Environment and Natural Resources Trust Fund
2020 Request for Proposals (RFP)

Project Title: **ENRTF ID: 243-F**

Predicting Agriculture's Outcomes with Sensors and Machine Learning

Category: F. Methods to Protect, Restore, and Enhance Land, Water, and Habitat

Sub-Category:

Total Project Budget: $ 887,005

Proposed Project Time Period for the Funding Requested: June 30, 2024 (4 yrs)

Summary:

We will use low-cost sensors on long-term cropping system experiments to develop advanced machine learning algorithms that will predict yield and water quality outcomes across the southern half of Minnesota

Name: Philip Pardey

Sponsoring Organization: U of MN

Job Title: Professor

Department: GEMS Agroinformatics Initiative

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Location:

Region: Central, Metro, Southwest, Southeast

County Name: Blue Earth, Brown, Carver, Chippewa, Cottonwood, Dakota, Dodge, Faribault, Fillmore, Freeborn, Goodhue, Houston, Jackson, Kandiyohi, Lac qui Parle, Le Sueur, Lincoln, Lyon, Martin, McLeod, Meeker, Mower, Murray, Nicollet, Nobles, Olmsted, Pipestone, Redwo

City / Township:

Alternate Text for Visual:

Visual illustrates field sites at Waseca and Lamberton. Shows how small each sensor node is and how the nodes will be deployed across each field site. Illustrates how we combine sensor data with machine learning to map water quality and yields.

_____ Funding Priorities	_____ Multiple Benefits	_____ Outcomes	_____ Knowledge Base
_____ Extent of Impact	_____ Innovation	_____ Scientific/Tech Basis	_____ Urgency
_____ Capacity Readiness	_____ Leverage	_____ TOTAL	_____%

PROJECT TITLE: Predicting agriculture's outcomes with sensors and machine learning

I. PROJECT STATEMENT

This proposal seeks $887,005 over four years to 1) build, test, and deploy low cost, high resolution sensor systems at the Waseca and Lamberton Research and Outreach Centers, 2) validate the low cost system against high cost, low resolution sensors, and 3) build a machine learning model to map water quality and crop productivity using data from sensor systems to "train" the model. The specific field plots are the Long-Term Agricultural Research Network sites. Subplots within rotation treatments test minor variants, such as different cover crops or fertilizer treatments. A few nodes will be allocated to subplots that show the greatest potential to improve water quality while increasing yields. The resulting maps of Mn will be relevant to farmers and crop consultants who need to select practices that enhance water quality and profitability, as well as state agencies responsible for evaluating and managing the impacts of agriculture on water quality.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1 Title: Build, test, and install 875 sensor nodes across three LTARN sites that stream data to databases hosted by the GEMS agroinformatics initiative.

Description: *Our hardware and software will be installed as follows:*

1. ***Two Long Range (LoRa; 915MHz) gateways****. Similar to a home Wifi router; 10 mile range.*
2. ***675 in-field sensor nodes.*** *Size of coffee mug; collects soil temperature, soil moisture, air temperature, humidity, barometric pressure, and photosynthetically active radiation. Deployment: 3 per plot within the 3 LTARN trials; data used to understand the relationship between crop productivity and location.*
3. ***200 water quality sensing nodes.*** *Size of a hockey puck; measures water conductivity to estimate nitrate and phosphorus pollution, water temperature, and turbidity. Installed in tile drains and open water areas near LTARN sites.*
4. **Build the software to stitch the data together and make it available to researchers.** Sensors nodes stream data to the gateway, then to Particle Internet of Things (IoT) platform. Using webhooks, the Particle IoT Platform pushes data into a PostgreSQL database stored on GEMS's agroinformatics platform. Researchers access data two ways: 1) a custom built web portal, or 2) SQLAlchemy, a Python library for accessing databases.

ENRTF BUDGET: $ 575,552

Outcome	Completion Date
1. Two Long Range gateways built and tested in the lab	*October 2020*
2. 675 in-field sensor nodes built and tested in the lab	*February 2021*
3. 200 water quality sensing nodes built and tested in the lab	*April 2021*
4. In-field and water quality sensor nodes and gateways deployed	*May 2021*
5. Built the software to stitch the data together and make it available to researchers	*February 2021*
6. Maintain technical system – repair and replace sensor nodes that fail	*October 2022*

Activity 2 Title: Validate low cost sensors' ability to capture crop water use, photosynthesis, and stress levels

Description: *To be highly effective, the deployed sensors need to reflect the physiological status of the crop, an ability that will be crucial for Activity 3 (details below). To this end, we will seek to establish robust quantitative relationships between sensor data and key physiological parameters such as transpiration rate, photosynthetic rate, and stomata conductance, which will be measured at various positions inside plant canopies. Based on this information, we expect the sensors to enable the development of indices that will*

provide direct insight into: i) the stress level experienced by the crop, ii) its physiological status, as a function of the environment and potentially, iii) determine which crops or even cultivars may be more water-use efficient. This system will allow us to further fine-tune the low-cost sensors by simulating various environmental conditions and calibrating the relationships between the plant's status and sensor outputs.

ENRTF BUDGET: $ 126,234

Outcome	Completion Date
1. Deploy gas exchange equipment in the field	*Sept 2020*
2. Use growth chambers to fine tune sensor development	*May 2021*
3. Analyze data from Activity 1 and 2	*January 2022*
4. Academic papers on plant physiology and sensors	*June 2024*

Activity 3 Title: Use the data and machine learning to predict water quality and crop productivity across the landscape of southern Minnesota

Description: *We will use spatial Bayesian networks (SBN) to understand the causal and spatial relationships between crop rotation, location of crop rotation, crop productivity, and water quality outcomes. SBN are a machine learning approach to deal with large, complex datasets where the spatial relationships between factors makes traditional statistical approaches inappropriate. We will build two SBN using the variables we collect in Activity 1 and 2 to predict crop yields and water quality. Then, using these SBN and data on precipitation, slope, soil type, and other relevant spatial information from the Mn Geospatial Commons, we will predict the yield performance and water quality performance of the LTARN cropping systems across southern Minnesota. The final result will be two maps series of how well cropping systems will: 1) yield, and 2) support water quality. Jointly, each map series will provide insights into the performance of different cropping systems for farmers and policymakers,*

ENRTF BUDGET: $185,219

Outcome	Completion Date
1. Clean and harmonize all data from Activity 1 and 2	*December 2022*
2. Create Bayesian networks to predict yields and water quality	*May 2023*
3. Collate data from MN Geospatial Commons	*September 2023*
4. Use Bayesian networks to predict water quality and crop productivity	*January 2024*
4. Final white paper; publish academic articles on Bayesian networks	*June 2024*

III. PROJECT PARTNERS AND COLLABORATORS: Philip Pardey, Applied Economics; **Bryan Runck**, **Kevin Silverstein** - GEMS Agroinformatics Initiative; **Gregg Johnson**, **Axel Garcia y Garcia**, **Walid Sadok** – Agron. and Plant Genetics; **Peter Marchetto**, Bioproducts and Biosystems Engineering; **Forrest Izuno**, **Curt Miller** - Southern Research and Outreach Center; **Ford Denison,** Ecology, Evolution and Behavior

IV. LONG-TERM IMPLEMENTATION AND FUNDING: The digital hardware – sensor nodes, gateways – will be supported through additional grant funds for researchers as they need the data and sensor nodes or gateways need to be repaired. The data will be maintained under long-term GEMS fixed funding on GEMShare – a data sharing portal. We are also seeking additional funding through the National Science Foundation to provide long term funding for sensor node and gateway maintenance. Generally speaking, the hardware and software portions of this proposal should be understood as infrastructure investments that will also be leveraged by other research teams to answer additional scientific questions.

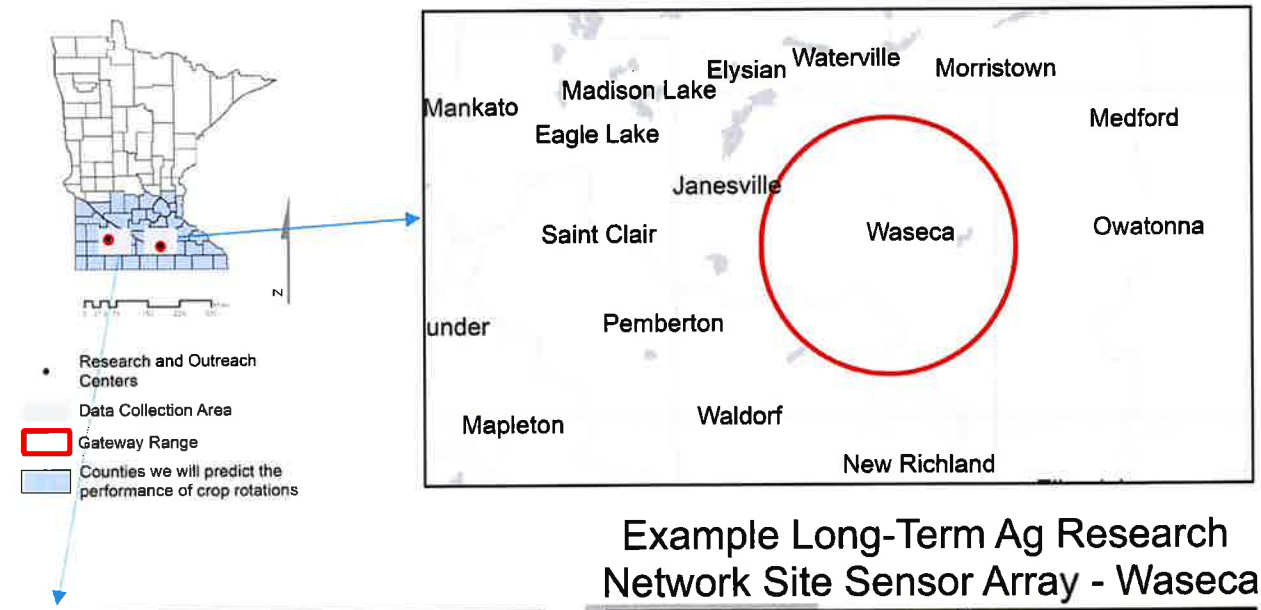
Attachment A: Project Budget Spreadsheet
Environment and Natural Resources Trust Fund
M.L. 2020 Budget Spreadsheet
Legal Citation:
Project Manager: Philip Pardey and Bryan Runck
Project Title: Predicting agriculture's outcomes with sensors and machine learning
Organization: GEMS Agroinformatics Initiative, University of Minnesota
Project Budget:
Project Length and Completion Date: 4 years; July 2020 - July 2024
Today's Date: 4/9/2019

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	$ 697,005	$ -	$ 697,005
Prof. (PI) 5% FTE, $52768; 65.8% sal; 34.2% frg			$ -
2 - Asst Prof 28.4% FTE, $61422 65.8% sal; 34.2% frg			$ -
Researcher 5 10% FTE, $47,436 65.8% sal; 34.2% frg			$ -
GEMS Developer , 50% FTE, $120,600 65.8% sal; 34.2% frg			$ -
Researcher 3, 25% FTE $62,172 71.6% sal; 28.4% frg			$ -
Post-Doc 75% FTE, $208,080 65.8% sal; 34.2% frg			$ -
2 - Undergraduate Assistants $26,000 sal; 0% frg			$ -
Adjunct Prof 10% FTE $45,898 65.8% sal; 34.2% frg			$ -
Grad Student 25% FTE $48,245 $12,061 sal; 49% frg			$ -
Prof 8.4% FTE, $24,384 65.8% sal; 34.2% frg			$ -
Professional/Technical/Service Contracts			
	$ -	$ -	$ -
Equipment/Tools/Supplies			
Sensor nodes, 875, $200 each	$ 175,000	$ -	$ 175,000
Gateways, 2, $500	$ 1,000	$ -	$ 1,000
Solder paste, 286, $3.50 each	$ 1,000		$ 1,000
Solder iron tip replacements, 40, $25 each	$ 1,000		$ 1,000
Capital Expenditures Over $5,000			
DC Fluke Sensor Calibrator, 1, $7,000	$ 7,000	$ -	$ 7,000
Fee Title Acquisition			
	$ -	$ -	$ -
Easement Acquisition			
	$ -	$ -	$ -
Professional Services for Acquisition			
	$ -	$ -	$ -
Printing			
	$ -	$ -	$ -
Travel expenses in Minnesota			
Lamberton ROC, installation, maintence, testing sensors and experiment management, 4 trips per year, 296.80 miles per trip	$ 2,500		$ 2,500
Waseca ROC, installation, maintence, testing sensors and experiment management, 6 trips per year, 153.4 miles per trip	$ 2,500	$ -	$ 2,500
Other			
	$ -	$ -	$ -
COLUMN TOTAL	$ 887,005	$ -	$ 887,005

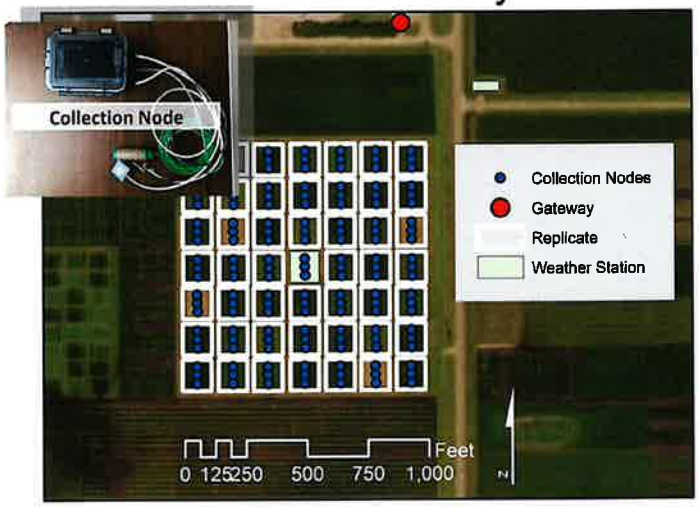
SOURCE AND USE OF OTHER FUNDS CONTRIBUTED TO THE PROJECT	Status (secured or pending)	Budget	Spent	Balance
Non-State: None		$ -	$ -	$ -
State: Minnesota Agricultural Experiment Stations	Secured	$ 16,923	$ -	$ 16,923
In kind: None		$ -	$ -	$ -

Other ENRTF APPROPRIATIONS AWARDED IN THE LAST SIX YEARS	Amount legally obligated but not yet spent	Budget	Spent	Balance
		$ -	$ -	$ -

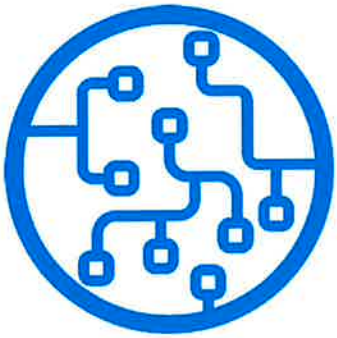
Low cost, sensor arrays + Machine learning = prediction of cropping system performance across southern Minnesota



Example Long-Term Ag Research Network Site Sensor Array - Waseca



Sensor-trained Machine Learning Models



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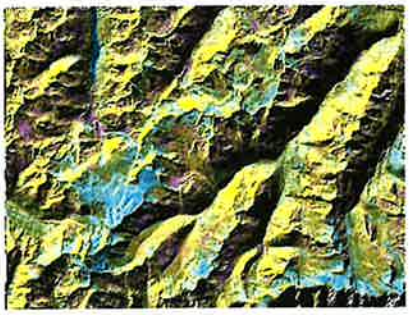
Geospatial Data



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High Resolution Maps

1. Yield performance of cropping systems
2. Water quality outcomes

F. Project Manager Qualifications and Organization Description

Philip Pardey, PhD
Philip Pardey is Director of Global Research Strategy for the University of Minnesota's CFANS (College of Food, Agricultural and Natural Resource Sciences) and the Minnesota Agricultural Experiment Station (MAES), and Director of InSTePP (International Science and Technology Practice and Policy center). He is a Fellow of the American Association for the Advancement of Science (AAAS) and the American Agricultural Economics Association (AAEA), a Distinguished Fellow and Past President of the Australian Agricultural and Resource Economics (AARES) Society, a Distinguished Life Member of the International Association of Agricultural Economists (IAAE), and winner of the Siehl Prize for Excellence in Agriculture. He has spent his career developing and analyzing data to improve innovation-driven outcomes in food and agriculture worldwide. Phil has authored more than 360 books, articles, and papers. Phil will be responsible for supporting Runck in managing the project budget, implementation, and mapping outcomes.

Bryan C. Runck, PhD
Bryan Runck is an Eco-informatics Scientist with the GEMS Agroinformatics Initiative at the University of Miinnesota. His work focuses on the application of advanced spatial machine learning and artificial intelligence techniques to problems in food and agriculture. Over the past seven years, Bryan has supported the management of 3 different projects that each involved teams of 10 plus researchers with over 60 people across the non-profit and for-profit agricultural community. Bryan will work with Phil to manage the project budget, guide implementation of the hardware system, and oversee the final mapping outcomes.

University of Minnesota
The University of Minnesota, founded in the belief "that all people are enriched by understanding; is dedicated to the advancement of learning and the search for truth; to the sharing of this knowledge through education for a diverse community; and to the application of this knowledge to benefit the people of the state, the nation, and the world." This mission is aptly illustrated in the Long-Term Agricultural Network Trials at the Waseca and Lamberton Research and Outreach Stations, which seeks to accumulate large bodies of evidence around the performance of multiple cropping systems. This information serves farmers, crop advisors, and policymakers in understanding what cropping systems to select for their purposes. The result of this work is to provide information that supports agriculture in Minnesota transitioning toward more sustainable production practices.