Environment and Natural Resources Trust Fund

2027 Request for Proposal

General Information

Proposal ID: 2027-322

Proposal Title: Precision Water and Nitrogen Management for Sustainable Agriculture

Project Manager Information

Name: Prodromos Daoutidis

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: We will develop an optimization-based decision-support tool for the precise management of irrigation and nitrogen fertigation on Minnesota farms to protect the freshwater quantity and quality while sustaining crop productivity.

ENRTF Funds Requested: $664,000

Proposed Project Completion: June 30, 2030

LCCMR Funding Category: Water (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.

Irrigation and fertilizer application are essential to agricultural productivity in Minnesota, but excessive utilization and/or imprecise management of both also threaten the quantity and quality of the state's freshwater. Minnesota farmers annually irrigate over 600,000 acres using 81.5 billion gallons of water. Groundwater withdrawals can exceed natural recharge in certain regions or during drought conditions. Water quality also faces concerns: agricultural activities are responsible for more than 70% of nitrates in Minnesota water. Precision variable rate irrigation can reduce water use and nutrient leaching driven by excessive soil moisture. Including nitrogen fertilizer directly in irrigation water ("fertigation") can further reduce water use and nitrogen leaching without sacrificing crop productivity by more efficiently delivering nitrogen to crop root zones. Precision management of irrigation and fertigation scheduling is complex due to differing nitrogen and water requirements for various crop types, seasonal variability in weather (e.g., precipitation) that affect soil and groundwater conditions, and seasonal use limits for water and fertilizer which vary regionally throughout Minnesota. A comprehensive decision-support tool for integrated precision irrigation and fertigation does not exist, yet such a framework can play an essential role in maximizing the potential of precision agriculture to protect Minnesota's water.

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 an optimization-based decision-support framework that jointly manages irrigation and fertigation decisions toward sustainable water and nitrogen management. This framework comprises complementary seasonal planning and daily scheduling layers. The planning layer will use uncertain, long-term weather forecasts to identify season-long irrigation and fertigation strategies to meet crop productivity targets while minimizing water use and nitrate leaching and adhering to seasonal water allocation and fertilizer application limits. The daily scheduling layer will respond to updated weather forecasts and field condition measurements to refine optimal irrigation and fertigation decisions which minimize water use and nitrate leaching while meeting planning layer targets for water and nitrogen delivery to crop root zones. Integrated two-way communication between the planning and scheduling layers will form a decision-support tool that can advise farmers on when and how much to irrigate and fertigate for specific crop types and farm locations. We will demonstrate the use of this tool over a comprehensive range of crop and soil types, using field data from UMN's Research and Outreach Centers (ROCs) for model development and subsequent validation. These demonstration results will allow quantification of statewide reductions in water use and nitrogen externalities achievable by adopting precision irrigation and fertigation.

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 goal of this project is to support the adoption of precision irrigation and fertigation which can reduce water use by 27-43% (Sharma and Herbert, 2023) and nitrate leaching by up to 90% (Azad et al., 2020). Reductions in the use of water, irrigation pump power, and nitrogen fertilizer would also lead to lower farm input costs. To this end, the project will provide: (1) a decision-support tool which can recommend when and how much to irrigate and fertigate at specific Minnesota farms and (2) a Minnesota-wide assessment of the water-related benefits of adopting integrated precision irrigation and fertigation.

Activities and Milestones

Activity 1: Development and calibration of water and nutrient transport models

Activity Budget: $220,956

Activity Description:
We will develop two sets of models which will form the basis of the proposed planning and scheduling optimization layers. The planning layer involves decisions across a full growing season and many weather scenarios. We will therefore develop macroscopic water-balance and nutrient-balance models which balance accuracy with computational efficiency in describing season-long changes in soil moisture and nitrate levels as a function of weather along with water and nitrogen inputs from irrigation and fertigation. The scheduling layer makes daily decisions where accuracy in representing soil water and nutrient movement is critical to prevent excessive drainage and nutrient leaching. We will therefore develop detailed physics-based models to describe how water and nitrates move through soil. We will formulate both models for comprehensive sets of crop types and soil types representative of Minnesota agriculture. We will collect field data including soil moisture measurements, irrigation and fertilizer application records, and weather observations by working with UMN's ROCs. We will calibrate our models by adjusting soil water and nutrient transport properties until model predictions match the collected field measurements. We will then validate these models against independent field measurements before incorporating them into the planning and scheduling layers described in Activities 2 and 3.

Activity Milestones:

Description	Approximate Completion Date
Development and calibration of water-balance and nutrient-balance models	December 31, 2027
Establishment of UMN ROC working relationships and field data collection	June 30, 2028
Development and calibration of physics-based soil water and nutrient transport model	June 30, 2028
Validation of calibrated macroscopic and physics-based water and nutrient models	September 30, 2028

Activity 2: Development and validation of seasonal planning optimization layer

Activity Budget: $110,518

Activity Description:
The seasonal planning optimization layer will incorporate the macroscopic water-balance and nutrient-balance models from Activity 1 as well as a model which describes crop productivity as a time-dependent function of soil water and nitrogen fertilizer content. The planning layer will determine daily irrigation and fertigation strategies and recursively update these strategies as the growing season progresses. At each update, the planning layer will solve a mathematical optimization problem that considers multiple possible weather scenarios and identifies irrigation and fertigation strategies that minimize water use and nitrate leaching while meeting crop productivity targets as well as adhering to seasonal water allocation and fertilizer application limits. Weather scenarios will be generated using historical data from multiple Minnesota stations. The planning layer will incorporate a risk measure to ensure that optimal irrigation and fertigation strategies avoid adverse outcomes (e.g., water stress) which could result from extreme weather conditions. We will use state-of-the-art optimization decomposition techniques when solving the planning layer to enable this large-scale optimization problem to be efficiently solved using standard computing resources. Ultimately, the planning layer will provide robust season-long irrigation and fertigation strategies, which will then be communicated with and refined by the scheduling layer developed in Activity 3.

Activity Milestones:

Description	Approximate Completion Date
Generation of weather scenarios from Minnesota historical data	December 31, 2028
Formulation of scenario-based seasonal planning optimization layer	March 31, 2029
Integration of risk measure into planning layer to avoid adverse outcomes	March 31, 2029
Validation of planning layer using historical weather records	June 30, 2029

Activity 3: Development and validation of daily scheduling optimization layer

Activity Budget: $110,518

Activity Description:
The daily scheduling layer will incorporate the physics-based models from Activity 1 in an optimization model which finalizes daily irrigation and fertigation decisions using a two-week scheduling horizon. This layer will be re-solved each day of the growing season as new weather forecasts become available. At each daily update, the optimal irrigation and fertigation decisions will minimize water use and nitrate leaching while meeting daily crop water and nutrient requirements set by the planning layer developed in Activity 2. A key challenge is that soil moisture and nutrient conditions cannot be directly measured at every field location. We will thus develop a computational framework that infers unmeasured conditions from available sensor data to estimate these quantities from field sensors (e.g., soil moisture probes) and weather observations. Using the physics-based models to solve the scheduling layer at daily resolution would be computationally demanding so we will use machine learning to develop surrogate models which approximate how soil conditions change over time to enable computationally efficient daily optimization. The scheduling layer results will inform the next recursive update of the planning layer by communicating current soil conditions as well as new water allocation and fertilizer application limits considering amounts already used.

Activity Milestones:

Description	Approximate Completion Date
Formulation of daily scheduling optimization layer	December 31, 2028
Development and testing of field measurement and soil property inference framework	March 31, 2029
Training and validation of machine learning models to accelerate solution of daily scheduling optimization layer	March 31, 2029
Implementation and testing of scheduling layer using simulated field conditions	June 30, 2029

Activity 4: Integration of planning and scheduling layers into user interface for irrigation and fertigation decision-support tool

Activity Budget: $130,092

Activity Description:
We will integrate the seasonal planning and daily scheduling layers from Activities 2 and 3 into a computational decision-support tool. A key feature of the integrated framework is two-way communication between the layers. Initial guidance on when and how much to irrigate and fertigate as well as daily soil water and nutrient targets are sent from the planning layer to the scheduling layer. Simultaneously, the planning layer will be updated as the growing season progresses with the measured soil conditions and remaining water and fertilizer allocations which result from daily implementation of the optimal daily irrigation and fertigation decisions determined by the scheduling layer. We will develop a user interface for the decision support tool which allows for the input of soil characteristics, crop type, and seasonal water allocations and fertilizer application limits. This interface will then output daily irrigation and fertigation recommendations. We will test the tool through UMN ROCs to assess its practical value under real field conditions. We will specifically assess performance over a representative range of Minnesota cropping systems and using historical

weather records spanning wet, average, and dry growing seasons. The field evaluation will inform refinement of the decision support tool functionality and user interface.

Activity Milestones:

Description	Approximate Completion Date
Integration of planning and scheduling optimization layers for two-way communication	September 30, 2029
Development of prototype user interface for decision-support tool	December 31, 2029
Field evaluation and refinement of decision support tool functionality and user interface	June 30, 2030
DELIVERABLE: Irrigation and fertigation decision support tool with user interface	June 30, 2030

Activity 5: Quantitative assessment of Minnesota-wide benefits of precision irrigation and fertigation

Activity Budget: $91,916

Activity Description:
We will assess the potential of precision irrigation and fertigation to conserve and protect Minnesota's water relative to current agricultural practices. We will use data on current county-resolution acreage for five crop types (corn, soy wheat, alfalfa, and sugar beet crops), irrigation water use, nitrogen fertilizer use, and water nitrate levels from the Minnesota Department of Agriculture and Department of Natural Resources (DNR). We will then allocate each county with non-zero crop acreage into one of Minnesota's six groundwater provinces as defined by the DNR. We will use the decision support tool developed in Activity 4 to determine annual water use, nitrate leaching, and fertilizer use for each of the five considered crop types in each of the six groundwater provinces, excluding analysis for crop types not present in a given province. These results will be used to determine the optimal county-level and Minnesota-wide water use, nitrate leaching, and fertilizer use which would result from adopting the proposed integrated irrigation and fertigation decision-making approach. A comparison with Minnesota's current practices will determine the quantitative benefits of precision irrigation and fertigation in terms of reductions in water use, fertilizer use, and nitrate leaching along with the associated cost savings.

Activity Milestones:

Description	Approximate Completion Date
Collection of county-level crop acreage, water and nitrogen fertilizer input, and water nitrate level data	September 30, 2029
Allocation of all crop-growing counties into groundwater provinces based on soil characteristics	December 31, 2029
Irrigation and fertigation optimization for each crop type in each groundwater province	May 31, 2030
DELIVERABLE: Quantification of state-wide reductions in water use, nitrogen fertilizer use, and nitrate leaching	June 30, 2030

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Matthew J. Palys	University of Minnesota	Co-PI. Palys is a senior post-doc in the Daoutidis group. He has extensive expertise in techno-economics of green ammonia and urea fertilizers, and in sustainable farm systems. He is the CEO of Power-To-X Analytics. He will lead the activities on farm partnerships, data collection, and state-wide assessment of proposed technology.	Yes
Bernard Agyeman	University of Minnesota - CEMS	Co-PI. Agyeman is a post-doc in the Daoutidis group. In his Ph.D. thesis at the University of Alberta he worked extensively on irrigation scheduling. He will lead the proposed activities on model development, and irrigation and fertigation scheduling.	Yes

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.
The proposed research will be disseminated broadly via publications in journals and conference presentations. The developed models and software will be made publicly available. Once the decision support tool is developed we will work closely with farm partners to test and streamline its implementation. A broad dissemination effort within the Minnesota agricultural community and policy makers will also be undertaken. We will work closely with the UMN ROCs to reach out to agricultural communities and co-ops to educate them about the use and the potential benefits of the proposed framework. We will present the developed irrigation and fertigation decision-support tool in outlets such as the Minnesota Sustainable Farming Association Annual Conference, the Minnesota Farmfest, the MN Ag Expo, and the Nutrient Management Conference.

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?
Our proposed collaboration with UMN ROCs will enable community dissemination and could lead to partnerships with commercial farm for implementation of precision irrigation and fertigation using our decision support tool. These partnerships could also be established through the Minnesota Farmers Union and agricultural cooperatives, especially by highlighting the economic benefits of implementing precision irrigation and fertigation. On-farm implementations, including physical infrastructure, could be funded by numerous Minnesota Department of Agriculture grant and financial assistance programs focused on sustainable agriculture, water quality, and nitrogen management as well as U.S. Department of Agriculture programs for agricultural water conservation.

Project Manager and Organization Qualifications

Project Manager Name: Prodromos Daoutidis

Job Title: College of Science and Engineering Distinguished Professor

Provide description of the project manager's qualifications to manage the proposed project.
Prodromos Daoutidis is a College of Science and Engineering Distinguished Professor and Distinguished University Teaching Professor in the Department of Chemical Engineering and Materials Science at the University of Minnesota. Daoutidis has a long record of contributions in process systems engineering and sustainability research, having published over 360 refereed papers and 6 books. He has pioneered methods for designing and operating green ammonia

production systems, optimizing fertilizer supply chains that incorporate locally produced green fertilizers, and enabling the utilization of green ammonia as an energy storage medium, and as a fuel in the power and transportation sectors. He has collaborated closely with the West Central Research & Outreach Center (WCROC) researchers at Morris Minnesota and has co-founded a company, Power-To-X Analytics, specializing in designing green ammonia plants tailored to location-specific resources and demand. His group provides techno-economic support to the green ammonia demonstration project currently underway at WCROC. Daoutidis has received numerous honors and awards, including the IChemE Hutchison Medal, the AIChE Sustainable Engineering Forum Research Award, the AIChE Computing in Chemical Engineering Award, the C.A. Floudas Award in Mathematical Optimization, the PSE Model Based Innovation Prize, and Best Paper Awards from the Journal of Process Control and Computers and Chemical Engineering (the latter on a paper on the use of hydrogen and ammonia for renewable energy storage). He has given more than 100 invited lectures, including at the Fertilizers Europe Association Open Board Meeting and the Midwestern Legislative Conference. Daoutidis has supervised to completion 44 Ph.D. students and post-docs, 15 of whom currently hold academic positions. He currently supervises a group of 2 post-docs and 8 Ph.D students.

Organization: U of MN - College of Science and Engineering

Organization Description:
The College of Science and Engineering (CSE) is one of the colleges of the University of Minnesota. CSE contains 12 departments and 24 research centers that focus on engineering, the physical sciences, and mathematics. The mission of the college is to train the next generation of scientists and engineers and conduct high-quality research that advances science and addresses major societal challenges. The project will take place in the Department of Chemical Engineering and Materials Science (CEMS), which is part of CSE. CEMS is one of the top chemical engineering departments in the country (currently ranked #6 according to U.S. News). CEMS is widely known for our cutting-edge research programs, a highly collaborative atmosphere, and a dedication to world-class undergraduate and graduate education. Energy and sustainability are major research themes in the department. At CEMS, there is a strong emphasis on mathematics, modeling, and data science, which is reflected in our recently established first-of-its-kind M.S. program Data Science in Chemical Engineering and Materials Science as well as the $3M NSF-funded training program focused on training the next generation to use AI for improving energy security, sustainability, and human health (both directed by PI Daoutidis).

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Prodromos Daoutidis, Professor		PI, will manage and direct the overall project			36.6%	0.12		$56,733
Matthew Palys, Post-doctoral Associate		Co-PI: will direct and participate in farm partnerships and the state-wide assessment of the benefits of the proposed research			26.1%	1.8		$144,097
Bernard Agyeman, Post-doctoral Associate		Co-PI: Will direct and participate in the development of the models and the scheduling and planning tools			26.1%	3		$240,164
Graduate student		PhD student from CEMS to be assigned on the project and participate in the modeling and scheduling tasks, and the development of the integrated decision support tool.			24.2%	1.5		$200,645
							Sub Total	**$641,639**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Equipment	2 computers	Needed to carry out the modeling and simulation studies					$4,000
							Sub Total	**$4,000**
Capital Equipment								
							Sub Total	**-**
Acquisitions and Stewardship								

							Sub Total	**-**
Travel In Minnesota								
	Other	3 trips a year, ~300 miles per trip (at a rate $0.6/mile), 2 nights of lodging per trip, meals	meeting with farm partners and data collection and testing/evaluation					$9,160
	Conference Registration Miles/ Meals/ Lodging	participation in 2 agricultural conferences per year, registration, travel (~200 miles per trip, 0.61$/mile), lodging for 1 night and meals	participation in ag conferences and expo to meet with stakeholders and disseminate the results.					$9,201
							Sub Total	**$18,361**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$664,000**

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	**-**

Total Project Cost: $664,000

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: a5944cbd-723.pdf

Alternate Text for Visual Component

A graphical illustration of the different elements of the decision-support tool proposed and its proposed use for assessing state-wide benefits from precision irrigation and fertigation....

Supplemental Attachments

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

Title	File
Letter from SPA	d8b7f95b-5e2.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Do you understand that travel expenses are only approved if they 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 understand the UMN Policy on travel applies.

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

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?

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

Provide the name(s) and organization(s) of additional individuals assisting in the completion of this proposal:

none

Do you understand that a named service contract does not constitute a funder-designated subrecipient or approval of a sole-source contract? In other words, a service contract entity is only approved if it has been selected according to the contracting rules identified in state law and policy for organizations that receive ENRTF funds through direct appropriations, or in the DNR's reimbursement manual for non-state organizations. These rules may include competitive bidding and prevailing wage requirements

N/A