Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2018 LCCMR Work Plan

Date of Submission: June 15, 2018

Date of Next Status Update Report: January 1, 2019

Date of Work Plan Approval: June 27, 2018

Project Completion Date: June 30, 2021

Does this submission include an amendment request? No

PROJECT TITLE: Agricultural Weed Control Using Autonomous Mowers

Project Manager: Eric Buchanan

Organization: Regents of the University of Minnesota

Mailing Address: 450 McNamara Alumni Center, 200 Oak Street SE

City/State/Zip Code: Minneapolis, MN 55455-2070

Telephone Number: (612) 624-8869

Email Address: buch0123@morris.umn.edu

Web Address: www.umn.edu

Location: Statewide

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$750,000**
	Amount Spent:	**$0**
	Balance:	**$750,000**

Legal Citation: M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 08d

Appropriation Language: $750,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the West Central Research and Outreach Center at Morris to design, integrate, and field-test new technology mowers to control weeds, reduce herbicide use, reduce energy costs, and improve native vegetation and forage quality on agricultural lands. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: LCCMR 157E "Agricultural Weed Control Using Autonomous Mowers"

II. PROJECT STATEMENT:

Minnesota farmers and land managers are engaged in an annual battle to control weeds. Each year, significant amounts of herbicide, diesel fuel, labor, and money are expended in an effort to stay ahead of weed infestations. Control of weeds is critical in the production of food. Current methods of weed control using herbicides have been very effective, but may have unintentional and harmful consequences to our air, land, water, and wildlife resources. We propose to develop improved methods using robots to control weeds on agricultural lands. Solar energy will be used to power the robots. In this first phase, weed control robots will be tested within pastures. In a future phase, testing will include weeding robots within row crops such as corn and soybeans. In accomplishing these goals, we aspire to:

- Significantly reduce the use of herbicides on agricultural and natural lands across the State of Minnesota,
- Replace fossil fuel and resulting air emissions with clean energy produced locally,
- Protect water resources by preventing surface and ground water contamination with herbicides,
- Reduce the impact of herbicide on wildlife, desired native plant species, and the evolution of herbicide tolerant 'super' weeds,
- Develop new time-saving tools for farmers as well as natural lands managers to control weeds,
- Advance the rapidly growing field of robotics within the State,
- Partner with MN companies to development and manufacture cutting-edge robotic technologies.

The project team will develop and test a robotic mowing system to control weeds and improve forage quality in a dairy pasture. An electric powered robot will be recharged by a portable solar PV charging station that will be installed on a cargo trailer. The robotic pasture mower will be developed in partnership with a Minnesota manufacturing company, The Toro Company, and researchers at U of MN. Safety protocols will be developed and tested. The mowing robot will then be field tested in pastures at the U of MN West Central Research and Outreach Center (WCROC). Finally, the robot will be demonstrated to farmers and land managers at workshops, field days, and events such as Farmfest. Additional funding will be sought in a future second phase and will include field robots for weed control in corn and soybean fields. The second phase inter-row and intra-row weed hunter robots will be more technically advanced requiring additional engineering, navigation and visual identification hardware and software development, and testing.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of January 1, 2019:

Project Status as of July 1, 2019:

Project Status as of January 1, 2020:

Project Status as of July 1, 2020:

Project Status as of January 1, 2021:

Overall Project Outcomes and Results:

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1:

Description: Design, Integrate, and Field Test an Autonomous Pasture Mower

A robotic mower capable of operating in harsh pasture terrains will be jointly developed by the U of MN and a Minnesota turf equipment manufacturer, The Toro Company (Toro). A diesel Groundsmaster™ mower will be

provided by Toro as an in-kind contribution. Toro will convert the mower from diesel to electric power by removing the diesel engine and fuel tank, then an electric motor and battery pack capable of powering the mower will be installed. A 100V Lithium battery pack (2 x 14.4 kWh) along with a high efficiency PMAC electric motor is anticipated to be used to power the mower. The Parker liquid cooled Permanent Magnet Alternating Current (aka. brushless) motor is manufactured in New Ulm, MN. The mower will be converted to an autonomous ready state with electronic control enabled to start, shutoff, steer, engage / disengage mower, change of operating speed, implement lift, and change of direction (FWD/REV). Toro will also develop and incorporate control parameters that will prevent the mower to be operated outside of normal /safe operating parameters. These control parameters will include operating speed, cornering speed, engagement of mower, and motor RPMs. Toro will acquire and install a rough mower attachment which the project team believes will be best suited for pasture mowing.

As Toro is modifying the Groundsmaster™ mower, researchers in the U of MN Department of Computer Science and Engineering will purchase and assemble instruments and components for the mower to operate autonomously. A GPS-based system will be developed which will allow the mower to navigate through the pasture using pre-determined GPS points. A LiDAR system will be utilized for hazard detection and avoidance and to signal when necessary to shut down the mower. A laptop computer will be purchased for which control logic will be programmed into the hardware for the mower to operate autonomously. The control logic will include energy awareness planning. Energy awareness planning allows for the efficient use of energy in planning routes traveled by the robot. Simultaneously, researchers in the U of MN Department of Bioproducts and Biosystems Engineering will consult with Toro and Computer Science researchers in the overall development. In addition, the researchers will serve in an important capacity in conducting a Hazardous Operability study (HazOP) which essentially addresses all the “what if?” scenarios and assists in risk reduction. The project team will review the design and integration of the mower identifying potential hazards (including but not limited to mechanical failure, obstacles, and wildlife and/or human interactions), designing control systems to mitigate hazards, and incorporate redundant controls in case one or more systems fail. The system will be designed and constructed to “fail safe”.

Toro and the U of MN researchers will work together to integrate the autonomous operation hardware and software into the modified Groundsmaster™ mower. Once completed, the mower will be commissioned at The Toro Company Headquarters in Bloomington, MN and/or their local field test site in Farmington, MN. Commissioning will include a series of operational tests for basic operation as well as HazOp / fail safe verification. Once the autonomous mower has been commissioned and certified operational by the research team, the mower will be transported to the U of MN West Central Research and Outreach Center (WCROC) near Morris, MN for field-testing in a dairy pasture.

The WCROC utilizes several pastures in a Management Intensive Grazing (MIG) system at its research farm. Approximately 250 cows are pastured at the WCROC and are milked twice per day. Each time the cows are milked, they are moved into a fresh paddock allowing access to new forage. Since half the dairy is organic, weeds within the pasture cannot be sprayed. Mowing is then required to control weeds and also to improve forage quality. As the cows graze, they selectively pick the lushest forage leaving mature grass and forbs as well as weeds. The weeds then tend to flourish and takeover a pasture. So as the cows finish grazing a pasture and move on to the next, the traditional practice is to mow the grazed pasture with a tractor and flail mower. This process is energy intensive and time consuming. The WCROC is working to reduce the fossil energy consumption and the carbon footprint of dairy production. Combined with the certified organic requirements, limited tools are available for effective weed control in pastures without using diesel-powered equipment. In addition, dairy farms in general do not have available labor to continuously mow pastures. Therefore, a battery-powered robot coupled with a solar powered charging station, may be viable.

Beginning in the Spring of 2020, the robotic mower will be put through a series of initial operational tests and then will move into field tests. Initial testing will include line following, obstacle detection, and the coverage

with integrated obstacle avoidance. For the field tests, a 10 to 15 acre pasture will be utilized. The pasture will consist of a cool season grass mixture consistent with conventional Minnesota pastures. The pasture will be divided into 3 blocks each consisting of two treatments. The first treatment will be a control utilizing a tractor and flail mower driven by a WCROC employee. The second treatment will be the robotic mower. After the dairy cows graze through the pasture, the tractor will mow three replicated blocks and the robotic mower will also mow three replicated blocks. Variables will be measured such as time required to complete mowing, energy consumed, length and quality of cut, effectiveness of weed control (plant counts in randomly placed squares), hours of labor required, maintenance / repairs required, and navigation / hazardous issues encountered. Refinements will be made to the robotic mower throughout the test period. Testing will continue throughout the grazing season (generally May through September). Each time the dairy cows are rotated through, the experiment will be repeated.

The robotic mower will be demonstrated to farmers and other land managers during several tours, field days, and workshops at the WCROC and potentially at other locations within the State. Finally, the robotic mower will be displayed at FarmFest near Redwood Falls, MN in August 2020. Farmfest is one of the largest farm industry events in the Midwest and thousands of farmers attend each year.

Following the initial grazing / mowing season in 2020, refinements will be made by the project team and final field testing will be completed in Spring / Early Summer 2021. Field test data will be analyzed and a final report issued on or before August 15, 2021.

Summary Budget Information for Activity 1:

ENRTF Budget: $ 357,059
Amount Spent: $ 0
Balance: $ 357,059

Outcome	Completion Date
1. Convert Toro Groundsmaster Mower from diesel to electric power	*5/1/2019*
2. Develop navigation / logic systems to allow for autonomous operation	*7/2/2019*
3. Develop and test safety and fail-safe logic and protocols	*10/1/2019*
4. Integrate and commission mower with navigation systems and conduct HazOP	*4/1/2020*
5. Field test robot within pastures at the WCROC	*6/1/2021*
6. Display / demonstrate the mowing robot at state-wide events	*6/30/2021*

Activity 1 Status as of January 1, 2019:

Activity 1 Status as of July 1, 2019:

Activity 1 Status as of January 1, 2020:

Activity 1 Status as of July 1, 2020:

Activity 1 Status as of January 1, 2021:

Final Report Summary:

ACTIVITY 2:
Description: Design, Develop, and Field Test a Portable Solar-Powered Charging Station
The team will design, assemble, and test a portable, solar-powered charging station that can be trailered to the field location and allow proof-of-concept for robots to re-charge.

Beginning in July 2018, a solar-powered charging station will be designed by renewable energy scientists at the WCROC in Morris, MN. The charging station will include a cargo trailer, a 1 to 4 kW solar array that can be mounted to the trailer and easily disassembled / folded in for transport, a battery storage pack, and balance-of-plant components to allow for effective and efficient charging of the robotic mower in the field. The cargo trailer will also be sized to allow for transport of the mower to the pasture and outreach events.

Following completion of the charging station design, components will be purchased and assembled at the WCROC. Researchers at the WCROC will use an existing cargo trailer and battery bank. A solar PV system and balance-of-plant components will be purchased. The systems will be fastened into the trailer and an electrician will install the wiring for the solar PV system, battery bank, and charging station. The portable charging station will be inspected and commissioned prior to operation. Initial testing will measure power generation, battery storage capacity, discharge and recharge times, and field setup and charging time.

When field testing begins with the robotic mower in Spring of 2020, the cargo trailer will be used to transport the mower to the pasture. The portable charging station will be placed in or near the pasture to allow efficient recharging of the robotic mower. As the mower's power is diminishing, a signal will be sent to the autonomous control to return to the charging station. When the mower returns, the charging system will be manually connected and the robotic mower's batteries will be re-charged. A future goal (not a deliverable of this project) is to enable autonomous connection of the robot with the charging station. Throughout the grazing season, the portable charging station will be tested and variables recorded include energy production, effective energy stored, efficiency, number of charges and discharges, time required for charging, and labor required. The mower will be recharged at the farm site using on-site renewable energy generation when not in use mowing pastures. The data will be analyzed and included in the final report.

The portable charging station will be demonstrated to farmers and land managers through tours, workshops, and events such as Farmfest.

Summary Budget Information for Activity 2:

ENRTF Budget: $ 66,852
Amount Spent: $ 0
Balance: $ 66,852

Outcome	Completion Date
1. Design a portable hybrid solar PV and electric storage system for charging	*2/1/2019*
2. Integrate solar PV, electric storage, and a charging station on a trailer	*6/1/2019*
3. Field test the portable solar PV charging station and on-board solar at the WCROC	*6/1/2021*
4. Demonstrate the portable solar PV charging station at state-wide events	*6/30/2021*

Activity 2 Status as of January 1, 2019:

Activity 2 Status as of July 1, 2019:

Activity 2 Status as of January 1, 2020:

Activity 2 Status as of July 1, 2020:

Activity 2 Status as of January 1, 2021:

Final Report Summary:

ACTIVITY 3:
Description: Develop and Field Test Autonomous Vehicle(s) Capable of Early Weed Control in Row Crops

The team will design, assemble, and field test at least one and up to two autonomous vehicles capable of weed control in row crops approximately 12 inches and less in height.

Beginning in July 2018, the project team will source UTV and similar platform vehicles that can be powered by renewably produced energy. The vehicles will most likely be four wheel drive, convertible to autonomous operation, and capable of incorporating tracks. Up to two types of platforms may be tested.

Beginning in November 2018, up to four different types of weeding implements will be designed, fabricated, installed, and tested at the WCROC. Initial concepts are the single and-/-or combined use of a rotary hoe, spring tooth harrow, rotary harrow, and scrapper blades. The effectiveness of the implements will initially be tested with a non-autonomous vehicle platform on row crops at the WCROC during the spring and summer of 2019.

Beginning in July 2019, autonomous controls will be designed, installed, and tested on the vehicles. The navigation and awareness sensors, hardware, and software within the mower project will be adapted for these vehicles. GPS-based navigation will be complemented with a vision-based system to meet the higher navigation needs for weeding in row crops.

The row crop vehicles will be converted to an autonomous ready state with anticipated control enabled to start, shutoff, steer, change of operating speed, implement lift, and change of direction (FWD/REV). We anticipate control parameters that will prevent the vehicle to be operated outside of normal /safe operating parameters. These control parameters will include operating speed, cornering speed, engagement of implements, and motor RPMs.

Researchers in the U of MN Department of Computer Science and Engineering will again further develop a GPS-based system developed in Activity 1 to allow the vehicle to navigate through the row crops using pre-determined GPS points. If GPS accuracy is not sufficient, a vision and LiDAR based system for following rows and turning will be developed. A LiDAR system will be utilized for hazard detection and avoidance and to signal when necessary to lift the implement over obstructions or end rows or shut down the vehicle. Simultaneously, researchers in the U of MN Department of Bioproducts and Biosystems Engineering will consult Computer Science researchers in the overall development of the autonomous vehicles. The project team will review the design and integration of the integrated vehicles and implements identifying potential hazards (including but not limited to mechanical failure, obstacles, and wildlife and/or human interactions), designing control systems to mitigate hazards, and incorporate redundant controls in case one or more systems fail. The system will be designed and constructed to “fail safe”.

Commissioning will include a series of operational tests for basic operation as well as HazOp / fail safe verification. Once the autonomous vehicle(s) have been commissioned and certified operational by the research team, the row crop weeding autonomous vehicles will be field tested within organic certified corn and soybean fields at the U of MN West Central Research and Outreach Center (WCROC) near Morris, MN.

Beginning in the Spring of 2020, the autonomous row crop weeding vehicle(s) will be put through a series of initial operational tests and then will move into field tests. Initial testing will include line following, row and obstacle detection, and the coverage with integrated obstacle avoidance. For the field tests, approximately 10 acre row crop plots of corn and soybeans will be utilized. The row crops will be divided into 3 replications each consisting of at least three treatments- Non-Autonomous Implement, Autonomous Implement #1, Autonomous Implement #2, ETC. The first treatment will be a control utilizing a tractor and implement driven by a WCROC employee. The second treatment is anticipated to be the autonomous vehicle and rotary hoe. The third and subsequent treatments will include the autonomous vehicles and different implements. Variables will be measured such as time required to complete row crop weeding (acres per hour), energy consumed (kWh or fuel / acre) , effectiveness of weed control (weed counts / acre extrapolated from smaller sample size), row crop plants per acre (extrapolated from smaller sample size) hours of labor required, maintenance / repairs required,

and navigation / hazardous issues encountered. Refinements will be made to the autonomous vehicles and implements throughout the test period including the possibility of multiple passes or combinations of implements. Testing will continue throughout the early growing season (generally May through early June).

The autonomous vehicle capable of early weed control in row crops will be demonstrated to farmers and land managers through tours, workshops, and events such as Farmfest.

Summary Budget Information for Activity 3:

ENRTF Budget: $ 326,088
Amount Spent: $ 0
Balance: $ 326,088

Outcome	Completion Date
1. Design, develop, and test a UTV or comparable platform to weed in row crops	*7/1/2019*
2. Design, develop, and test row crop weed implements on a UTV or comparable platform	*7/1/2019*
3. Develop navigation / logic systems to allow for autonomous operation	*1/1/2020*
4. Develop and test safety and fail-safe logic and protocols	*4/1/2020*
5. Integrate and commission UTV or comparable platform with navigation systems	*4/1/2020*
6. Field test autonomous weeding vehicle within row crops at the WCROC	*6/20/2021*
7. Display / demonstrate the autonomous vehicle at state-wide events	*6/30/2021*

Activity 3 Status as of January 1, 2019:

Activity 3 Status as of July 1, 2019:

Activity 3 Status as of January 1, 2020:

Activity 3 Status as of July 1, 2020:

Activity 3 Status as of January 1, 2021:

Final Report Summary:

V. DISSEMINATION:
Description:
Several different mechanisms will be utilized to disseminate the information. First, the mowing robot will be demonstrated to farmers and land managers at workshops, field days, and a large event such as Farmfest. Information learned in the project will be posted on-line at the University of Minnesota West Central Research and Outreach Center site. As the project achieves milestones, news briefs will be sent to local and regional news outlets as well as agricultural trade magazines such as The Farmer and The Land to report progress.

Status as of January 1, 2019:

Status as of July 1, 2019:

Status as of January 1, 2020:

Status as of July 1, 2020:

Status as of January 1, 2021:

Final Report Summary:

VI. PROJECT BUDGET SUMMARY:

A. Preliminary ENRTF Budget Overview:
See attached budget spreadsheet

Explanation of Use of Classified Staff: N/A

Explanation of Capital Expenditures Greater Than $5,000: One solar PV system will be purchased for not more than $13,600. The solar system will include solar panels, bracketing, inverter, battery pack, balance-of-plant, and a charging station. One or more of these components may need to be purchased separately. At least one and up to two UTV or comparable platforms will be purchased and customized for autonomous operations in row crop weeding activities. The total expenditure will be $42,000 or less. One Velodyne E-Puck LiDAR and related components will be purchased for a price not to exceed $10,000. The LiDAR will be used to make the mowing robot aware of potential hazards in the general area and then a signal will be sent for the system to shut down or to avoid the hazard.

Total Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: ~4.05 FTE

Total Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: ~0.33 FTE

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
The Toro Company	$ 124,000	$	In-kind contribution of equipment and labor
State			
	$	$	
TOTAL OTHER FUNDS:	**$ 124,000**	**$**	

VII. PROJECT STRATEGY:
A. Project Partners:
Partners receiving ENRTF funding
Edric Funk, Director of Toro Center for Advanced Turf Technology, and Jack Gust, Research and Development Chief Engineer, The Toro Company, $99,000 ($37,000 labor and $62,000 components and supplies) , Convert a Toro diesel mower to electric power including adding an electric motor and battery storage. Aquire and integrate a flail mower. Assist in integrating controls for autonmous operation and in commissioning and testing of the mower system. The Toro Company will provide an in-kind match of $124,000 in equipment and labor.

B. Project Impact and Long-term Strategy:
Successful development of economic solar-powered robotic systems for weed control in pastures and fields will have significant positive impacts to Minnesota's air, land, water, and wildlife resources. The long term strategy is to develop marketable robotic weed control systems that can be manufactured by Minnesota companies and utilized by Minnesota farmers and land managers; and expand the utilization of solar PV within the State. A Minnesota original equipment manufacturer (OEM) is participating on the project team and will provide invaluable experience in developing products for the commercial market. The project team anticipates submitting a future funding request for a second phase of this project which will involve the use of robots to control weeds in row crops.

C. Funding History: This is a novel project. The Project Manager has received LCCMR funding in the past but for unrelated projects.

Funding Source and Use of Funds	Funding Timeframe	$ Amount
		$

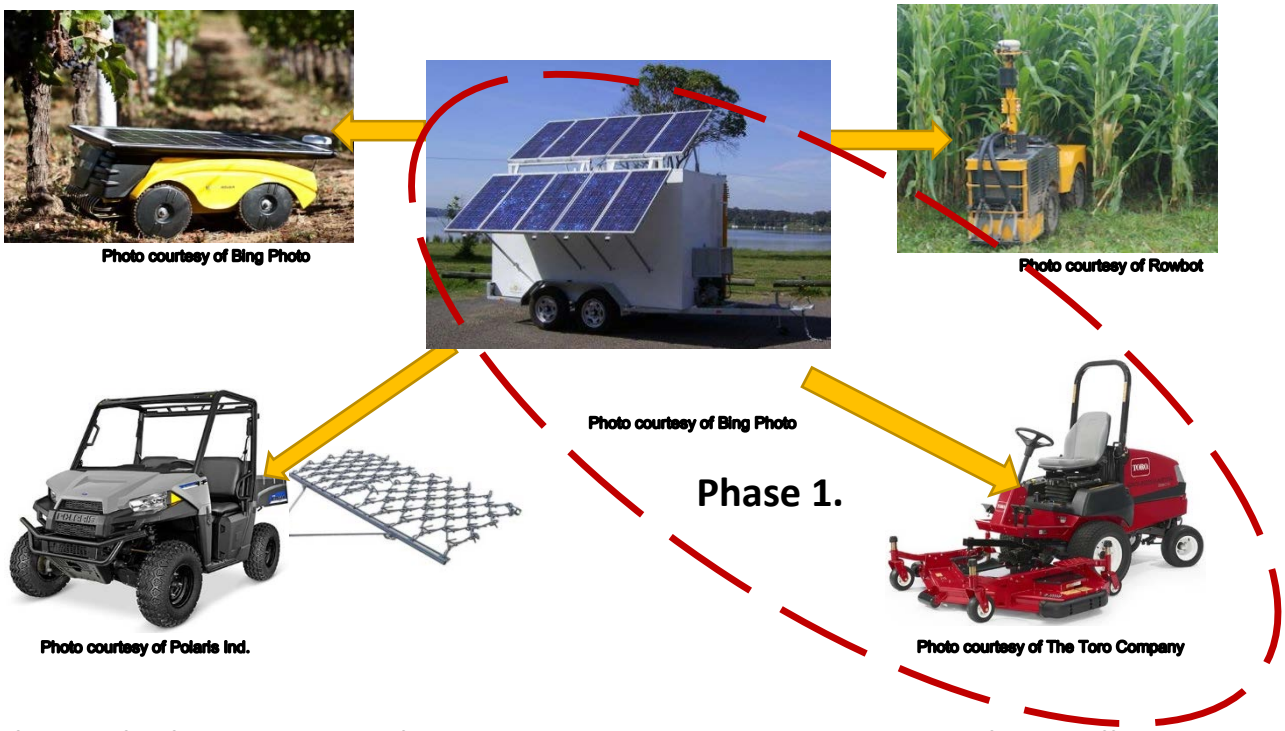
VIII. REPORTING REQUIREMENTS:

- **The project is for 3 years, will begin on 07/01/2018, and end on 06/30/2021.**
- **Periodic project status update reports will be submitted January 15th and July 15th of each year.**
- **A final report and associated products will be submitted between June 30 and August 15, 2021**.

IX. VISUAL COMPONENT or MAP(S):

Conventional weed control processes typically use large, diesel-powered sprayers and chemical herbicides are broadcast across crop fields and pastures. Control of weeds is very effective, however, there are unintended and potentially harmful consequences.

Our concept is to evaluate the control of weeds in pastures and row crops using robots powered by the sun. Our project team will utilize off-the-shelf as well as pre-commercial technologies which will be modified to operate autonomously in the mowing of pastures and weeding of fields.



If successful, fossil-based diesel fuel and chemical herbicide use as well as harmful side-effects will be significantly reduced. Local production of clean energy will be increased. Farmers will have new time-saving tools for effective weed control and Minnesota companies will benefit by leading the manufacture of new solar-powered robotic technologies.

Environment and Natural Resources Trust Fund
M.L. 2018 Project Budget

Project Title: Agricultural Weed Control Using Autonomous Mowers
Legal Citation: M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 08d
Project Manager: Eric Buchanan
Organization: Regents of the University of Minnesota
M.L. 2018 ENRTF Appropriation: $ *750,000*
Project Length and Completion Date: *3 Years, June 30, 2021*
Date of Report:

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	TOTAL BUDGET	TOTAL SPENT	TOTAL BALANCE
BUDGET ITEM			
Personnel (Wages and Benefits)	$ 516,699	$ -	$ 516,699
Project Coordinator - Eric Buchanan, $88,934 (FTE Yr 1 at 10% and Yrs 2-3 at 50%) 33.5 % fringe rate, 2.25% COLA -U of MN WCROC			
Researcher, $75,440 (10 % FTE Yr 1, 50% Yr 2, 40% Yr 3) 33.5% Fringe Rate, 3% COLA - U of MN Bioproducts and Biosystems Engineering			
Farm Technician - Fabrication and testing of weeding implements, $11,898 (FTE Yr 1 - 25%) 27.2% Fringe Rate, U of MN WCROC			
Post Doctorate Research Associate, $81,830 (50 % FTE-Yrs 1-2) 23% Fringe Rate, 3% COLA - U of MN CS&E			
Graduate Student Research Assistant #1 to train under Dr. Volkan Isler with autonomous mower - CSE, $132,760 (Yrs 1-3, 9 months in final year, 50% FTE, hourly rate $24.92 plus tutition at $19.90 / AY hr, 17.7% fringe)			
Graduate Student Research Assistant #2 to train under Dr. Volkan Isler with autonomous row crop weeder - CSE, $132,760 (Yrs 1-3, 9 mo. in final year, 50% FTE, hourly rate $24.92 plus tutition at $19.90 / AY hr, 17.7% fringe)			
Professional/Technical/Service Contracts			
Subcontract with The Toro Company, Bloomington, MN for labor ($37,000), components, and supplies to convert a diesel powered mower to electric power and to assist and provide a location to integrate and commission the autonomous hardware and software being developed at the U of MN.	$ 99,000	$ -	$ 99,000
Contract with an electrician to complete wiring of the portable solar-powered charging station. University of Minnesota professional service policy will be followed in securing services of an electrician to perform this work.	$ 5,500	$ -	$ 5,500
Equipment/Tools/Supplies	$ -	$ -	$ -
Lab supplies for Dr. Isler including a laptop computer with NVidia GPU, GPS systems, multiple cameras, component enclosures, and supplies for wiring, soldering, etc.	$ 9,599	$ -	$ 9,599
Materials to fabricate custom weeding implements (steel, part assemblies, wheels, paint, welding rods, etc.)	$ 18,000	$ -	$ 18,000
Supplies for Buchanan including energy meters / sensors, and supplies for wiring and securing systems on the portable charging station.	$ 1,526	$ -	$ 1,526
Capital Expenditures Over $5,000	$ -	$ -	$ -
Solar PV system which will include solar panels, bracketing, inverter, battery pack controller, balance-of-plant and charging station	$ 13,600	$ -	$ 13,600
UTV or comparable platforms customized for autonomous field operations	$ 42,000	$ -	$ 42,000
Velodyne E-Puck LiDAR and components	$ 10,000	$ -	$ 10,000
Travel expenses in Minnesota	$ -	$ -	$ -
Twelve trips by CSE and BBE Faculty from Saint Paul to Morris, MN (330 miles @ $.56 / mi)	$ 2,218	$ -	$ 2,218
Lodging and meals for CSE and BBE Faculty in Morris (3 people / 6 nights @ $80 / room and $40 ea for meals)	$ 5,760	$ -	$ 5,760
WCROC Staff travel from Morris to Twin Cities (330 miles and 4 trips @ .56, 2 nights @ $120 / room and $40 ea for meals)	$ 2,069	$ -	$ 2,069
Travel, lodging, and meals for one in-state outreach event FarmFest (4 people, 4 days /3 nights, 2 trips, 400 mi @$.56/mi, $120 / room, and $40 ea for meals)	$ 2,049	$ -	$ 2,049
Other	$ -	$ -	$ -
Computer Services Fee - Standard fee charged by U of MN Department of Computer Science and Engineering for use of computers by staff for programming and analysis.	$ 19,581	$ -	$ 19,581
Farmfest Exhibitor Fee, Tickets, Signage, and Display	$ 2,400	$ -	$ 2,400
COLUMN TOTAL	**$ 750,000**	**$ -**	**$ 750,000**