Environment and Natural Resources Trust Fund

2024 Request for Proposal

General Information

Proposal ID: 2024-258

Proposal Title: Developing a Subfield Scale Soil Nitrate Virtual Estimator

Project Manager Information

Name: Yuxin Miao

Organization: U of MN - College of Food, Agricultural and Natural Resource Sciences

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Project Basic Information

Project Summary: This project will develop a virtual tool that can accurately estimate soil nitrate concentrations to help corn growers, researchers, crop consultants and state regulatory agencies to minimize nitrate contaminations.

Funds Requested: $199,000

Proposed Project Completion: June 30, 2027

LCCMR Funding Category: Small Projects (H)

Secondary Category: Water Resources (B)

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.

Minnesota has more corn acres than any other crop, ranking among the top five corn producing states in the nation. Nitrogen (N) is the most yield-limiting nutrient for corn. Management of applied N fertilizers is the key to secure environmentally sustainable and economically profitable corn production. Unfortunately, 27 percent of surface water samples and 10 percent of private well samples of the state had nitrate levels above the health risk limits of 10 mg/L. According to the University of Minnesota, analysis of preplant or pre-side dress soil nitrate-N from a depth of 0-6 inches and 6 to 24 inches is an important parameter to make N-recommendation to corn fields. It is necessary to take enough samples to capture the spatial and temporal variability of soil nitrate, although high-quality intensive soil nitrate sampling and analysis is very difficult. Studies have shown that soil nitrate samples may become unrepresentative when it gets beyond 10 square meters to up to 0.25 acres. Thus, corn production in Minnesota is constrained by a lack of high-resolution soil nitrate data. It is imperative to have a virtual tool that can be used to estimate the spatiotemporal variability of soil nitrate levels.

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.

A virtual tool to estimate soil nitrate would be the solution to detect subfield scale and continuous time soil nitrate levels. This can be done by coupling deterministic crop and hydrologic models with a machine learning (ML) technique. Several years of data from previous field research studies and lab analysis of soil nitrate concentrations will be used. Such data will be available for this project through our collaborators. Thus, the work procedures of this project will be to: 1) Collect, clean and organize available data from previous research and monitoring projects on the distribution of soil characteristics, corn varieties planted, agronomic management practices, weather conditions, data on hydrology, crop growth, and nitrogen balance components; 2) Build three field scale hydrologic and cropping system models in southeast Minnesota, and another three in southwest MN, five in Central Sands region of MN and seven in South Central MN; 3) Couple the selected hydrologic model with the crop model; 4) Calibrate, and validate the new hydrology-crop growth (HCG) model; 5) Couple the new HCG model with a ML model; and 6) Train the new ML model to predict soil nitrate concentrations.

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?

The virtual tool can be used to estimate spatiotemporal soil nitrate concentrations, and as a decision support tool by regulatory agencies, researchers, crop consultants, and corn producers. The new virtual tool would help to make appropriate decisions on N fertilizer applications and thereby minimize nitrate leaching losses and contamination of groundwater and surface water resources. The user only needs to provide a few details, such as their location, previous year crop, and this season's crop, N application rate and timing, and the virtual tool will provide daily, monthly, and end of season soil nitrate concentrations.

Activities and Milestones

Activity 1: Gathering, organizing, and soliciting primary and secondary data

Activity Budget: $96,000

Activity Description:
We will collaborate with Dr. Fabian Fernandez on N experiments conducted at University of Minnesota research and outreach centers at Waseca, Becker, Lamberton, Morris and Crookston. Data collected from these field experiments will be used for this study, including soil properties and sampling analysis, monitored hydrologic parameters, crop yield, crop biomass, crop LAI, nitrate leaching losses. The project will conduct on-farm testing and data collection for soil electrical conductivity (EC), soil pH, CEC and soil moisture data using Spectrum Field Scout TDR 300 field equipment for three years, 2024-2026. Arable Mark 2 sensors will be used to collect experimental site weather (temperature, relative humidity, precipitation, and solar radiation), growth growth, and evapotranspiration data.

Secondary data sources from state agencies and University of Minnesota, including GIS layers of soils data, weather data, field monitored soil moisture and nitrate concentrations, cropping systems and agronomic management practices, etc. will be reviewed and used as model inputs. Calibrated and validated models provided by our collaborators will be reviewed, tested, and their simulation results will be used for the model development and application in this project.

Activity Milestones:

Description	Approximate Completion Date
Compile previously collected soil nitrate data and related data by project members and collabrators.	December 31, 2024
Identify, collect, and organize various independent and dependent model input parameters.	December 31, 2024
Constrain some of the database through inverse modeling	June 30, 2025
Collect additional needed data from N experiments conducted at Waseca, Becker, Lamberton, Morris and Crookston	November 30, 2025

Activity 2: Develop & Couple Field Scale Crop Growth and Hydrology Models (HCG).

Activity Budget: $45,000

Activity Description:
Tested and proven process-based field scale crop growth models like Decision Support System for Agrotechnology Transfer (DSSAT) or Environmental Policy Integrated Climate (EPIC) model will be built at the initial step. These models have very simplified algorithms to simulate hydrologic processes such as tile drainage, leaching, and irrigation. To obtain a higher accuracy on both simulated hydrology and crop growth, it is very important to couple the selected crop model with another hydrology model with better subroutines. The coupling procedures involve simulation of key water balance components including potential evapotranspiration, crop water uptake, percolation, tile drainage in the hydrological model, then pass it on to the crop model for the simulation of the crop growth process in the crop model. The coupled model (HCG) efficiency will be tested using multiple statistical evaluations, including Nash Sutcliffe efficiency (NSE), percent bias (PBIAS), and root mean square error – observation standard deviation ratio (RSR).

Activity Milestones:

Description	Approximate Completion Date
Data assimilation and model parameterization	March 31, 2025
Constrain and optimize model results by inverse modeling	June 30, 2025
Couple the hydrology model with crop growth model to create HCG	September 30, 2025
Validation of the simulation results from the coupled model, HCG	December 31, 2025

Run HCG model for 32 years and analyze the simulation results.	March 31, 2026

Activity 3: Couple HCG Model with machine learning (ML) model to create Virtual Soil Nitrate Estimator engine, the HCG-ML model

Activity Budget: $58,000

Activity Description:

Once the coupled hydrology and crop growth model (HCG) is built and proven to provide consistent water balance and N balance under diverse locations, it will be coupled with the machine learning model to create a new virtual tool called HCG-ML. The HCG-ML model algorithms will be trained, and the preliminary simulation outputs of water balance and N balance will be evaluated. A more detailed evaluation will be made for soil nitrate concentrations. The evaluation process will involve multiple statistical measures of NSE, PBIAS and RSR.

Activity Milestones:

Description	Approximate Completion Date
Couple the HCG model with the ML model to create the HCG-ML model	June 30, 2026
HCG-ML algorithm training and validation for soil nitrate simulation: k-Nearest Neighbors (KNN), Artificial Neural Networks	September 30, 2026
Preliminary evaluation of HCG-ML on selected fields under dry, normal, and wet conditions	December 31, 2026
Evaluation of HCG-ML virtual soil nitrate estimator in all corn producing regions of Minnesota	May 31, 2027
Release the beta version of the model	June 30, 2027

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
David J. Mulla	University of Minnesota	Professor, W. E. Larson Endowed Chair of Soil and Water Resources, and Director of the Precision Agriculture Center, UMN, will guide hydrologic model calibration and simulation and machine learning modeling for soil nitrate prediction.	No
Solomon M. Folle	University of Minnesota	Researcher and modeler; will be responsible for crop growth model and hydrologic model modification, calibration and coupling, and the final model developing combining crop growth model, hydrologic model and machine learning model. He will compile the database using multi-source data, and model validation.	Yes
Fabian Fernandez	University of Minnesota	Professor, nutrient management and water quality research and extension, will provide previously compiled databases related to soil nitrate data based on past experiments conducted by multiple researchers in Minnesota. He will validate the tool developed in this study using N experiments conducted in different parts of Minnesota.	No
Vasudha Sharma	University of Minnesota	Assistant Extension Professor irrigation specialist: will provide support related to soil nitrate prediction in irrigated corn yields and share data collected previously in her N x irrigation experiments.	No

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 beta version of the tool will be available to government agencies, academic institutions, and research organizations after the project is finished. This will be for testing and validation only. The tool will be available for use by the general public once the testing and validation procedure is finished and it is ready for use. The next iteration of the tool will be developed to improve and expand to other crops like potato. We will apply for support from commodity groups and collaborate with the industry.

Project Manager and Organization Qualifications

Project Manager Name: Yuxin Miao

Job Title: Associate Professor, Associate Director

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

Dr. Yuxin Miao is an Associate Professor of Precision Agriculture and Nutrient Management, and Associate Director of the Precision Agriculture Center (PAC) at University of Minnesota. He is an internationally recognized expert on precision agriculture and nutrient management. He has been engaged in numerous N management research projects using a variety of techniques, including small plot and on-farm experimentation and measurements, active canopy sensors, UAV and aerial imagery, satellite remote sensing, crop growth modeling, geospatial analysis and machine learning. His study is focused on creating new approaches to nutrient management that will increase crop quality, yield, and nutrient use efficiency while minimizing environmental contamination. He received the Pierre C. Robert Precision Agriculture Young Scientist Award from International Society of Precision Agriculture (ISPA) in 2012, the Outstanding Chinese Alumni Award of UMN in 2014, and the ASA Kingenta Agricultural Science Award in 2022. He has been serving as Country Representative at ISPA. He is the founding leader of the ISPA Precision Nitrogen Management Community. He has published over 130 journal articles, conference papers and book chapters. He is serving as Associate Editor for several international journals, including Precision Agriculture, Remote Sensing, and Agronomy Journal. Dr. Miao has extensive experience in precision nitrogen management and on-farm collaboration with corn growers on precision agriculture technology applications. He is leading a NRCS project to demonstrate and evaluate an innovative and

practical satellite remote sensing-based precision nitrogen management sysyem across Minnesota and Indiana to improve nitrogen use efficiency and reduce nitrate leaching. Dr. Miao has extensive experience managing budgets and personnel in academic settings.

Organization: U of MN - College of Food, Agricultural and Natural Resource Sciences

Organization Description:
The College of Food, Agricultural and Natural Resource Sciences (CFANS) of UMN is the leading college in the state for agricultural research, education, extension and outreach, with deep expertise in disseminating research to the agricultural community.

The Precision Agriculture Center (PAC) was established in 1995 as the world's first center for precision agricultural research, education and extension, housed in CFANS of UMN. Precision agriculture was developed at UMN in the early 1980s. The center was the organizer of the International Conference on Precision Agriculture for many years, and founded the Precision Agriculture journal. The Center provides a platform for exploring new digital agriculture frontiers on production, environment, and sustainability of various cropping systems. It is forging interdisciplinary research collaborations across disciplines and growers, both within and beyond UMN. The PAC has been focusing on precision N management strategies and technologies, involving proximal, UAV, aerial and satellite remote sensing technologies, crop growth modeling, slow release fertilizers, machine learning and artificial intelligence, soil-landscape analysis, management zone delineation strategies, and soil sensing.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Yuxin Miao		Lead PI and Project manager			36.8%	0.1		$16,400
Solomon Folle		Co-PI, modeler			36.8%	0.3		$24,200
Postdoc		Postdoc associate, Database building, analysis, coordination of field activities, machine learning model development, field validation and evaluation of the developed tool.			25.7%	1.05		$73,000
Undergraduate Student Worker		Field data collection and sampling			8%	1.2		$14,000
							Sub Total	**$127,600**
Contracts and Services								
Soil lab analysis	Professional or Technical Service Contract	To analyze collected samples for soil nitrate, soil electrical conductivity (EC), soil pH, CEC and soil moisture				-		$16,000
							Sub Total	**$16,000**
Equipment, Tools, and Supplies								
	Tools and Supplies	Sampling bags, 500	for collecting ground truth samples					$1,000
	Tools and Supplies	Batteries for GPS, UAV, and Sensors, 10	For field data collection					$600
	Equipment	Arable Mark 2 sensor	To monitor on-farm local weather					$8,800
	Equipment	50 Ceramic suction lysimeters	To extract soil water samples from various depths for measurement of nitrate levels, salinity, EC, and other chemical elements.					$17,500
	Equipment	Soil Auger	To drill soil samples for analysis					$2,000
							Sub Total	**$29,900**

Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	The postdoc and undergraduate workers will need to travel to different corn production regions, plot and on-farm trial sites to collect needed soil nitrate and other related data using university fleet services vehicle, covering mileage, lodging and meals, about 20 trips each year, each trip costs an average of $160.	to collect soil nitrate data and other related data					$9,600
	Miles/ Meals/ Lodging	10 in-state water quality, soil health ad nitrogen management related meetings at locations not determined yet, covering mileage, and each trip costs about $90.	to present project progress and promote the adoption of the nitrate prediction tool.					$900
							Sub Total	**$10,500**
Travel Outside Minnesota								
	Conference Registration Miles/ Meals/ Lodging	2 annual nitrogen use efficiency network meetings organized in different states not determined yet, covering mileage, lodging, meals and incidentals, 2 people for each conference	to present project progress and receive feedback and advice	X				$1,000
	Conference Registration Miles/ Meals/ Lodging	2 annual American Society of Agronomy conferences at cities not determined yet, covering registration, abstract fee, air ticket, lodging, meals and incidentals,1 person for each conference in each year, each conference costs about $2,000	to present project progress, share the results with wider audiences, and receive feedback and advice for improvement	X				$4,000
							Sub Total	**$5,000**
Printing and Publication								
	Printing	Training Materials and Handouts, 100 copies	for organizing training workshops and providing training materials to grower and crop consultant participants					$1,000

	Publication	Publication fees for research and extension papers, 3 papers in total	for wider dissemination of project results					$3,000
							Sub Total	**$4,000**
Other Expenses								
		Arable Mark 2 Sensor annual subscription fee	To allow daily monitoring of field weather, soil moisture, and crop growth conditions and wireless access to the data.					$2,000
		On-farm trial and testing	We will work with 4 farmers in the third year to conduct on-farm trials with different N rates and use the model to estimate soil nitrate levels at different times of the year to evaluate the performance of the model under on-farm conditions. We will need to provide $1000 to each farmer for compensation.					$4,000
							Sub Total	**$6,000**
							Grand Total	**$199,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Travel Outside Minnesota	Conference Registration Miles/Meals/Lodging	2 annual nitrogen use efficiency network meetings organized in different states not determined yet, covering mileage, lodging, meals and incidentals, 2 people for each conference	Nitrogen use efficiency network meeting is organized each summer by different universities in the mid-west to share latest research progress on N management research and development, and it is important for us to share the project progress with peers in other states for better outreach and also for their suggestions to improve the App development for Minnesota.
Travel Outside Minnesota	Conference Registration Miles/Meals/Lodging	2 annual American Society of Agronomy conferences at cities not determined yet, covering registration, abstract fee, air ticket, lodging, meals and incidentals,1 person for each conference in each year, each conference costs about $2,000	The American Society of Agronomy Annul Meeting is organized together with Crop Science Society of America (CSSA) and Soil Science Society of America (SSSA) each year in different cities of US. It is attended by several thousands of people each year. It is a great opportunity not only to share our research progress, but also a great opportunity to learn the latest advances and technologies by researchers from around the world to improve our research in Minnesota.

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: fa107354-510.docx

Alternate Text for Visual Component

A Subfield Scale Soil Nitrate Virtual Estimator for Efficient Monitoring of Soil Nitrate Levels...

Optional Attachments

Support Letter, Photos, Media, Other

Title	File
Support Letter from Minnesota Department of Agriculture	e975e0a2-bc4.pdf
Sponsored Projects Administration Letter	824f0e84-1d4.pdf
Support Letter from Agricultural Fertilizer Research and Education Council	d979c2c4-028.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?

No

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

N/A

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

N/A

Does your project include original, hypothesis-driven research?

No

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

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