**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**

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| **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** |  |  |

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| **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**

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| **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** |  |

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| **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.