Environment and Natural Resources Trust Fund

2024 Request for Proposal

General Information

Proposal ID: 2024-116

Proposal Title: Soil Gas Measurements Protect/Enhance Minnesota Soil Health

Project Manager Information

Name: Jacob Swanson

Organization: Minnesota State Colleges and Universities - Minnesota State University Mankato

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Project Basic Information

Project Summary: We seek to build and deploy 25 soil gas instruments across the state that will measure soil health, to preserve and enhance farming and other land resources.

Funds Requested: $415,000

Proposed Project Completion: December 31, 2026

LCCMR Funding Category: Methods to Protect, Restore, and Enhance Land, Water, and Habitat (F)

Project Location

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

Statewide

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

Statewide

When will the work impact occur?

During the Project and In the Future

Narrative

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

Healthy soil is critical to farming, recreation and wildlife habitat in MN. Healthy farmland soil health plays an integral role in food production and security. One measure of soil quality can be determined by measuring gas concentrations distributed in the depth of the soil. Gases in soil can provide information on the nutrients in the soil and on the activity of beneficial microorganisms (e.g. the nitrogen cycle). Gases of interest include carbon dioxide (CO2), methane (CH4), oxygen (O2), an nitrous oxide (N2O). Typical soil measuring techniques including extracting a column of soil and transporting the column to laboratories for a measurement or measuring gas permeating from the soil surface. Laboratory measurements are tedious and do not provide temporally resolved information. Surface gas flux measurements are less accurate because they disturb the surface and are extremely expensive - a commercially available system costs ~$250,000. The standard commercial approach measures surface gas flux, which does not provide information about concentration gradients in the soil. To determine spatially and temporally resolved concentrations across all major land resource areas and representative farmlands in MN, one would need many commercial devices, putting the cost of these soil health measurements at millions of dollars.

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.

The objective of this research is to create an open-source soil sensing instrument that consists of 3 gas sensors (carbon dioxide (CO2), methane (CH4), oxygen (O2)) and probes that allows soil gas to be extracted from the soil at various depths and measured continuously. The instrument will be solar powered and will operate autonomously. It will be deployable in the field at a substantially lower cost (~$2,500/each vs ~$250,000/each) than current soil sensing devices on the market, and it is capable of measuring gas at various depths in the soil compared to just measuring surface gas fluxes. We will deploy 25 devices in major land resource areas and representative farmlands in MN and monitor soil health for one growing season. This will enable the unprecedented collection of information that is required to enhance and preserve soil health. Soil gas data will be collected at many diverse and important locations, over an entire season as opposed to one measurement in time, and at various soil depths. The soil gas data will be analyzed and shared with participating farmers, land owners and the public. Evidence-based actions to enhance and preserve soil health will be communicated with stakeholders.

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?

Soil gas measurement data will inform stakeholders what land use practices positively impact soil health. Enhanced farmland soils will allow our food supply to be better managed and more secure. Soil gas measurements will help identify land use practices that negatively impact soil health. This may lead to a voluntary reduction practices that are found to cause harm. These reductions will help preserve and protect farmland and other lands subject to active management. Knowing more about their impacts will lead to agriculturalists to be more intentional about the way they interact with the soil, which will enhance MN land resources.

Activities and Milestones

Activity 1: Design, build, evaluate 25 soil gas sensor instruements that are field deployable and operate automonously.

Activity Budget: $265,000

Activity Description:
We will design, build, evaluate a prototype soil gas sensing instrument that consists of 3 gas sensors (carbon dioxide (CO2), methane (CH4), oxygen (O2)) and two or more probes that allow soil gas to be extracted from the soil at various depths and measured continuously. The instrument will have a gas sampling pump and solenoid-controlled valves that sample from different depths in the soil. We will design a method for reducing the humidity of the gas stream to <95% so that humidity does not adversely interfere with sensor response. A solar system will be integrated into the design to allow the instrument to operate autonomously. Open-source software for operating the device and storing and collecting data will be written and tested. We will build one prototype device and evaluate it under field conditions and iterate this design until performance metrics are achieved. We will then build 25 identical instruments using design for manufacturability techniques. All instruments will be evaluated for operability and calibrated in house before being deployed to the field.

Activity Milestones:

Description	Approximate Completion Date
Build a working prototype consisting of gas sensors, humidity control, software	May 31, 2024
Evaluate the prototype in the field, add solar power and automony features	March 31, 2025
Iterate the design and then finalize the design of the prototype soil gas instrument	August 31, 2025
Build all 25 sensors based on the final design of the working prototype	May 31, 2026

Activity 2: Deploy 25 soil gas instruments to farmland and other land areas throughout Minnesota, initiate monitoring

Activity Budget: $110,000

Activity Description:
We will deploy 25 soil health measurement instruments across major land resource areas (MLRA) and representative farmlands subject to different agricultural practices in MN and monitor soil health for one growing season. MLRAs are used by farmers, foresters, and land managers to understand and manage land resources, but very little is known about how soil gas in MN varies by land use, soil depth, and with time. Land use in MLRAs includes grasslands, farming, forests, wetlands, feed grass agriculture, and others. We will work within our networks to identify measurement locations across the state. We will identify locations across different MLRAs to gather baseline soil health information for various land uses for comparative purposes. A fraction of our sites will be farms and we will focus on those engaged in practices that are expected to improve soil health. In summary, soil health data will be collected at many diverse and important locations, over an entire season as opposed to one measurement in time, and at various soil depths. Data collected will be important information aid in the preservation and enhancement of land resources; at the same time we are collecting important foundational natural resource data.

Activity Milestones:

Description	Approximate Completion Date
Work with farmers, landowners, public officials, etc to indentify 25 high impact measurement locations	January 31, 2026
Deploy a soil gas sensor to each location, initiate measurements, ensure data acquistion	May 31, 2026

Monitor collection of soil gas data for one growing season. Replace/fix instruments as required.	September 30, 2026
Collect all soil gas instruments, collect data if required.	September 30, 2026

Activity 3: Analyze soil health data and diseminate project information with participating farmers, land owners and the public.

Activity Budget: $40,000

Activity Description:

The soil gas data from all sensors will be collected and organized. The data will be analyzed by comparing trends in soil depth, location, and land use. These measurements will be compared against the limited existing data that is available. Results of gas measurements will be translated into information about soil health and shared with participating farmers, land owners and the public. Evidence-based actions to enhance and preserve soil health will be determined and communicated with stakeholders. The Southern MN Agriculture Center of Excellence will assist with identification of candidate farmlands and "student" farmer participants as described in Activity 2 and also with publicly disseminating results as through multiple channels, including through their impact reports and through activities associated with the Farm Business Management program (which reaches 7 community colleges across MN). One or more journal articles describing the project and results will be published. We intend to make all of the information required to reproduce the hardware and software elements on the soil gas instrument public so this information will be organized, licenses developed if required, and published online in an accessible format.

Activity Milestones:

Description	Approximate Completion Date
Analyze soil gas measurement data, translate findings into information consumable by stakeholders.	December 31, 2026
Disseminate soil gas information to the public, in journal articles and other meetings as appropriate.	December 31, 2026
Organize all instrument infromation and create open source licenses for the hardware and software.	December 31, 2026

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?

The timeline and amount of our request allows for the completion of the project and complete dissemination of results. The 25 sensors can continue to autonomously collect data for little expense. We will apply for addition funding from the Agriculture and Food Research Initiative Competitive Grants Program Foundational and Applied Science Program to expand the instrument network to strategically chosen locations and to fund maintenance of the existing network. All hardware and software will be published in open source arenas. The open source nature of our products will allow community scientists to build and deploy comparable instruments.

Project Manager and Organization Qualifications

Project Manager Name: Jacob Swanson

Job Title: Professor

Provide description of the project manager's qualifications to manage the proposed project.

Dr. Jacob Swanson is a Full Professor of Engineering in the Twin Cities Engineering Program in the Department of Integrated Engineering at Minnesota State University Mankato. He is also an Adjunct Associate Professor in the Department of Mechanical Engineering (ME) at the University of Minnesota. He was previously a Research Associate in the Department of Engineering at the University of Cambridge, UK and before that, a graduate of UMN's ME Department. Prof. Swanson is internationally recognized for his work on air quality, gas and particle measurement, and emissions from engine combustion engines. He has published 44 papers and given about 100 conference presentations on these topics. He is currently advising about 30 students as part of his ENGR Design course. He has 3-4 other external projects supporting about eight undergraduate students. He is currently leading projects 1) from the EPA on air quality monitoring, 2) from the National Academy of Sciences on improving ventilation in buses to reduce airborne virus transmission, and 3) from private donated funds on COVID mitigation. For three years prior, he worked on a project titled "Microwave plasma gasification" that seeks to generate electricity from waste wood by creating and combusting syngas in an internal combustion engine. All of these efforts involve consideration expertise is gas measurements, including instrumentation development. For the past three academic semesters Prof. Swanson has been working with his colleagues Prof. Robert Sleezer and Prof. Beth Fisher on concepts for the soil gas sensing suite proposed in this project. The concept is technically viable and can be engineered for mass production. The technical achievements in this project will be leveraged to aid in the success of the proposed work.

Organization: Minnesota State Colleges and Universities - Minnesota State University Mankato

Organization Description:

Minnesota State Mankato is a 14,600 student campus in the upper Midwest. Minnesota State Mankato offers more than 50 courses related to food and agriculture. More than 160 Agriculture, Food and Natural Resources (AFNR)-related companies recruit our students on campus. Twin Cities Engineering (TCE) is a program of the Department of Integrated Engineering of Minnesota State University, Mankato. TCE has the purpose of expanding the pool of qualified engineers in the Twin Cities Metro area by establishing an affordable, accessible, and unique option for the region's engineering students. TCE offers an inclusive and innovative learning experience that has attracted non-traditional students and veterans at a higher rate than traditional students. The BSE degree program includes several features that differentiates it from traditional engineering degree programs. TCE addresses the entire learning experience and not simply one component of the curriculum. Five features, designed to produce desired attributes in BSE graduates, are as follows: 1) trans-disciplinary thinking, 2) Industry-sponsored, project-based-learning, 3) experiential learning in context, 4)

competency-based assessments, 5). significant exposure to professionalism, design, creativity, and innovation. TCE students are thus very well suited to provide the engineering expertise needed for this effort.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Project manager / lead scientist		Manage project, supervise undergraduate students for 3 summers of work, and over the course of 3 acedemic years. Be responsible for submission of documents and reports due to LCCMR. Be responsible for all technical aspects of sensor design, deployment and data anaylsis.			38%	1.05		$140,000
Lead data analyst		Analyze soil data, interperate results, disseminate information			38%	0.3		$52,500
Undergraduate research assistant		Design and build prototypes. Test prototypes, deploy prototypes. Assist in gathering of data			8%	0.99		$72,000
Lead electronics technician		Oversee the process of converting the electronics in the prototype to electronics suitable for mass production			33%	0.15		$15,000
Undergraduate student research assistant - Farm Business Management students		We will seek to deploy some of the sensors (between 10 and 20) at farms in which a farm stakeholder (manager, farmer) is enrolled in the Ag COE's Farm Business Management (FBM) program. The student participate primarily as a learning opportunity but there will be a nominal amount of work associated with deploying or maintaining the sensor. For this effort, we would like to award a student stipend of $500/student. 20 students x 500 = $10,000			0%	0.15		$10,000
							Sub Total	**$289,500**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Equipment	CO2 gas sensors 30 @ 100/each	Core CO2 sensing technology to integrate into soil gas sensing unit					$3,000

	Equipment	O2 gas sensors 30 @ 150/each	Core O2 sensing technology to integrate into soil gas sensing unit					$4,500
	Equipment	Microprocessors 25 @ 250/each	Microprocessors control the system, collect data, storage data, transmit data					$6,250
	Equipment	25 enclosures @ 500/each	All of the gas sensors, pumps, electronics, etc will go in a custom enclosure					$12,500
	Equipment	Prototyping expenses. No single items is >5,000. Costs will include, PCB mfg, 3D printing, machining,etc	To create the custom sensor enclosures, circuits, fixtures, etc, a large amout of custom manufacturing is required					$25,000
	Tools and Supplies	Supplies to create 25 soil gas sensors suites - includes consumable gases, 3D printing filiment, electronics consumables, wires, breadboards, etc	To create the custom sensor enclosures, circuits, fixtures, etc, a large amout of supplies will be required					$25,838
	Equipment	30 methane sensors @ $100/each	Core CO2 sensing technology to integrate into soil gas sensing unit					$3,000
	Equipment	25 of 17 Watt 12 Volt Solar Power Systems, $400/each	Each sensor needs a solar system to run independantly					$10,000
	Equipment	Calibration gas equipment, flowmeters, manifolds, tubing, etc. No single item is >$5k	Calibration equipment required to calibrate the soil gas sensors					$15,412
	Equipment	Internal sensor manifold = 25 @ $300/each	The gas senors must be enclosed in a heated chamber that must be made of metal or 3D printed plastic					$7,500
	Equipment	Temperature and humidity sensor = $25 @ 200/each	Measure the temperature and humidity of the incoming soil gas					$5,000
							Sub Total	**$118,000**
Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	Travel to soil gas sensor site. 25 sites, various distances from location. Assume 3 trips per site, 100	25 sensors will be deployed at up to 25 locations throughout MN, covering all					$7,500

		mile average travel distance = 7500 miles total x 0.655/mile = $4910. To account for contingencies (extra repairs needed, locations are further aways, etc), we multiplied the calculated total by 1.5.	different soil types and usages. At least 3 trips to each sensors will be required - to deploy it, to fix a problem - to retrieve it.					
							Sub Total	**$7,500**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$415,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**-**

Attachments

Required Attachments

Visual Component

File: 6c53d195-752.pdf

Alternate Text for Visual Component

A map of Minnesota showing 25 soil health measurement approximate locations that are spread across the state. A schematic of a measurement with probes inserted into different soil depths. The probes are connected to the instrument that will be built for this project. The measurements provide soil health information....

Optional Attachments

Support Letter, Photos, Media, Other

Title	File
Letter of support from Minnesota State Southern Agricultural Center of Excellence (SACE)	5b23207f-833.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

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

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 design, construction, or renovation of a building, trail, campground, or other capital asset costing $10,000 or more?

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?

No