗ Treatment</td>
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<td>3.000</td>
<td>0.233</td>
<td>0.898</td>
<td>0.443</td>
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<tr>
<td>Residual</td>
<td>89.476</td>
<td>344.000</td>
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*Note. Type III Sum of Squares*
Descriptives Plot

References cited:


