



Environment and Natural Resources Trust Fund

M.L. 2024 Approved Work Plan

General Information

ID Number: 2024-076

Staff Lead: Lisa Bigaouette

Date this document submitted to LCCMR: June 13, 2024

Project Title: Improving Agricultural Ecosystems through Autonomous Weed Control

Project Budget: \$978,000

Project Manager Information

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Project Reporting

Date Work Plan Approved by LCCMR: June 20, 2024

Reporting Schedule: June 1 / December 1 of each year.

Project Completion: June 30, 2027

Final Report Due Date: August 14, 2027

Legal Information

Legal Citation: M.L. 2024, Chp. 83, Sec. 2, Subd. 07c

Appropriation Language: \$978,000 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 develop green hydrogen- and solar-powered autonomous mowers to remove weeds in row crop fields and improve agricultural ecosystems through reduction of herbicide and fossil fuel use. This appropriation is subject to Minnesota Statutes, section 116P.10.

Appropriation End Date: June 30, 2027

Narrative

Project Summary: Autonomous robots, powered by green hydrogen and solar power, designed to remove weeds in row crop fields can improve agricultural ecosystems with reduced herbicide application and fossil fuel use.

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

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 to stay ahead of weeds. 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. One of these consequences is herbicide drift to adjacent lands with negative impacts on desired native plant species including pollinator habitat. Another is the evolution of herbicide tolerant “super weeds” that are getting more difficult to control. Moreover, the use of fossil fuels in herbicide production and tractor-based weed control is a difficult-to-address portion of agriculture’s carbon footprint. Weeding robots powered by renewable energy provide an opportunity to address these concerns and provide a more robust weed control solution for organic farmers.

Continual pressure to increase crop yields results in more stress on agricultural ecosystems. Robotic weeding can eliminate some of this stress allowing productivity gains without the negative side effects. Furthermore, an effective weeding solution for organic crops could lead to more widespread organic adoption reducing the use of synthetic fertilizer.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

We propose to develop improved methods using robots to control weeds on agricultural lands. Solar energy and green hydrogen will be used to power the robots. In an earlier phase, a robot was developed to remove weeds in late term row crops, such as corn and soybeans, powered by a solar charging trailer. Now we propose to develop another vehicle to remove weeds autonomously in all phases of crop growth. Weed control methods optimized for young crops will be evaluated for effectiveness with the most promising ones tested on the robot. Furthermore, using smaller robots to replace traditional tractor operations requires multiple robots to work together in a field. Developing navigation and sensing algorithms to address these problems will be a significant part of this project. We will also modify the previously developed solar charging trailer to include a hydrogen fuel cell. The hybrid powered charging trailer will also demonstrate a robust, weather independent power station that could have other applications like providing emergency power after natural disasters.

This weed hunting robot will be field tested at the U of MN West Central Research and Outreach Center and demonstrated at workshops, field days, and events such as Farmfest.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state’s natural resources?

In accomplishing our project 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, especially organic farmer, as well as natural lands managers to control weeds,
- Advance the rapidly growing field of robotics within the State.

Project Location

What is the best scale for describing where your work will take place?

Region(s): Central

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

In the Future

Activities and Milestones

Activity 1: Design and develop a robotic vehicle with weed control implements.

Activity Budget: \$423,181

Activity Description:

A commercially available robotic vehicle like the SAGA Robotics Thorvald will be procured and modified to operate effectively in standard row crop fields. The vehicle will need to be configured geometrically to match standard row spacing and have robust wheels and drive traction to travel in typical field conditions. A frame will be designed and constructed to fit the robotic vehicle and provide for mounting of weed control implements, cameras and sensors, GPS navigation equipment, as well as control electronics and batteries.

Weed control methods for early term crops will be investigated for effectiveness and energy efficiency. The most promising methods will be prototyped and tested in crop fields. The best one(s) will be incorporated into the overall robot design.

An electric tractor was procured with an earlier LCCMR grant. A pull-behind implement using the selected weed control implement(s) will also be designed and built allowing a comparison of the effectiveness and energy consumption of three weed control methods: small autonomous weeding robots, a small electric tractor pulling a weed control implement, and traditional tractors pulling standard cultivators and spraying implements.

The robot will be demonstrated at the Midwest Farm Energy Conference (2026) and at Farmfest (2025 & 2026).

Activity Milestones:

Description	Approximate Completion Date
1. Procure autonomous capable robot vehicle.	July 31, 2025
2. Design and build robot frame and weed control implements.	April 30, 2026
3. Build pull-behind weed control implement for electric tractor.	April 30, 2026
Field test weed control methods at WCROC.	June 30, 2027
Final assessment of weed control implements and robotic vehicles	June 30, 2027

Activity 2: Develop software algorithms for multiple vehicle control, navigation, and weed identification.

Activity Budget: \$449,611

Activity Description:

Camera footage of emerging crops and weeds will be captured for analysis of methods to identify weeds from crops. Algorithms to process camera data in real time to locate weeds will be sought to allow weed elimination while maximizing robot speed. Note that this is a challenging problem because the rows are narrow which reduces the camera footprint. Furthermore, there is a trade-off between robot speed and the accuracy needed for positioning weed control implements. Additionally, identifying crop rows from camera images will supplement GPS data to aid in-field robot navigation. The robot will also need to navigate back to the charging station when battery levels are low without driving over crop rows.

A robot controller will be developed to create an efficient robot path through a field given the field boundaries and row orientation. The controller will also consider multiple vehicles working in the same field to avoid collisions and weeding overlap. The robot controller will be validated in WCROC crop fields with a second vehicle. Additionally, drones will be investigated for a potential to survey fields prior to weeding providing a weed map to increase robot efficiency.

Activity Milestones:

Description	Approximate Completion Date
1. Collect crop/weed image footage for analysis.	July 31, 2025
2. Develop control and navigation strategies and test with simulations.	July 31, 2025
3. Develop weed identification algorithms.	March 31, 2026
Assess the use of drones to improve robotic weeding results	September 30, 2026
Validate software performance in WCROC fields	June 30, 2027

Activity 3: Develop hybrid solar charging trailer to include a hydrogen fuel cell.

Activity Budget: \$105,208

Activity Description:

A solar powered charging station was developed on an earlier LCCMR project to transport and charge robots operated in remote fields. A donated hydrogen fuel cell will be installed into the charging trailer giving it two power sources. The battery storage capacity in the trailer will be doubled with 2 lithium iron phosphate wall-mounted batteries. This new, unique hybrid power station will have vastly increased capabilities being able to charge its batteries regardless of weather.

The hybrid power station will also be a model for potential disaster relief operations where emergency power may be needed. The power station will be part of numerous tours at the WCROC and demonstrated at the Midwest Farm Energy Conference (2026) and at Farmfest (2025/6). Research will be conducted to understand any safety and permitting requirements of the new power station.

Activity Milestones:

Description	Approximate Completion Date
Assess DOT requirements for H2 storage and use in charging trailer	April 30, 2025
1. Procure batteries and ancillary equipment.	May 31, 2025
2. Develop hybrid charging control system.	May 31, 2025
3. Install new equipment in trailer.	October 31, 2025
4. Test and validate trailer charging performance.	June 30, 2027

Dissemination

Describe your plans for dissemination, presentation, documentation, or sharing of data, results, samples, physical collections, and other products and how they will follow ENRTF Acknowledgement Requirements and Guidelines.

Autonomous weeding robots developed with ENTRF dollars will be demonstrated at the Midwest Farm Energy Conference hosted by the WCROC in Morris and at Farmfest in at least one year and possibly two. Additionally, it is expected that at least two scientific papers will be published in peer reviewed computer science journals. This project, like previous LCCMR funded robotics projects, is expected to garner a lot of media attention from Ag publications as well as statewide media. Outreach is an important part of the mission of the West Central Research and Outreach Center. Robots developed on this project, like their predecessors, will be prominently featured in the dozens of tours given every year to local farmers, visiting scholars and entrepreneurs, legislators, and international visitors for years to come.

The ENTRF logo will be included in all presentations, mailings, and brochures related to this project and the attribution language will be provided to all media personnel covering it.

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?

Machines developed for this project will continue to be maintained and used in general WCROC farm operations, and budget, where practical. Like previous ENTRF funded work, results from this project will continue to be part of numerous public tours and workshops conducted at the WCROC each year as part of our outreach mission. Project results will also be incorporated into the self-funded WCROC Farm Energy Experience Pathway consisting of signs to guide visitors on a tour of farm energy installations and research on the WCROC farm site.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Agricultural Weed Control Using Autonomous Mowers	M.L. 2018, Chp. 214, Art. 4, Sec. 2, Subd. 08d	\$750,000
Agricultural Weed Control Using Autonomous Mowers	M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 08g	\$900,000

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	\$ Amount
Personnel								
1 Principle Investigator (P&A)		Manage project budget, schedule, procurement, and completion of deliverables. Design hybrid energy system.			36.8%	0.99		\$106,590
2 Renewable Energy Scientists (civil service)		Design, build, and test robot structure and weed control implements. Install hybrid energy system into charging trailer.			32%	3.6		\$280,884
1 Postdoc		Lead software development for control, navigation and weed identification.			25.7%	2		\$174,467
2 PhD Graduate Students		Develop software for control, navigation and weed identification.			24.1%	4		\$224,501
2 Undergrad summer interns		Conduct small research projects concerning weed control implement design and charging trailer hybrid power design.			0%	0.5		\$15,600
							Sub Total	\$802,042
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Tools and Supplies	Carbon fiber tubes, fittings, epoxy, etc.	Materials to construct weeding robot frame and structure					\$4,000
	Tools and Supplies	Metal, motors, fasteners, etc.	Materials to construct and test weed control implements					\$15,000
	Tools and Supplies	Metal, motors, fasteners, wheels, etc.	Materials to construct and test a weed control implement to be pulled behind a small tractor.					\$15,000
	Equipment	Wiring, sensors, electrical boxes, control hardware, batteries, etc.	Materials to wire and control robot remotely including safety Estop switches					\$12,000
	Tools and Supplies	Hand tools, construction aids, power strips/cords, portable lighting, soldering supplies, etc.	General supplies and tools to aid in robot fabrication.					\$3,000

	Equipment	Swagelok tubing and fittings, pressure regulator, mounting hardware, etc.	Balance of system equipment to install hydrogen fuel cell into charging trailer. Fuel cell and hydrogen tanks have been donated to the WCROC previously.					\$7,000
							Sub Total	\$56,000
Capital Expenditures								
		1 autonomous capable electric vehicle	Vehicle will be the base of an autonomous weeding robot					\$85,000
		Approximately 15 kWh of lithium iron phosphate battery storage	This will be used to increase the electrical storage capacity of a hybrid portable power station to charge weeding robots in the field.					\$11,000
							Sub Total	\$96,000
Acquisitions and Stewardship								
							Sub Total	-
Travel In Minnesota								
	Miles/ Meals/ Lodging	6 trips of 340 miles for 3 people staying for 3 nights, \$2325 per trip	Computer science personnel traveling from Mpls to Morris for field testing					\$13,950
	Conference Registration Miles/ Meals/ Lodging	2 trips of 210 miles for 3 people for 3 nights at \$2175. \$4800 for Farmfest registration and tent rental	Demonstrate weed control robot(s) at Farmfest ag show. Annual attendance is about 28,000 folks.	X				\$9,150
							Sub Total	\$23,100
Travel Outside Minnesota								
							Sub Total	-
Printing and Publication								
							Sub Total	-
Other Expenses								

		Expenses to host the Midwest Farm Energy Conference at the WCROC	Expenses include reservation fee for dinner/keynote venue, printing and mailing save the date cards and conference brochures. Conference presentations will prominently feature weed control robot(s) and robots will be demonstrated during a farm tour					\$858
							Sub Total	\$858
							Grand Total	\$978,000

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Travel In Minnesota	Conference Registration Miles/Meals/Lodging	2 trips of 210 miles for 3 people for 3 nights at \$2175. \$4800 for Farmfest registration and tent rental	\$4800 for Farmfest registration is for rental of a seed plot, tent, and furniture to host a display and demonstration of the project. Successful integration of robotics into agriculture requires demonstrations to skeptical farmers. There is no better way to get the results of this project in front of farmers than actually demonstrating it in a corn field which is exactly what we do at Farmfest. We will operate at least 3 live demos everyday which puts our work, and ENTRF funding, in front of around 28,000 farmers over 3 days.

Non ENRTF Funds

Category	Specific Source	Use	Status	\$ Amount
State				
			State Sub Total	-
Non-State				
In-Kind	The TORO Company	TORO donated 2 hydrogen fuel cell vehicles to the WCROC which will provide the fuel cell and hydrogen tank for planned charging trailer upgrades.	Secured	\$55,000
			Non State Sub Total	\$55,000
			Funds Total	\$55,000

Attachments

Required Attachments

Visual Component

File: [cb6171b3-246.docx](#)

Alternate Text for Visual Component

Photographs of weed pressure in an organic corn field, herbicide resistant weeds, herbicide drift during application, an example small robot in a corn field, and an electric tractor that will be used to pull a weed control implement for comparison....

Supplemental Attachments

Capital Project Questionnaire, Budget Supplements, Support Letter, Photos, Media, Other

Title	File
1101377 Buchanan LCCMR	6f63353f-865.pdf

Difference between Proposal and Work Plan

Describe changes from Proposal to Work Plan Stage

Added the potential of providing demonstrations at Farmfest for 2 years. Added the investigation of using drones to enhance robot weeding performance. Moving labor from grad students to employees eliminates U of MN computer ISO charges.

Additional Acknowledgements and Conditions:

The following are acknowledgements and conditions beyond those already included in the above workplan:

Do you understand and acknowledge the ENRTF repayment requirements if the use of capital equipment changes?

Yes

Do you agree travel expenses must follow the "Commissioner's Plan" promulgated by the Commissioner of Management of Budget or, for University of Minnesota projects, the University of Minnesota plan?

Yes, I agree to the UMN Policy.

Does your project have potential for royalties, copyrights, patents, sale of products and assets, or revenue generation?

Yes

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

Yes

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

No

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

No

Does your project include the pre-design, design, construction, or renovation of a building, trail, campground, or other fixed capital asset costing \$10,000 or more or large-scale stream or wetland restoration?

No

Do you propose using an appropriation from the Environment and Natural Resources Trust Fund to conduct a project that provides children's services (as defined in Minnesota Statutes section 299C.61 Subd.7 as "the provision of care, treatment, education, training, instruction, or recreation to children")?

No