Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2019 ENRTF Work Plan (Main Document)

Today's Date: June 13, 2019

Date of Next Status Update Report: January 1, 2020

Date of Work Plan Approval: June 17, 2019

Project Completion Date: August 30, 2022

Does this submission include an amendment request? _No_

PROJECT TITLE: Agricultural Weed Control Using Autonomous Mowers – Phase 2

Project Manager: Eric Buchanan

Organization: University of Minnesota

College/Department/Division: West Central Research and Outreach Center

Mailing Address: 46352 State HWY 329

City/State/Zip Code: Morris, MN 56267

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Web Address: https://wcroc.cfans.umn.edu/

Location: Statewide

Total Project Budget: $900,000

Amount Spent: $0

Balance: $900,000

Legal Citation: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 08g

Appropriation Language:

$900,000 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.

I. 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 second 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,

The project team will develop and test a robotic weed hunting system to control weeds in mid to late term row crops. A weed hunter robot will be more technically advanced than the phase 1 pasture mowing and early term crop robots requiring additional engineering, navigation and visual identification hardware and software development, and testing. The phase 2 electric powered robot will be autonomously recharged by a portable solar PV charging station installed on a cargo trailer. Safety protocols will be developed and tested. The weed hunter robot will then be field tested 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.

II. OVERALL PROJECT STATUS UPDATES:

First Update March 1, 2020

Second Update September 1, 2020

Third Update March 1, 2021

Fourth Update September 1, 2021

Fifth Update March 1, 2022

Final Report between project end (August 30) and October 15, 2022

III. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1 Title: Develop Navigation and Weed Identification Systems
Description: A weed hunting robot needs to be able to navigate between crop rows, exit one row and find the next row, as well as maneuver within a row as weeds are identified. Algorithms and sensors will be developed to accomplish this without damaging the row crops. Additionally, autonomous vehicles will need to incorporate software safety protocols to ensure safety of equipment, operators, and bystanders.

A weed hunting robot also needs to be able to identify undesirable weeds and distinguish them from desirable row crops. Several different types of sensors or a combination of sensors could be used to identify weeds

including visual identification from a camera image. Multiple strategies will be considered and tested for effectiveness.

Initial testing of navigation and weed identification strategies will be done with a small robot model like the Rover Robotics 4 wheel drive robot. Testing will be conducted on the University of Minnesota campus and later in fields at the WCROC. Systems will be tested for accuracy and efficiency and refined as needed. Successful systems will then be transferred to the final robotic vehicle platform developed concurrently.

ACTIVITY 1 ENRTF BUDGET: $384,232

Outcome	Completion Date
1. Develop initial sensor/control systems	5/1/2020
2. Refine sensor/control systems with field trials	5/1/2021
3. Adapt navigation/weed ID systems to final weed hunter robot	7/1/2021
4. Performance testing of refined systems	9/1/2022

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ACTIVITY 2 Title: Weed Control System Development
Description: A weed hunting robot needs a means to kill identified weeds. Several methods are possible and will be considered including spot spraying of an herbicide, mowing/cutting, and root destruction (hoeing/pulling). Potential weed destruction methodologies will be assessed for their suitability using several factors including potential effectiveness, robot power requirements, safety, acceptability in organic fields, robustness of mechanisms, and control difficulty. Top contenders will be prototyped and tested on a small robot model like the Rover Robotics 4 wheel drive robot.

A final design will be selected and fabricated for testing on the final robotic vehicle platform developed concurrently.

ACTIVITY 2 ENRTF BUDGET: $136,946

Outcome	Completion Date
1. Develop matrix of weed control strategies and suitability factors	10/1/2019
2. Develop/test selected weed control strategy prototypes	8/1/2020
3. Select final weed control strategy(s)	10/1/2020
4. Performance testing of refined systems	9/1/2022

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ACTIVITY 3 Title: Robotic Vehicle Development
Description: In the initial phases of the development cycle, we will use a small research ground vehicle, like the Rover Robotics 4 wheel drive robot, to collect data and test individual components. However, such a vehicle will not have the ruggedness and payload capacity (and consequently battery life) to operate in real farm conditions. Specifically, a robotic vehicle platform is needed to carry the weed identification package and weed control mechanism through a field to eliminate weeds. The vehicle needs to be robust for an outdoor environment and able to travel effectively in loose soil with potentially muddy conditions. The vehicle will need to be as light as possible to maximize battery life and small enough to fit between standard crop rows that are planted 30 inches between rows. A SAGA Robotics Thorvald, or equivalent platform, will be procured and modified as needed to accommodate the selected weed control strategy(s) and navigation equipment.

ACTIVITY 3 ENRTF BUDGET: $302,376

Outcome	Completion Date
1. Develop initial vehicle requirements	10/1/2019
2. Purchase/modify Rover Robotics (or equiv.) research robot	2/1/2020
3. Adapt weed control prototypes to research robot	6/1/2020
4. Purchase/modify SAGA Robotics Thorvald (or equiv.) weed hunter robot	1/1/2021
5. Adapt selected weed ID/control systems to final weed hunter robot	5/1/2021
6. Performance testing of refined systems	9/1/2022

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ACTIVITY 4 Title: Develop Autonomous Solar Charging System
Description: A solar charging station is being developed in phase 1 of this project and will be adapted to interface with the new weed hunting robot. Additionally, the charging station will be modified to allow the robot to dock and charge autonomously. This will require software for the robot to find the charging station and navigate to it when the robot state of charge reaches a predetermined level. This will be performed in two phases: assuming that the location of the charging station is known in advance, a GPS + computer vision based module will be implement for the robot to get close to the station. Afterwards, a homing behavior will be developed for docking into the station. The interface geometry between the robot and charging station ports will be developed to maximize the ability of the robot to find and connect to the station while maintain charger safety.

Software enabling the robot to return to the charging station autonomously will be tested on the small robot model at the University of Minnesota campus and later in fields at the WCROC and finally adapted to the more robust weed hunter robot.

ACTIVITY 4 ENRTF BUDGET: $76,446

Outcome	Completion Date
1. Develop initial sensor/control systems for finding charge station	5/1/2020
2. Design and fabricate robot/charger interface hardware	5/1/2020
3. Refine autonomous charging system with field trials	5/1/2021
4. Adapt final charging software and hardware to the weed hunting robot	5/1/2021

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Fourth Update September 1, 2021

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IV. DISSEMINATION:

Description: Several different mechanisms will be utilized to disseminate the information. First, the weed hunter 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.

The Minnesota Environment and Natural Resources Trust Fund (ENRTF) will be acknowledged through use of the trust fund logo or attribution language on project print and electronic media, publications, signage, and other communications per the ENRTF Acknowledgement Guidelines.

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Third Update March 1, 2021

Fourth Update September 1, 2021

Fifth Update March 1, 2022

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V. ADDITIONAL BUDGET INFORMATION:

A. Personnel and Capital Expenditures

Explanation of Capital Expenditures Greater Than $5,000:
One small research robot, like the Rover Robotics 4 wheel drive robot, $10,380. This robot will be used to test concepts and collect navigation data, however, such a vehicle will not have the ruggedness and payload capacity (and consequently battery life) to operate in real farm conditions. The robot will continue to be used for field data collection after this project is completed.

One robust robotic platform, like the SAGA Robotics Thorvald, $130,000. This platform will be used to carry selected weed control strategy(s) and navigation equipment becoming a weed hunter robot capable of farm fieldwork. The robot will continue to be used for fieldwork research after this project is completed.

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 for entire duration of project: 15,350	Divide total personnel hours by 2,080 hours in 1 yr = TOTAL FTE: 7.4

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

Enter Total Estimated Contract Personnel Hours for entire duration of project: 325	Divide total contract hours by 2,080 hours in 1 yr = TOTAL FTE: .2

VI. PROJECT PARTNERS:

A. Partners outside of project manager's organization receiving ENRTF funding

B. Partners outside of project manager's organization NOT receiving ENRTF funding

VII. LONG-TERM- IMPLEMENTATION AND FUNDING:

Successful development of economic solar-powered robotic systems for weed control in 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 in phase 1 of this project and will provide invaluable experience in developing products for the commercial market.

VIII. REPORTING REQUIREMENTS:

- Project status update reports will be submitted March 1 and September 1 each year of the project
- A final report and associated products will be submitted between August 30 and October 15, 2022

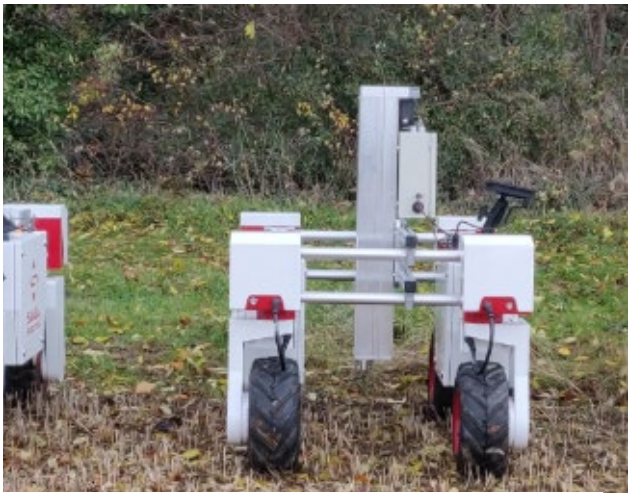
IX. SEE ADDITIONAL WORK PLAN COMPONENTS:

A. Budget Spreadsheet
B. Visual Component or Map
C. Parcel List Spreadsheet

IX.
B. VISUAL COMPONENT or MAP(S):

The Rover Robotics 4 wheel drive robot is a readily available robot testing platform from a Minnesota company. It can be configured to carry a variety of payloads and is electric powered. The project team has experience with this platform and will use it, or something similar, to test navigation systems and weed

SAGA Robotics has developed an autonomous robotic vehicle, called Thorvald, for agricultural tasks like fungus control on strawberry plants. The Thorvald platform is configurable to a variety of geometries to adapt to different tasks. The project team will use the Thorvald, or an equivalent platform, to test our weed control strategy in farm fields.



Attachment A:
Environment and Natural Resources Trust Fund
M.L. 2019 Budget Spreadsheet
Legal Citation: M.L. 2019, First Special Session, Art. 4, Chp. 2, Sec. 2, Subd. 08g
Project Manager: Eric Buchanan
Project Title: Agricultural Weed Control Using Autonomous Mowers
Organization: Regents of the University of Minnesota
Project Budget: $900,000
Project Length and Completion Date: 3.5 years, 12/31/2022
Today's Date: 6/13/2019

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	$ 662,821	$ -	$ 662,821
Project coordinator - Eric Buchanan - $55,220 (77% salary, 23% fringe)FTE yrs 1-2, 10%, yr 3, 50%			
Prject Engineer - WCROC - $154,754 (77% salary, 23% fringe)FTE yrs 1, 50%, yr 2-3, 100%			
Farm technician - WCROC - $50,000 (77% salary, 23% fringe)FTE yrs 1-2, 25%, yr 3, 0%			
Research technician -BBE - $50,000 (74% salary, 26% fringe)FTE yrs 1-2, 28%, yr 3, 0%			
Computer Scientist - Junaed Sattar - $49,969 (74% salary, 26% fringe)FTE yrs 1-2, 8%, yr 3, 6%			
Grad student RA#1 w/ Dr. Volkan Isler - CSE - $151,439 (86% salary, 14% fringe)FTE yrs 1- 3, 50%			
Grad student RA#2 w/ Dr. Volkan Isler - CSE - $151,439 (86% salary, 14% fringe)FTE yrs 1- 3, 50%			
Professional/Technical/Service Contracts	$ 15,000	$ -	$ 15,000
Contracts for robot platform modifications and/or weed control equipment design from TORO or equivalent following U of MN policies, $15,000			
Equipment/Tools/Supplies	$ 50,919	$ -	$ 50,919
Rover Robotics charging dock, or equiv., $1,450			
Rover Robotics payload supplies including a laptop computer with NVidia GPU, GPS systems, multiple cameras, component enclosures, and supplies for wiring, soldering, etc., $14,969			
Weed hunter robot sensors & control electronics for Dr. Isler, $15,000			
Weed control apparatus supplies and equipment for prototyping and fabrication, $15,000			
Solar charging trailor modifications to accommodate autonomous charging, $4,500			
Capital Expenditures Over $5,000	$ 143,380	$ -	$ 143,380
Weed hunter robot platform vehicle (SAGA Robotics, Thorvald, or equiv.) following U of MN policies, $130,000			
Rover Robotics 4 wheel drive robot platform with charger, payload package; or equiv. following U of MN policies, $ 13,380			
Printing	$ 1,500	$ -	$ 1,500
Printing conference materials for Midwest Farm Energy Conference to be held at the WCROC in 2021, $1,500			
Travel expenses in Minnesota	$ 9,699	$ -	$ 9,699
Twelve trips by CSE and BBE Faculty from Saint Paul to Morris, MN (340 miles @ $.58 / mi) , $2,366; Lodging and meals for CSE and BBE Faculty in Morris (3 people / 6 nights @ $120 / room and $40 ea for meals), $ 2,880			
WCROC Staff travel from Morris to Twin Cities (340 miles and 4 trips @ .58), $789; A Lodging and meals for WCROC staff in St. Paul (2 people / 4 nights @ $120 / room and $40 ea for meals), $ 1,280			
Conference-Farmfest Exhibitor Fee, Tickets, Signage, and Display, $2,500 for public presentation of the project and dissemination of project information; Travel for one in-state outreach event FarmFest (4 people, 4 days /3 nights, 2 trips, 400 mi @$.58/mi), $464 Lodging and meals for one in-state outreach event FarmFest (4 people, 4 days /3 nights, $120 / room, and $40 ea for meals), $1,920			
Other	$ 16,681	$ -	$ 16,681
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. $16,681			
COLUMN TOTAL	$ 900,000	$ -	$ 900,000

OTHER FUNDS CONTRIBUTED TO THE PROJECT	Status (secured or pending)	Budget	Spent	Balance
Non-State:		$ -	$ -	$ -
State:		$ -	$ -	$ -
In kind:		$ -	$ -	$ -

PAST AND CURRENT ENRTF APPROPRIATIONS	Amount legally obligated but not yet spent	Budget	Spent	Balance
Current appropriation: ML2018 CH 214 ART 4 SEC2 SUB 08D E818WCM		$ 750,000	$ 22,537	$ 727,463
Past appropriations:		$ -	$ -	$ -