Environment and Natural Resources Trust Fund
2018 Request for Proposals (RFP)

Project Title: **ENRTF ID: 070-B**

Nutrient Removal and Recovery Technology for Agricultural Drainage

Category: B. Water Resources

Total Project Budget: $ 880,000

Proposed Project Time Period for the Funding Requested: 3 years, July 2018 to June 2021

Summary:

The goal of this project is to improve water quality by removing nitrogen and phosphorus from agricultural runoff water, and to reclaim these nutrients for use as animal feed.

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Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

Excess inorganic nutrients from agricultural areas can pollute subsurface waters of Minnesota. Our novel bioreactor technology will remove these nutrients from agricultural drainage waters, thereby improving Minnesota's water quality. In addition, captured nutrients will be converted to animal feed ingredients to improve agriculture sustainability.

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

_____ Extent of Impact _____ Innovation _____ Scientific/Tech Basis _____ Urgency

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

PROJECT TITLE: Nutrient Removal and Recovery Technology for Agricultural Drainage

I. PROJECT STATEMENT

The overall goal of this project is to improve water quality by reducing nitrogen (N) and phosphorus (P) concentrations in agricultural runoff water (e.g., tile drain water), and to reclaim the nutrients for use as animal feed ingredients. We propose an innovative bioreactor system to achieve this goal, which uses self-sustaining, densely-packed aggregates of microorganisms composed of algae and bacteria.

This project is important because (1) transport of these nutrients to water bodies is of great concern for human health and aquatic ecosystem function (e.g., eutrophication) and (2) agricultural runoff water is considered as the major pathway for transport of nutrients to surface waters of Minnesota. Several approaches, such as constructed wetlands and woodchip bioreactors, have been used for nutrient removal from agricultural runoff water. However, the application of these technologies has been limited due to fluctuations in effluent quality, limited P removal, and large area requirement. New inventions are necessary to treat agricultural runoff water and to stabilize biological ecosystems, preserve biodiversity, and reduce risk to public health.

In the proposed bioreactor system, algae assimilate P and N into their biomass, thereby removing these nutrients from water. Bacteria residing in the oxygen-limited inner core of the aggregates further remove N by denitrification (i.e., reduction of nitrate to N_2 gas) using carbon substrate provided from algae. These aggregates sink fast, leaving clean water in the upper part of the bioreactor; therefore, this bioreactor system is easy to operate at a low cost with small ecological footprint (i.e., does not sacrifice farmland). In addition, because the biomass is rich in nutrients, excess biomass from the bioreactor can be used as a potentially high value animal feed ingredient. Our preliminary data suggest that microalgae and proteins derived from certain strains of bacteria are sources of valuable nutrients for livestock and poultry. Such nutrient recycling, especially of P, is important for sustainable agriculture because currently-available P reserves are predicted to be depleted by the end of this century, and P is the third most expensive nutritional component of animal feeds. Therefore, the proposed approach has multiple benefits including removal of environmentally sensitive chemicals from agricultural runoff water and converting these nutrients into higher value materials to improve agriculture sustainability.

The specific objectives are to (1) develop and optimize the novel bioreactor system to remove N and P, (2) apply the bioreactor system to treat actual agricultural runoff water, (3) examine the suitability of the bioreactor by-product as animal feed, and (4) analyze the economic feasibility of this approach.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Develop laboratory-scale bioreactors for N and P removal **Budget: $272,000**

Three laboratory-scale bioreactors will be designed and operated to develop algae-bacteria aggregates for high nutrient removal. The bioreactors will be fed with synthetic agricultural runoff water and operated under field-simulated conditions. The N and P removal efficiencies as well as the size, density, and microbial community structure of the algae-bacteria aggregates will be measured. The reactor operation conditions will be optimized to maximize the N and P removal efficiencies. Our target nutrient removal efficiency is >90%.

Outcome	Completion Date
1. Development of the lab-scale bioreactors with algae-bacteria aggregates	June 30, 2019
3. N and P removal efficiencies of >90% in the lab-scale bioreactors	Dec. 31, 2019

Activity 2: Demonstrate N and P removals in agricultural fields **Budget: $181,000**

Once we develop lab-scale bioreactors for N and P removal, we will feed actual agricultural runoff water to the bioreactors, and evaluate the nutrient removal efficiencies. We will use agricultural runoff water samples collected from different locations across the state. In addition, we will select a field site where high N and P leaching is observed, and install the bioreactors in the field. We will optimize reactor operation conditions based on the climate and hydrological conditions in the fields to maximize the nutrient removal efficiencies.

Outcome	Completion Date
1. Lab-scale bioreactors removing nutrients from actual agricultural runoff water	June 30, 2020
2. Installation of the bioreactors in agricultural fields	Dec. 31, 2020
3. Demonstration of N and P removals (>90%) in the field-based bioreactors	Dec. 31, 2020

Activity 3: Convert bioreactor biomass to animal feed **Budget: $380,000**

We will convert the bioreactor biomass to animal feed ingredients and determine their chemical composition and nutritional value. The primary focus will be to determine energy, protein, and P digestibility as well as determine if there are specific chemical components in the biomass that may have growth promoting and beneficial effects on animal health. Given the small quantities of biomass produced in the laboratory scale reactors, we will utilize mice for the nutritional investigations. Two experiments will be conducted to measure nutrient and energy digestibility (Exp. 1) followed by an experiment where diets will be adjusted to the nutritional requirement of mice for growth (Exp. 2). Samples of tissues will be collected from mice fed the biomass and control diets to determine metabolic and physiologic benefits of feeding the biomass to animals.

Outcome	Completion Date
1. Nutritional values of the bioreactor by-product	Dec. 31, 2020
2. Effects of the bioreactor by-product on growth promotion of mice	June 30, 2021

Activity 4: Analyze economic feasibility of the proposed approach **Budget: $47,000**

Although the proposed bioreactor system is small and easy to operate, it requires some costs for installation and maintenance. The bioreactor can produce profit if the bioreactor by-product is proven useful as animal feed in Activity 3. Therefore, in the Activity 4, we will evaluate the economic feasibility of the bioreactor system under several scenarios (e.g., with or without using bioreactor by-product for animal feed). We will calculate the dollar required to remove kg of N and P from agricultural runoff water, and compare this value with other removal technologies (e.g., constructed wetlands, woodchip bioreactors).

Outcome	Completion Date
1. Operational cost of the bioreactor under several scenarios	Dec. 31, 2020
2. Dollar value required to remove kg of N and P from agricultural runoff water	June 30, 2021

III. PROJECT STRATEGY

A. Project Team/Partners

Dr. Satoshi Ishii (Assistant Professor, Dept. Soil, Water and Climate, U of M) will lead and manage the project. He will be responsible in Activity 1 and 2. **Dr. Roger Ruan** (Professor, Dept. Bioproducts and Biosystems Engineering, U of M) will be responsible in the biomass conversion to high value by-product in Activity 3. **Dr. Gerald Shurson** (Professor, Dept. Animal Science, U of M) and **Dr. Pedro Urriola** (Research Assistant Professor, Dept. Animal Science, U of M) will be responsible in testing the bioreactor by-product for animal production in Activity 3. **Dr. Dean Current** (Director, Center for Integrated Natural Resource and Agricultural Management, U of M) will be responsible in Activity 4. **Dr. Gary Feyereisen** (Research Agricultural Engineer, USDA Agricultural Research Service, Soil & Water Management Research Unit) will assist with the field deployment (Activity 2), without funding support from ENRTF. Two postdoctoral research associates, three graduate research assistants, and one research technician will be hired in this project.

B. Project Impact and Long-Term Strategy

The long-term goal of this research is to improve water quality by reducing N and P concentrations in agricultural runoff water in upper Midwest states. The proposed project is the initial step (phase 1) of a three-phase project to achieve this goal. In the phase 2 project, multiple bioreactors will be installed and operated in the fields in the upper Midwest states, and their N and P removal efficiencies will be evaluated. We seek support from federal agencies such as USDA, EPA, and NSF at this stage. (NSF). In the third phase, we will develop low-cost bioreactors (e.g., <$1,000) to promote the installation of the bioreactors in the fields.

C. Timeline Requirements

We expect to complete the proposed project in 3 years: Activity 1 from July 2018 to Dec. 2019; Activity 2 from July 2019 to Dec. 2020; Activity 3 from July 2019 to June 2021; and Activity 4 from July 2020 to June 2021.

2018 Detailed Project Budget

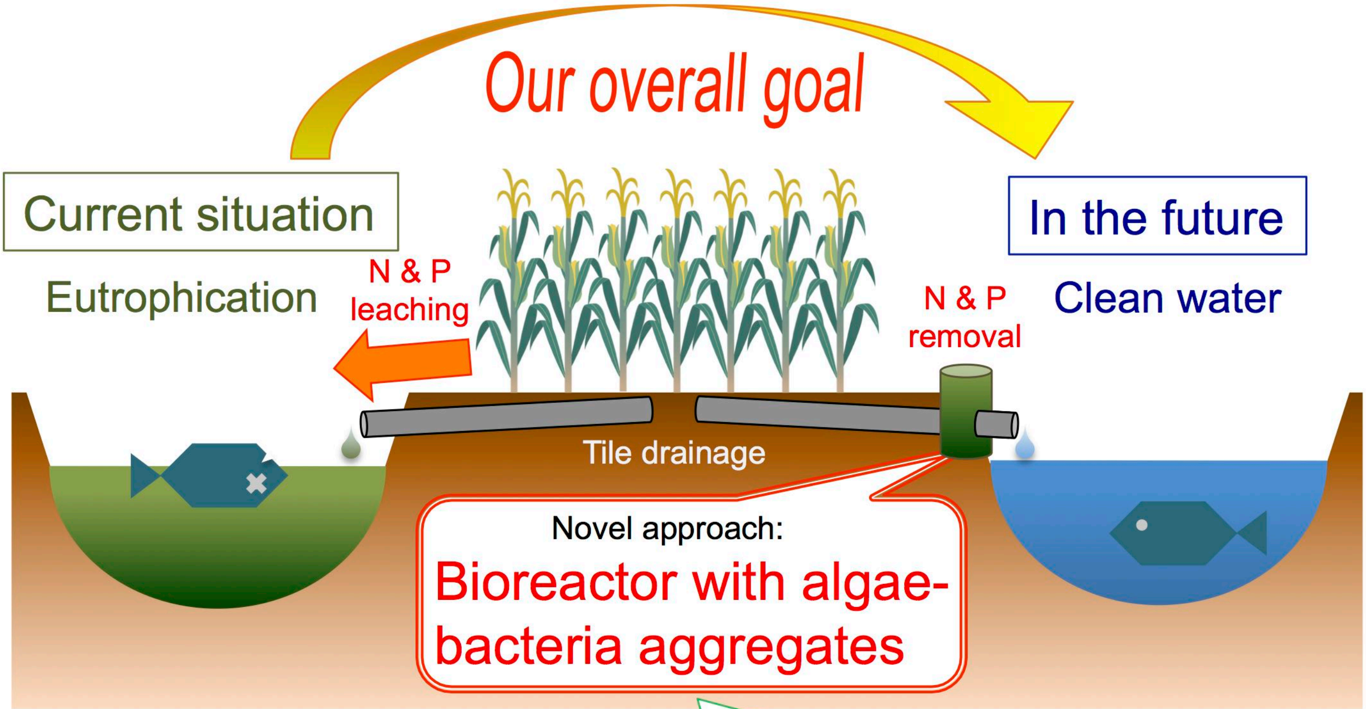
Project Title: Nutrient Removal and Recovery Technology for Agricultural Drainage

IV. TOTAL ENRTF REQUEST BUDGET 3 years

BUDGET ITEM	AMOUNT
Satoshi Ishii, Assistant Professor (75% salary, 25% benefits); 8% FTE for three years; overall project supervision, supervision of post-doctoral, graduate student, and research technician, project reporting.	$ 41,000
Roger Ruan, Professor (75% salary, 25% benefits); 8% FTE for three years; project supervision, supervision of post-doctoral and graduate student, project reporting.	$ 57,000
Pedro Urriola, Assistant Professor (75% salary, 25% benefits); 5% FTE for two years; project supervision, supervision of a graduate student, project reporting.	$ 13,000
Dean Current, Research Associate (82% salary, 18% benefits); 15% FTE for one years; project supervision, supervision of a graduate student, project reporting.	$ 20,000
Postdoctoral research associate #1 (82% salary, 18% benefits); 100% FTE for three years; perform Activity #1 and #3 experiments, analyze data, write manuscripts	$ 180,000
Postdoctoral research associate #2 (82% salary, 18% benefits); 5% FTE for two years; perform Activity #3 experiments, analyze data, write manuscripts	$ 6,000
Graduate research assistant #1 (55% salary, 45% benefits); 50% FTE for three years; perform Activity #1 and #3 experiments, analyze data, write manuscripts	$ 138,000
Graduate research assistant #2 (55% salary, 45% benefits); 50% FTE for two years; perform Activity #3 experiments, analyze data, write manuscripts	$ 92,000
Graduate research assistant #3 (55% salary, 45% benefits); 25% FTE for one years; perform Activity #4 data analysis, write manuscripts	$ 23,000
Research technician (75% salary, 25% benefits); 100% FTE for three years; perform Activity #1 and #2 experiments, data analysis	$ 150,000
Professional/Technical/Service Contracts: University of Minnesota Genomics Center: Algae/microbial community analysis ($3,000/run x 4 runs)	$ 12,000
Equipment/Tools/Supplies: Bioreactors ($5,000/lab-scale reactors x 3; $10,000/field-scale reactors x 3; Water quality analysis ($40/sample x 1,000 samples); DNA extraction ($5/sample x $600 samples); Culture media ($4,000); Animal feeds ($15/mouse x 40 mice + $50/kg feed x 8 kg); Animal incubation ($25 x 80); Nutrition analysis (LC-MS $150/sample x 120 sample); Animal health examination ($100/sample x $120 samples); Chemicals and reagents ($3,000); Glassware and plastic consumables ($5,000)	$ 133,000
Travel: In-state travel to collect samples: (Approximately 200 miles/day x 30 trips at .54/mile, meals at maximum $36/day)	$ 7,000
Printing: Publication fees for scientific manuscripts, poster and handout printing	$ 8,000
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 880,000

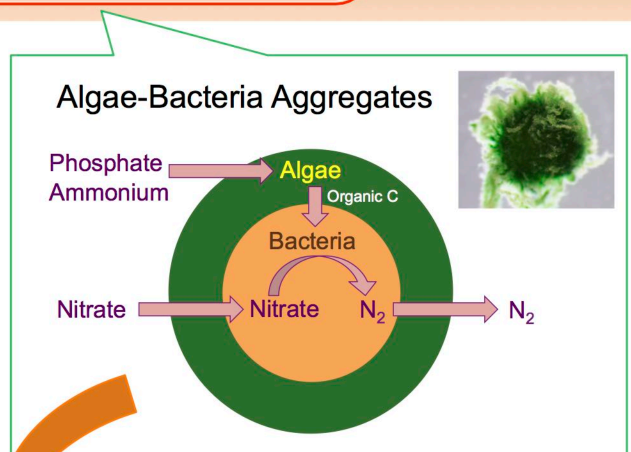
V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period:	N/A	
Other State $ To Be Applied To Project During Project Period:	N/A	
In-kind Services To Be Applied To Project During Project Period: The University of Minnesota does not charge the State of Minnesota its typical overhead rate of 54% of the total modified direct costs (graduate tuition and academic fringe are excluded).	$ 414,000	Secured
Past and Current ENRTF Appropriation:	N/A	
Other Funding History: Minnesota Corn Research & Promotion Council (from April 2017-March 2018)	$ 10,000	Secured



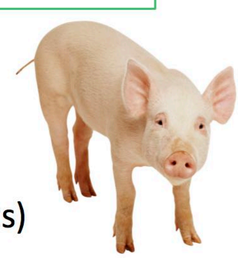
Potential advantages:

- High nutrient removal efficiency
- Low cost to operate
- Does not sacrifice farmland
- Nutrients captured in the biomass can be used as animal feed



Nutrient recovery

Animal feed ingredient
(e.g., algae pellets)



Collaborative effort to achieve this goal

Activity 1: Development of laboratory-scale bioreactors for N and P removal
Activity 2: Field demonstration of the bioreactors
Activity 3: Conversion of bioreactor biomass to animal feed
Activity 4: Economic feasibility analysis

Will contribute to the establishment of:

- Improved water quality
- Sustainable agriculture

PROJECT TITLE: Nutrient Removal and Recovery Technology for Agricultural Drainage

Project Manager Qualifications and Organization Descriptions

Satoshi Ishii, Ph.D.
Satoshi Ishii is Assistant Professor in the BioTechnology Institute (BTI) and the Department of Soil, Water, and Climate (SWC) at the University of Minnesota. He joined the BTI and SWC in April, 2015. He is also a faculty member of the Civil Engineering (CivE) and Water Resources Sciences (WRS) graduate programs. He has over 10 years of experiences on water quality microbiology. He has worked on nutrient removal from agricultural soil and wastewater. In addition, he has extensive experience on microbial aggregates in both natural and engineered systems.

Roger Ruan, Ph.D.
Roger Ruan is Professor in the Department of Bioproducts and Biosystems Engineering (BBE) at the University of Minnesota. He is the leading expert in the use of algae for food, feed and fuel production and wastewater treatment.

Gerald Shurson, Ph.D.
Gerald Shurson is Profesor in the Department of Animal Science at the University of Minnesota. He is an internationally recognized expert in evaluating novel feed ingredients and their environmental impact on environmentally sustainable food animal production.

Pedro Urriola, Ph.D.
Pedro Urriola is Research Assistant Professor in the Department of Animal Science at the University of Minnesota. His area of expertise is animal nutrition.

Dean Current, Ph.D.
Dean Current is Director of the Center for Integrated Natural Resource and Agricultural Management (CINRAM) at the University of Minnesota. He is an economist with expertise in economic and environmental impact assessment and natural resource-based sustainable development.

Gary Feyereisen, Ph.D.
Gary Feyereisen is Research Agricultural Engineer, USDA-Agricultural Research Service-Soil & Water Management Research Unit, St. Paul, MN. He is a hydrologist working on agricultural tile drainage water quality issues and mitigation practices.

Organization Descriptions
The University of Minnesota is the main research and graduate teaching institution in the state of Minnesota. The BioTechnology Institute provides advanced research, training, and university-industry interaction in biological process technology. In the Department of Soil, Water, and Climate, we seek to improve and protect the quality of soil, air, and water resources in natural and managed ecosystems, through research, reaching, and extension.