2018 Project Abstract
For the Period Ending June 30, 2022

PROJECT TITLE: Develop BioMulch to Replace Plastic Soil Covering in Vegetable and Fruit Production to Increase Yield and Reduce Waste
PROJECT MANAGER: Dr. Paulo Pagliari
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 08b as extended by M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18

APPROPRIATION AMOUNT: $310,000
AMOUNT SPENT: $310,000
AMOUNT REMAINING: $0

Sound bite of Project Outcomes and Results
This project was used to develop a biodegradable product that can be used to replace plastic mulch used in vegetable production. The results of research showed that the current formulation of BioMulch worked as expected for watermelon and zucchini; and underperformed (yield was reduced) for tomatoes, peppers, and strawberry.

Overall Project Outcome and Results
This project was used to develop a biodegradable product, BioMulch, that can be used to replace plastic mulch used in vegetable production in MN. Plastic mulch cause environmental pollution as it slowly breaks down and creates pollutants such as micro and nanoplastics. Micro and nanoplastic have been proven to be endocrine disruptors and also cause severe health issues to human, animals, and aquatic life. Our intent with this project was to develop a biodegradable product which would replace plastic. Field trials were set up at the University of Minnesota Research and Outreach center at Lamberton. The BioMulch was tested on bell peppers, tomatoes, strawberry, watermelon, and zucchini. Our main goals with this project were to test the efficacy of BioMulch on preventing weeds from emerging and growing and keep the soil moist in comparison with plastic mulch. The results of our project showed that a biodegradable product can be safely created and used to replace plastic mulch used in vegetable production. Yield for watermelon and zucchini were similar between plastic cover and BioMulch; however, yield of tomatoes, peppers, and strawberry were reduced with the use of BioMulch. This management practice should minimize the agricultural footprint on the environment by minimizing the amount of waste being produced in Minnesota by vegetable producers. The use of a biodegradable soil cover means that at the end of the season a simple tillage practice can incorporate the soil cover into the soil and eliminate the waste currently being produced with plastic. Therefore, Minnesotans could benefit from this project by having lower amounts of plastic being used in vegetable production, lower amounts of micro and nanoplastic being created as plastic covers brake-down, and as a result cleaner air, soil, and water. In addition to, healthier Minnesota grown foods.

Project Results Use and Dissemination
The results of this project have been disseminated to growers that have attended Extension events at the Southwest Research and Outreach Center (SWROC) from 2021 to Summer 2022. The last phase of the research project was completed in June 2022 and now we are working on Extension materials which will be posted on the SWROC nutrient management website. Technology commercialization efforts continue at AURI.

Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2018 ENRTF Work Plan Final Report(Main Document)

Today's Date: August 4, 2022

Final Report

Date of Work Plan Approval: 06/05/2018

Project Completion Date: June 30, 2022

PROJECT TITLE: Develop BioMulch to Replace Plastic Soil Covering in Vegetable and Fruit Production to Increase Yield and Reduce Waste

Project Manager: Dr. Paulo Pagliari

Organization: University of Minnesota

College/Department/Division: CFANS/Department of soil water and climate/Southwest Research and Outreach Center

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Web Address:

Location: Statewide

Total Project Budget: $310,000

Amount Spent: $310,000

Balance: $0

Legal Citation: M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 08b as extended by M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18

Appropriation Language: $310,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop and test the performance of biodegradable BioMulch to increase yield, conserve water, suppress weeds and pests, add nutrients to the soil, and replace large amounts of nonrecyclable and nondegradable plastic used in vegetable and fruit production. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18. ENVIRONMENT AND NATURAL RESOURCES TRUST FUND; EXTENSIONS. [to June 30, 2022]

II. PROJECT STATEMENT:

This LCCMR proposal is an interdisciplinary, interinstitutional (Agricultural Utilization Research Institute – AURI – and the University of Minnesota) partnership focused on developing a material that would replace petroleum derived polyethylene plastic films in vegetable and fruit production in MN. Plastic films are indispensable in vegetable production as they help to increase yield, conserve water while suppressing weeds and pests, and serve as pathogen protection for the plants. Unfortunately, the plastic is largely non-recyclable, often chemically contaminated (herbicide and pesticide), labor intensive to remove, and overall a source of environmental pollution. Therefore, a biodegradable replacement is needed for cleaner vegetable and fruit production in MN, and potentially nationwide. Such new material must be engineered to achieve three critical functions:

- be a soil cover that provides all the benefits the currently used non-degradable plastic provides
- be biodegradable so that at the end of the season the material can be incorporated into the soil
- be a nutrient source for plants during the years following incorporation as it slowly decomposes

In this project we will test and refine a product (BioMulch) which will meet all of the requirements stated above. The product will be sprayed on top of the soil just prior to transplanting the vegetables, and within a couple of hours the product will harden to seal the beds and start working in a similar manner as traditional plastic. At the end of the season in the fall, the product will be tilled into the soil so that it can start to naturally decompose. Therefore, it is important the BioMulch be designed in a way that it is hard enough to function like a plastic during the season, but then decompose when mixed into the soil. This project will also be used to generate all of the information related to applicability of the product, ease of distribution, longevity, decomposition rate, nutrient release rate, and its horticultural impacts. The results will be publicly disseminated through applicable peer reviewed journal articles, the University of Minnesota Research and Outreach Centers (ROCs), AURI online and print publications including AG Innovation News and as a component of public field days at AURI and/or the ROCs.

II. OVERALL PROJECT STATUS UPDATES:

This project was used to develop a biodegradable product, BioMulch, that can be used to replace plastic mulch used in vegetable production in MN. Plastic mulch cause environmental pollution as it slowly brakes-down and creates pollutants such as micro and nanoplastics. Micro and nanoplastic have been proven to be endocrine disruptors and also cause severe health issues to human, animals, and aquatic life. Our intent with this project was to develop a biodegradable product which would replace plastic. Field trials were set up at the University of Minnesota Research and Outreach center at Lamberton. The BioMulch was tested on bell peppers, tomatoes, strawberry, watermelon, and zucchini. Our main goals with this project was to test the efficacy of BioMulch on preventing weeds from emerging and growing and keep the soil moist in comparison with plastic mulch. The results of our project showed that a biodegradable product can be safely created and used to replace plastic mulch used in vegetable production. Yield for watermelon and zucchini were similar between plastic cover and BioMulch; however, yield of tomatoes, peppers, and strawberry were reduced with the use of BioMulch. This management practice should minimize the agricultural footprint on the environment by minimizing the amount of waste being produced in MN by vegetable producers. The use of a biodegradable soil cover means that at the end of the season a simple tillage practice can incorporate the soil cover into the soil and eliminate the waste currently being produced with plastic. Therefore, Minnesotans could benefit from this project by having lower amounts of plastic being used in vegetable production, lower amounts of micro and nanoplastic being created as plastic covers brake-down, and as a result cleaner air, soil, and water. In addition to, healthier Minnesota grown foods.

First Update January 31, 2019

The research project if progressing as expected. We have completed the BioMulch formulations to be tested in the first greenhouse study. The objective of the first greenhouse study was to test how the BioMulch compared with black plastic in stopping weeds from germinating and growing. The results of the first study were very satisfactory and we were able to stop more than 95% of the weeds from germinating and growing. Though there were a few weeds which were able to germinate, the number were very small and we do not anticipate this to be an issue for the next phase of the study. We were also able to start the soil incubation study to test the rate of biomulch degradation when BioMulch is mixed with soil. One of the most important aspects of the BioMulch is that it must breakdown easily after being mixed with the soil. The initial results of the incubation study are also very good, as after one week the BioMulch has already shown significant degradation.

Second Update June 30, 2019

The research project has been on target in most cases. We experienced some difficulties with the sprayer needed to apply to the BioMulch during the set-up of our field trial. However, the delay in having the sprayer set up and ready to go coincided with the delay on planting of the crops due to the extremely wet conditions observed this spring. Our trial was initially expected to start in May, but the weather conditions pushed the start of the trial to mid-June. We are now caught up on the field trial and the evaluation of BioMulch under field conditions is within our targeted schedule. We were also expected to start the greenhouse study in the Spring, but because we had issues with the sprayer we had to delay the start of the greenhouse to the fall of 2019. Temperatures are too high in the greenhouse during the summer months which restricts crops from growing in there. So we decided to push back the date of the start of the greenhouse study. The greenhouse study new start date will be November 2019.

Third Update January 31, 2020

The research project is on target as expected. Our first field trial ended in October 2019. The results of our first field trial showed that modifications had to be made to the formulation. We observed that the first formulation tested caused toxicity to the plants. Soil tests showed that the high levels of sodium were present where the damage was observed. A new formulation was developed and testing started on the greenhouse in November 2019. We are currently testing the new formulation in tomato plants in our greenhouse study.

Forth Update June 30, 2020

The project continues to be running according to the planned timeline. During the winter months and early spring we conducted our greenhouse study to evaluate plant growth performance under greenhouse conditions with the new formulation of the BioMulch. This study would allow us to identify any potential problems with the new formulation which was developed to eliminate the phytotoxicity observed in the 2019 field trials. In this study tomatoes plants were grown under three different conditions. One of the conditions the tomatoes plants were grown in pots with potting soil without any BioMulch present. The second condition had tomatoes plants growing in potting soils and the soil was covered with BioMulch. The third condition had tomatoes plants growing in potting soils mixed with BioMulch. Qualitative data was collected for this study was the plants were only growing for 4 weeks due to confounding effects of growing plants in small pots for too very long periods of time. The results of this greenhouse showed that plants grown under the conditions of no BioMulch or BioMulch on the surface of the soil had similar development. In contrast, plants growing under the condition where soil and BioMulch were mixed showed significant phytotoxicity. The plants growing on soils mixed with BioMulch showed severe leaf necrosis which would lead to plant death should the study be conducted for a longer period of time. This study rises concerns about potential phytotoxicity when BioMulch is mixed with soil. This condition would happen when BioMulch is mixed with soil at the end of a growing season in preparation for the following season. For example, BioMulch and soil are mixed in the Fall of 2020 to complete the 2020 growing season. Then in 2021, plants are grown on the same area. In this condition, there is a significant chance that plants would not develop well and would be negatively impacted by the BioMulch and soil mixture. It will be important to evaluate this condition under field conditions in 2021 during this research.

Fifth Update January 31, 2021

The 2020 was a very good season for testing the BioMulch under field condition and great data was produced. We have found that all crops tested are very sensitive to some components of the BioMulch with some species being more visually sensitive than others. For example, phytotoxicity was observed on tomatoes plants from the time we transplanted the plants into the beds that were covered with BioMulch. Within a week after transplant, tomato plants started to show stress, reduced growth, and some plants died. Produce productivity was significantly reduced in BioMulch plants compared with plants grown in black plastic. On average, BioMulch caused a reduction of 50% in produce productivity compared with black plastic for all species tested. However the yield reduction varied by species. Peppers was the most sensitive crop and yield reduction was 81% in plots treated with BioMulch when grown in the high tunnel and 63% under outside plots. Tomato yield reduction was 41% under high tunnel and 64% under outside plots. Strawberry yield reduction was 57% in the high tunnel and 21% in the outside plots. Zucchini was the least affected crop tested and yield reduction was 20% in the high tunnel and 22% in the outside plots. Tomato and strawberry yield were twice as high in the high tunnel than in the outside. While zucchini and pepper yield were the same in the high tunnel and outside. The drastic yield reduction observed in plants grown after BioMulch application were not expected and we are not sure why this happened. We are currently doing more greenhouse tests to try and determine the cause for the negative effect of BioMulch on plant productivity.

Sixth Update June 30, 2021

Field trials were started at the SWROC and we are testing the BioMulch under open field and also in the high tunnel conditions. After testing during the winter and new formulation development we are confident that this version of the BioMulch will be much better than the previous formulations tested.

Seventh Update January 31, 2022:

The second field trial to test BioMulch was concluded in October 2021. We had issues with wild deer eating some of the strawberry plants in the outside portion of the trial. In the high tunnel trial we had disease issues with watermelon and we were not able to have yield for this crop in the high tunnel in 2021. In general, black plastic yield was higher than for BioMulch, except for bell peppers inside the high tunnel. For the outside trial, yields in the black plastic treatment were 7, 21, and 42% high than in BioMulch for zucchini, tomato, and peppers, respectively; no differences were observed for watermelon; no yield strawberry. For the high tunnel trial, yields were 2, 8, and 9% greater in the black plastic than in the BioMulch for strawberry, tomato, and zucchini, respectively; in contrast, pepper yield was 18% greater in the BioMulch than in the black plastic; no yield for watermelon. Although yield differences were still present, the magnitude of the differences were lower than what was observed for the 2020 season, as reported in the fifth update from Jan 31, 2021. There was very little phytotoxicity observed in plants 2021, with most visual symptoms being observed for peppers. Rainfall in 2021 was very limited from April to the second week in July. It is possible that we have found a formulation that has very low toxicity, or the limited rainfall in the early spring resulted in lower leachate reaching the plant roots and therefore the lack in phytotoxicity.

Final Update June 30, 2022

In early April 2022, soil samples were collected from the location where the 2021 field trial took place. Those samples were used for the assessment of BioMulch residual toxicity to tomato plants. This was a greenhouse study where plants were grown in the soil samples collected from areas that were treated with BioMulch and areas that were under plastic film. The results for this final greenhouse trial showed that no residual toxicity was observed when BioMulch has the chance to breakdown during the fall and spring.

AMENDMENT REQUEST August 1, 2019

We are requesting fund to be shifted from the supplies and travel budget lines to personnel.

- Sample analysis budget would be reduced by $6,000 to a revised budget of $3,600

- Moisture and temperature probes budget would be reduced by $20,000 to a revised budget of $7,000
- In state travel budget would be reduced by $10,000 to a revised budget of $5,234
- Personnel budget would increase by $36,000 to a revised budget of $197,227

These changes are being requested because there was an initial mistake in the calculations done for the personnel salary category. As it can be seen the salary line for U of M research technician has $40,620.80 for salary and $11,048.86 for fringe. The text in parenthesis says the total is $119,185, which reflects only the salary and not the fringe. $40,620.80 for salary added to $11,048.86 for fringe for three years equals $155,008.98 as opposed to $119,185. This was the mistake in the budget. The budget line would be changed from $161,227 to $197,051.

The rebudget will not result in any changes in the work that we have proposed to do. Mostly we will use equipment for moisture level and temperature monitoring that we currently have on site. This equipment is not ideal but will give the same measurements that we need. The reduction in sample analysis budget is also okay as we can do all of those analysis at our laboratory, and by doing the analysis ourselves we save funds. We will limit travel to only when it is required for in-person meetings. We have been using video conferencing which is working great and will help alleviate the changes in the budget.

Amendment Approved by LCCMR **8/15/2019.**

AMENDMENT REQUEST January 31, 2021
Due to Covid-19 we have to make a few changes on the project and we would like to make the following changes:

From the Professional/technical/Service Contracts line:

- we need to move $5,500 from AURI project coordinator to the Supplies line

From the Travel expenses in Minnesota line:

- we need to move $5,000 from travel to the Supplies line
- and also need to move $410 from travel to Personnel Overall line.

From the Supplies line:

- We would like to request the transfer of $94 from the moisture and temperature probes to the Personnel Overall line.

The changes being requested will not cause any change in the work we have proposed to do. The changes will make sure that we have the funds in the proper categories to be able to complete the work in the planned time frame.

Amendment Approved by LCCMR **2/26/2021**.

Project extended to June 30, 2022 by LCCMR 6/30/21 as a result of M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18, legislative extension criteria being met.

III. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Incubation study for initial assessment of BioMulch decomposition rate

Description:

In this activity, the BioMulch formulations developed at AURI will be refined through collaborative testing of the products in small greenhouse trails and laboratory soil decomposition testing. The primary goals of this activity are to determine the optimal formulation composition, establish standardized operating procedures (SOPs) to be used for the remainder of the project and to determine the degradation and nutrient release rate of BioMulch after mixing into soil.

The BioMulch smart material base formulations have already been developed in the laboratory at AURI. Testing is required to establish application protocols and confirm the primary functionality of the materials in order to select the final material to be used in the greenhouse trials and field plot tests. AURI will provide small batch formulations of different compositions for rapid analysis in the laboratory at southwest research and outreach center (SWROC) testing site location to determining soil coverage, soil temperature as a result of solar absorption and stability of BioMulch in different conditions. The initial testing effort will provide the whole team experience with the products and time to establish SOPs for the testing locations. Additionally, the results will provide the data needed to select the final formulation for further study. Analytical analysis will be performed at the SWROC and AURI with any required formulation modifications completed by AURI. The formulation found to have the best performance will enter into further decomposition studies to begin the long-term field experiments testing product decomposition in soil.

The team will set up incubation studies where soil and small pieces of BioMulch will be mixed together and placed in an incubator with controlled temperature and moisture. Soil will be added at about 100 grams while BioMulch will be added as small strips of 1 to 2 cm and weighing approximately 1 to 2 grams. The incubation study will be carried on for about 10 weeks, or longer if needed, and visual inspection will be done to determine the rate of decomposition. In this activity, we will also determine the rate of nutrient release as BioMulch decomposes by using tradition soil tests used for the determination of available phosphorus and nitrogen. We expect that about two sets of incubation studies will be sufficient to complete the initial benchmarking assessment. We will use the results gathered in these incubation studies to determine how to perform Activities Two and Three. Expected starting day for the first incubation study is November 1st 2018 after the initial formulation testing has been completed, the soil samples gathered, dried and sieved for the decomposition study.

ENRTF BUDGET: $52,000

Outcome	Completion Date
1. Final BioMulch composition identified and standard operating procedures completed	October 31, 2018
2. Known decomposition rate of BioMulch	March 31, 2019
3. Known nutrient release rate as BioMulch decomposes	March 31, 2019

First Update January 31, 2019

The BioMulch formulations testing were completed prior to October and in October the first greenhouse study was initiated with the top eight formulation. From those formulations, the best ones will be selected for the field study to start in the spring 2019. At the same soil incubation studies were started to test the breakdown of BioMulch when BioMulch is mixed with the soil and incubated for 8 weeks. We are in the middle of this incubation study and the results are very good. BioMulch has shown easy degradation and after one week the material being tested had already shown significant decomposition in the soil.

Final Update June 30, 2019

This phase of the study is completed. We successfully tested a field different composition of BioMulch which allowed us to determine the best composition for use in the field study and greenhouse study. We also completed the study investigating the rate of decomposition of BioMulch once BioMulch is mixed with the soil. The thickness of 2mm was found to provide ideal weed gemination barrier under the laboratory condition. Also

we observed that once mixed in the soil, BioMulch will start to decompose within 2 weeks and after 8 weeks no residue is present showing great rate of decomposition.

ACTIVITY 2: Greenhouse study for initial assessment of BioMulch, plants, and soil interaction and plant growth response

Description:

Our objective with this activity is to determine how BioMulch, plants, and soil interact and what the potential detrimental effects could be so that improvements can be done prior to the start of the larger field trials. The greenhouse study will be conducted in the fall and winter months of 2018 and, if needed in 2019 so that the product can be refined for the field trials. Initially the greenhouse study will mimic the incubation study with a few differences. Larger pots will be used which will accommodate more soil, as much as 1.5 kilograms; plants will be grown so that we can assess the interaction effect of plant and soil on the decomposition rate of the BioMulch. Tomatoes, peppers, and strawberries will be the test crops for this phase of the study. Plants will be grown for as long as possible to assure enough yield is recorded. In addition, this phase of the study will assess the effectiveness of the BioMulch at supplying plants with nutrients while it decomposes. The experimental design in the greenhouse will be a completely randomized block design with four replications per treatment. To determine how much nutrients are coming from the BioMulch there will be pots that will be treated with commercial fertilizer so that a yield response curve to N and P can be developed. Nitrogen rates will vary from 0 to 200 lbs per acre and P rates will vary from 0 to 100 bls per acre. During the growing season water will be added to assure it is not limiting to plant growth. At the termination stage, soil samples will be collected for nutrient analysis for soil available N and P. The winter of 2019 will provide an additional opportunity to refine the BioMulch formulation and collect additional testing after the data has been collected and analyzed from the first field trial growing season.

ENRTF BUDGET: $68,000

Outcome	Completion Date
1. Nutrient release from BioMulch to plants determined	March 2019
2. Plant yield when BioMulch is used as a fertilizer source	March 2019
3. Effects on plants of using BioMulch as a soil cover	March 2019
4. Refinement formulation from results of first field trial season (if needed)	March 2019

First Update January 31, 2019

This activity has not started yet as of Feb 28 2019. Everything is in order for the activity to start by May 2019.

Second Update June 30, 2019

The start of this activity has been delayed to November 2019. Having a functioning sprayer was ideal for the start of this greenhouse study. As explained in the summary report we had difficulty getting the sprayer setup to perform at is ideal and deliver the rate of BioMulch needed for maximum weed germination protection. The sprayer is now functioning at its best and the greenhouse is going to be started in November. Temperature in the greenhouse during summer months are too high and limits plant development. It was therefore decided to wait until the colder months to start this study so that meaningful data can be collected.

Third Update January 31, 2020

This activity is progressing as expected. We have completed on initial evaluation of the new formulation and we the results were very positive. We are now testing the new formulation on tomatoes plants and this study should be completed early in the spring.

Final Update June 30, 2020

The last part of the greenhouse study was completed in April, 2020. In this greenhouse study tomatoes plants were grown under three different conditions. One of the conditions the tomatoes plants were grown in pots with potting soil without any BioMulch present. The second condition had tomatoes plants growing in potting soils and the soil was covered with BioMulch. The third condition had tomatoes plants growing in potting soils mixed with bimulch. Qualitative data was collected for this study was the plants were only growing for 4 weeks due to confounding effects of growing plants in small pots for too very long periods of time. The results of the this greenhouse showed that plants grown under the conditions of no BioMulch or BioMulch on the surface of the soil had similar development. In contrast, plants growing under the condition where soil and biomulch were mixed showed significant phytotoxicity. The plants growing on soils mixed with BioMulch showed severe leaf necrosis which would lead to plant death should the study be conducted for a longer period of time. This study rises concerns about potential phytotoxicity when BioMulch is mixed with soil. This condition would happen when BioMulch is mixed with soil at the end of a growing season in preparation for the following season. For example, BioMulch and soil are mixed in the Fall of 2020 to complete the 2020 growing season. Then in 2021, plants are grown on the same area. In this condition, there is a significant chance that plants would not develop well and would be negatively impacted by the BioMulch and soil mixture. It will be important to evaluate this condition under field conditions in 2021 during this research.

ACTIVITY 3: Field trials for in field evaluation of BioMulch effectiveness as a plastic replacement

Description:

The field trials will be implemented in the spring of 2019 after the incubation and greenhouse studies are concluded and will be continued until the fall of 2020. The field study will be conducted at the Southwest research and outreach center at Lamberton and at the southern research and outreach center in Waseca, MN. The same plots will be used in the second year so that we can assess the nutrient release from the BioMulch as it decomposes. Field trial will be conducted in the open are as well as in the high tunnels as both practices rely heavily on the use of soil plastic covers. In the field study BioMulch will be applied a differing thickness (e.g. 2, 4, and 6 mm but the proper range will be determined during the incubation and greenhouse studies) to assess its ability to stop weed growth; in addition to provide good soil cover, and the desired amounts of nutrients. However, it is not intended that BioMulch will supply 100% of the crops demand for nutrients. This research is being developed to determine how much nutrient can be delivered as the BioMulch decays. We expect that BioMulch will perform as well as ordinary plastic films in terms of stopping weed emergence. Therefore, plots with plastic films will also be used for direct comparison. We will monitor for the effectiveness of the BioMulch in stopping weed emergence by visual weekly inspection which will also aid in assessing overall integrity of the product. Nutrients will be added in the first year as inorganic fertilizer to supply the crops needs for N, P and K. In the second year, different levels of fertilizer will be added to different plots so that we can determine how much fertilizer is available to crops from the BioMulch under field conditions. The experimental design for the field trials will be a completely randomized block design with four replications for each treatment. The crops tested will be the same as in the greenhouse study, tomato, peppers, and strawberry in both years and crop rotation will be used to avoid diseases in the second year as can be observed in mono-cropping tomatoes and other *Solanaceae*.

To determine how much nutrients are coming from the BioMulch there will be pots that will be treated with commercial fertilizer so that a yield response curve to N and P can be developed. Nitrogen rates will vary from 0 to 200 lbs per acre and P rates will vary from 0 to 100 bls per acre. Water will be provided by drip tape irrigation which will be installed prior to the BioMulch being sprayed onto the plots. The BioMulch will sprayed as a liquid which solidifies a few minutes after being applied. Two methods for creating the opening for transplanting the seedlings will be used: i) a small opening will be done after the materials solidifies; ii) small containers (2 to 3 inches wide) will be placed where the plants will go prior to spraying the BioMulch and removed soon after the BioMulch is sprayed but prior to hardening.

After the harvest in each year, we will collect soil samples to assess the BioMulch decomposition as well as nutrient availability at the end of the season. Produce yield will also be monitored every year and will be the main parameter used to assess the effectiveness of the BioMulch in comparison with yields obtained by using

regular plastic. After the first year data is gathered the team will assess the results and implement any necessary formulation adjustments which will be tested in the greenhouses prior to implementation in the field in the second field trial demonstration.

ENRTF BUDGET: $ 200,000

Outcome	Completion Date
1. Effectiveness of BioMulch as a weed barrier	October 2020
2. Produce yield when BioMulch is used as a soil cover	October 2020
3. Assessment of soil properties after BioMulch is used	March 2021

First Update January 31, 2019
This activity has not started yet as of Feb 28 2019. Everything is in order for the activity to start by May 2019.

Second Update June 30, 2019
This activity is currently ongoing. We had extreme wet weather conditions which limited our ability to get this study started at the ideal time of May 2019. We were able to start the activity in Mid-June 2019. We also had some unforeseen problems related to the sprayer. However, by the time the weather conditions were conducive for the start of the trial the sprayer was ready.

Third Update January 31, 2020
We are getting everything ready for the second field season for this study.

Forth Update June 30, 2020
The field trial started in May. BioMulch is being compared with black plastic under high tunnel as well as in the open field. Crops being tested are tomatoes, bell peppers, zucchini, strawberry and watermelon. In addition, there is a treatment with BioMulch only and no crops to see how effective BioMulch is at stopping weed growth. The results so far from the 2020 field season shows that BioMulch is showing to not be very effective at stopping weeds from growing under open conditions as well as inside the high tunnel. Crop yield is being monitored and so far there seems to be equivalent yields for all produce between BioMulch and black plastic, regardless of the amount of weeds that are present under the two treatments. It will be important to continue to monitor the yield from both treatments throughout the growing season to see how well BioMulch performs compared with black plastic.

Fifth Update January 31, 2021

The 2020 growing season proved to be a great season to evaluate the effectiveness of BioMulch at replacing black plastic when used in high tunnel and also in outside conditions. One of the critical aspects of BioMulch is that it should serve as a barrier stopping weed seed to germinate and emerge. Weeds can have a significant negative impact on produce productivity. During the 2020 growing we observed that BioMulch failed in this task and plots treated with BioMulch showed significant weed emergence and growth. Due to a combination effect of BioMulch toxicity and weed growth, plants grown in BioMulch applied plots showed an average 50% yield reduction. Strawberry and zucchini were found to be the least affected crops with averages yield reductions of 49 and 21% reduction for strawberry and zucchini, respectively. Tomato yield reduction was at 51% and pepper yield reduction was the most at 72%.
As in the previous season, we also had a treatment where no plants were grown so that we could evaluate BioMulch performance at stopping weed emergence. We collected soil samples from these plots during the season to investigate potential nutrient and salts leaching from the BioMulch as it broke down during the growing season. The results of the soil tests showed that sodium had a steady increase during the growing

season, increase in the order of 10 to 20 ppm over the entire season. Although there was a continuous flow of sodium from the BioMulch into the soil, it is not likely that sodium is the cause for the yield reduction observed.

Sixth Update June 30, 2021:
We are currently conducting field trials in the high tunnel and out in the open to test the latest BioMulch formulation. Crops being tested are the same as last years including: tomatoes, bell peppers, zucchini, strawberry and watermelon. In addition, there is a treatment where BioMulch was applied in 2020 and we is now being used to look at potential residue effect of BioMulch on soil properties and produce yield.

Seventh Update January 31, 2022:

The 2021 growing season was a very dry season which could have limited our ability to fully test BioMulch. The dry spring limited weed emergence pressure as well as limited the amount of leachate that could have moved from the BioMulch into the root zone and cause phytotoxicity. The results of the 2021 season showed that in most cases yield in BioMulch beds were lower than those in the black plastic beds. However, differences in yield were more accentuated in the outside trial than in the high tunnel trial. For the outside trial, yields in the black plastic treatment were 7, 21, and 42% high than in BioMulch for zucchini, tomato, and peppers, respectively; no differences were observed for watermelon; no yield strawberry. For the high tunnel trial, yields were 2, 8, and 9% greater in the black plastic than in the BioMulch for strawberry, tomato, and zucchini, respectively; in contrast, pepper yield was 18% greater in the BioMulch than in the black plastic; no yield for watermelon.

Final Update June 30, 2022

The final test to assess BioMulch toxicity was performed in the spring of 2022. Soil samples were collected from plots that were treated with BioMulch in the 2021 season and also plots that were under plastic mulch. Tomato plants were transplanted into the soils in the greenhouse and grown for 4 weeks. Visual evaluation of plant toxicity was done on a weekly basis during the 4 weeks. None of plants showed visual signs of toxicity in any of the treatments showing that BioMulch breakdown did not affect plant growth.

IV. DISSEMINATION:

Description:
It will be important that Extension events be developed to highlight the findings of this research. Activities 1 and 2 do not have any direct need for dissemination to the public, as those activities are to guide the larger field trial which will be generating all of the needed information for guidelines development. The results of the field trial will be publicly disseminated through applicable peer reviewed journal articles, the University of Minnesota Research and Outreach Centers (ROCs), AURI online and print publications including AG Innovation News and as a component of public field days at AURI and/or the ROCs.

First Update January 31, 2020
On July 10th the SWROC held an organic field day and the participants of the field day were taken on a tour around the research center which included stops at several research plots. One of the featured stops was the Biomulch trial. We will continue with Extension events highlighting this research as well as start producing written materials to help with dissemination of our research on the Biomulch.

Second Update June 30, 2020
Dissemination of the results has been difficult this season due to COVID-19 and the fact that no in person field days are being planned for the season. Written fact sheets will be prepared to highlight the results of the 2020 growing season once the season ends.

Third Update January 31, 2021
COVID-19 has limited our ability to disseminate the results of the study. However, we have made changes to how we are providing extension education this year and we are confident that we will be able to start sharing our results with the public.

Fourth Update June 30, 2021:
Covid-19 has continued to limit our ability to have extension events at the SWROC to disseminate the results of this research. We did have one event on August 12th where a field tour with about 50 people stopped at the location where the trial is being conducted. This audience learned about the study and its objectives and potentials to improve agriculture and reduce the use of black plastic in produce production.

Fifth Update January 31, 2022:
In 2021 our ability to provide extension services and deliver information regarding this study was very limited. However, now that we have concluded the study we will start producing online content to inform the public of our study and results.

Final Update June 30, 2022
The results of this project have been disseminated to growers that have attended Extension events at the Southwest Research and Outreach Center (SWROC) during the Summer 2022. The last phase of the research project was completed in June 2022 and now we are working on Extension materials which will be posted on the SWROC nutrient management website. Technology commercialization efforts continue at AURI.

V. PROJECT BUDGET SUMMARY:

A. Preliminary ENRTF Budget Overview: See attached budget sheet

Explanation of Capital Expenditures Greater Than $5,000: N/A

Explanation of Use of Classified Staff: N/A

Total Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation:

Enter Total Estimated Personnel Hours: 1,768	Divide by 2,080 = TOTAL FTE: 0.85

Total Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation:

Enter Total Estimated Personnel Hours: 624	Divide by 2,080 = TOTAL FTE: 0.30

B. Other Funds:

SOURCE OF AND USE OF OTHER FUNDS	Amount Proposed	Amount Spent	Status and Timeframe
Other Non-State $ To Be Applied To Project During Project Period: *N/A*			
	$ *N/A*	$ *N/A*	
Other State $ To Be Applied To Project During Project Period: *N/A*			
	$ *N/A*	$ *N/A*	
Past and Current ENRTF Appropriation: *N/A*			
	$ *N/A*	$ *N/A*	
Other Funding History: *N/A*			
	$ *N/A*	$ *N/A*	

VI. PROJECT PARTNERS:

A. Partners receiving ENRTF funding

Name	Title	Affiliation	Role
N/A			

B. Partners NOT receiving ENRTF funding

Name	Title	Affiliation	Role
Dr. Forrest Izuno	Professor	University of Minnesota	Help with data interpretation
Dr. Vincent Fritz	Professor	University of Minnesota	Help with data interpretation

VII. LONG-TERM- IMPLEMENTATION AND FUNDING:

The long-term implementation of this study will be adoption of the new technology by growers in the state replacing currently used petroleum derived plastics. It will be important that Extension events be developed to highlight the findings of this research. The results will also be publically disseminated through applicable peer reviewed journal articles, the University of Minnesota Research and Outreach Centers (ROCs), AURI online and print publications including AG Innovation News and as a component of public field days at AURI and/or the ROCs.

VIII. REPORTING REQUIREMENTS:

- **The project is for 4 years, will begin on July/1/2018, and end on June/30/2022.**
- **Periodic project status update reports will be submitted January/31 and June/30 of each year.**
- **A final report and associated products will be submitted between June 30 and August 15, 2022.**

IX. SEE ADDITIONAL WORK PLAN COMPONENTS:

A. Budget Spreadsheet
B. Visual Component or Map
C. Parcel List Spreadsheet
D. Acquisition, Easements, and Restoration Requirements
E. Research Addendum

Attachment A:
Environment and Natural Resources Trust Fund
M.L. 2018 Budget Spreadsheet

Project Title: BioMulch to Replace Plastic Soil Covering in Vegetable and Fruit Production to Increase Yield and Reduce Waste
Legal Citation: M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 08b
Project Manager: Paulo Pagliari
Organization: University of Minnesota
College/Department/Division: CFANS/Department of soil water and climate/Southwest Research and outreach center
M.L. 2018 ENRTF Appropriation: $310,000
Project Length and Completion Date: 4 years, June 30, 2022
Date of Report: August 15, 2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Revised Budget [01/28/2021]	AMOUNT SPENT	TOTAL BALANCE
BUDGET ITEM			
Personnel (Wages and Benefits) - Overall	$197,803	$197,803	**$0**
Project Manager Paulo Pagliari responsible for overall project management. 0.1 FTE per year. Salary at $11,202 and fringe at $2,812 (Total estimated amount $42,042)		$42,042	
U of M Research Technician reponsible for sample collection and preparation at 0.75 FTE for salary request at $40,620.80 and $11,048.86 fringe (Total estimated amount $119,185)		$155,761	
Professional/Technical/Service Contracts			
AURI Project Coordinator responsible for project coordination with AURI 10% FTE for salary at $40/hr and fringe at $15/hr (27%), total for three years $33,330.	$27,830	$27,830	**$0**
AURI Research Engineer responsible for application technology at 10% FTE at $40/hr and fringe at $15/hr (27%), total for two years $22,220.	$22,220	$22,220	**$0**
AURI Research Chemist responsible for formulation technology 10% FTE at $40/hr and fringe at $15/hr (27%), total for two years $22,220.	$22,220	$22,220	**$0**
Equipment/Tools/Supplies			
Ingredients for three demonstration sites (100 ft x 3 ft each) total $10,409. Ingredients for formulation refinement and long term decomposition studies $5,359.	$25,969	$25,969	**$0**
Nutrients for production of biomulch at $1,000 per year.	$2,752	$2,752	**$0**
Sample Analysis at $40 per samples to determine the rate of biotarp degradation and nutrient availability (40 samples at each of 2 sites for 3 years, total 240 samples)	$3,600	$3,600	**$0**
Moisture and temperature probes, 30 per location at $250 per probe; total $15,000 for all three ROC locations. 6 dataloggers at $1,000 each per location; total of $12,000 for all three ROC locations.	$6,906	$6,906	**$0**
1 Helium (at $400.00 each) and 1 Oxygen (at $300.00 each) gas cylinders required for carbon nitrogen and sulfur analysis. Total of $700.00 per year.	$700	$700	**$0**
Travel expenses in Minnesota			
In state travel to maintain plots and collect soil samples at the different locations being managed. Estimated 4,000 miles per year, for 20 (weekly travel during May-Spring) x 200 miles round trip from Lamberton to Waseca. Travel estimated at $0.535 per mile to a total of $2,140 per year.	$0	$0	**$0**
In state travel to plots for applications, sample aquisition and for project meetings estimated average 455 mile round trip and 15 trips per year at $0.535 per mile, total $11,050.	$0	$0	**$0**