2021 Final Report Summary Sheet

Grantee Information

Project Title: Bioreactors for Illinois: Smaller, Better, Faster

Institution: University of Illinois

Primary Investigator: Laura Christianson (Co-PI: R. Cooke)

NREC Project # 2017-4-360498-302

Is your project on target from an IMPLEMENTATION standpoint? ☒ **Yes** ☐ **No**
If you answered "no" please explain:

Is your project on target from a BUDGET standpoint? ☒ **Yes** ☐ **No**
If you answered "no" please explain:

Based on what you know today, will you meet the objectives of your project on-time and on-budget? ☒ **Yes** ☐ **No**
If you answered "no" please explain: An additional NCE was approved in early Dec 2021 to extend our end date from 30 Jan 2022 to 31 July 2022. We previously received a 1-year NCE and this new one will be the second NCE request to allow us to pay page charges on our publications.

Have you encountered any issues related to this project? ☐ **Yes** ☒ **No**
If you answered "yes" please explain:

Have you reached any conclusions related to this project that you would like to highlight? ☐ **Yes** ☒ **No**
If you answered "yes" please explain:

Have you completed any outreach activities related this project? Or do you have any activities planned? ☐ **Yes** ☒ **No**
If you answered "yes" please explain and provide details for any upcoming outreach:

NREC December 2021 5.0 Year Report and Renewal Proposal
Bioreactors for Illinois: Smaller, Better, Faster
NREC Project #2017-4-360498-302

PI: Dr. Laura Christianson, Assistant Professor of Water Quality, Department of Crop Sciences, University of Illinois, S322 Turner Hall, 1102 S Goodwin Ave., Urbana, IL 61801.
Co-PI: Dr. Richard Cooke, Agricultural and Biological Engineering, University of Illinois

Summary:

All three bioreactors in this study have been design, built, and monitored as proposed with additional studies leveraged that help address new and interesting bioreactor questions. Data collection at the paired in-ditch and ditch diversion bioreactors on a private farm ended in fall 2021 and the ditch diversion bioreactor was retrofit with a pump as part of our new NREC/NRCS CIG project (Project #2021-3-360498-144). A manuscript describing results of the first three years at this paired bioreactor is under revision at the journal *Water*.

Dr. Bryan Maxwell is leading manuscript development to report the first three years of the High-Flow Booster Bioreactor's (Monmouth Farm, UIUC) performance. Gas sampling led by MS student Ms. Annie Brunton and woodchip bag analysis led by PhD Student Ms. Niranga Wickramarathne were additional studies leveraged using these Monmouth bioreactors. Ms. Brunton and Ms. Wickramarathne will be defending their work in Spring 2022. Dr. Luciano Alves de Oliveira is leading the hydraulic analysis comparing tracer testing results which included the Monmouth bioreactor as well as several others.

While the Heat-Enhanced Bioreactor (South Farm, UIUC) did not provide improved nitrate removal as hoped, this site was used for an additional study of *in situ* woodchip bulk density (**Figures 1 and 2**). The woodchips in the bioreactor were excavated carefully in three lifts, and all the woodchips from each lift were weighed. The volume of each lift was estimated using three methods: surveying; laying plastic and pumping it full of water through a flow meter; and LiDAR shot on an iPhone 12. Bulk density of the woodchips will be calculated as the woodchip mass (corrected for moisture content) divided by volume. See a 41 second excavation video here: https://mediaspace.illinois.edu/media/t/1_7qckhbm3.

Figure 1. Photo collage of summer 2021 excavation of a UIUC Ag Engineering Farm pilot-scale bioreactor to estimate *in situ* woodchip bulk density.

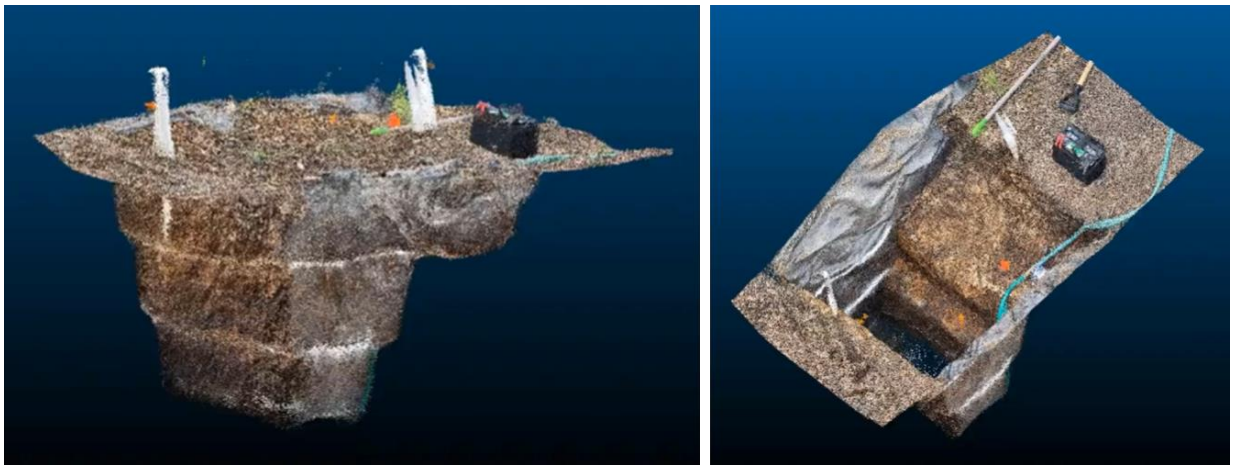


Figure 2. iPhone LiDAR image of excavated UIUC Ag Engineering Farm pilot-scale woodchip bioreactor. The bioreactor was excavated to estimate how densely compacted the woodchips were after 2 years (that is, to determine the *in-situ* woodchip bulk density). See 41 second excavation video here: https://mediaspace.illinois.edu/media/t/1_7qckhbm3

Cooperators

- **PI**: Dr. Laura Christianson, Assistant Professor of Water Quality, Department of Crop Sciences, UIUC, S322 Turner Hall, 1102 S Goodwin Ave., Urbana, IL 61801.
- **Co-PI**: Dr. Richard Cooke, Agricultural and Biological Engineering, University of Illinois
    - Additional assistance from Dr. Reid Christianson, CPSC, for field operations (electrical work, weir deployment)
- **Staff**:
    - Mr. Ronnie Chacón, Field Research Specialist responsible for data collection
    - Mr. Mike Wallace, Research Specialist Lab Manager performing samples analysis
- **Postdoctoral Associate**:
    - Dr. Bryan Maxwell, assisting with data analysis and writing
    - Dr. Luciano Alves de Oliveira, doing tracer testing across all bioreactors
- **Graduate Students**:
    - Ms. Ana Paula Sanchez-Bustamante Bailon, graduated with MS in CPSC 2020; thesis: *Dissolved P removal in denitrifying bioreactors: Field and lab studies*
    - Ms. Annie Brunton, current MS student in ABE, who led the intensive data collection at the heat-enhanced bioreactors
    - Ms. Niranga Wickramarathne, current PhD candidate in CPSC, who is leading the woodchip analysis for the High-Flow Booster Bioreactors

Locations

- Two Ditch Bioreactors – Private Farm in Livingston County
- One High-Flow Booster Bioreactor – University of Illinois Department of Crop Sciences Northwest Research and Education Center at Monmouth, Illinois

- One Heat-Enhanced Bioreactor – University of Illinois Department of Crop Sciences South Farms at Urbana, Illinois

List of objectives

The specific assessable objectives are to:

- ***DONE*** **Design** and **build** four new types of denitrifying bioreactors in Illinois:
  - Two Ditch Bioreactors (Private Farm)
  - One High-Flow Booster Bioreactor (Monmouth Farm, UIUC)
  - One Heat-Enhanced Bioreactor (South Farm, UIUC)
- **Compare** the nutrient removal efficiency and hydraulic performance of these novel bioreactors to existing conventional bioreactors
- Perform an **economic evaluation** ($ per acre treated and $ per pound of nitrogen removed).
- Per the RFP, the final objective is "*to include a final report at the conclusion of this project to address each of the objectives stated above*."

Length of project - number of years completed: 5.0 years (of 4.0 years)

NOTE: a 1-year No Cost Extension was granted extending the project to 30 Jan 2022.

NOTE: a 6-month No Cost Extension was approved in Dec 2021 extending the project to 31 July 2022.

Accomplishments

- Bioreactors
  - Two Ditch Bioreactors (Private Farm in Livingston County): A manuscript with three years of results is under revision at a peer-reviewed journal (see publication section below). In fall 2021, the ditch diversion bioreactor was retrofit with a pump as part of our new NREC/NRCS CIG project.
  - One High-Flow Booster Bioreactor (Monmouth Farm, UIUC): Results of three years of monitoring as well as the tracer testing results will be submitted for peer-review in Spring 2022 (see planned activities).
  - One Heat-Enhanced Bioreactor (South Farm, UIUC): A period of intensive data collection and heating-associated effort resulted in no notable nitrate removal benefit of the heated bioreactor. However, this bioreactor set-up was additionally used for the bulk density experiment (**Figures 1 and 2**).
- Results from this work were presented during this period at (presenter in bold):
  1. **Oliveira**, L. A., Miranda, J. H., Cooke, R, Christianson, L. 2021. Water and nitrate movement in woodchip bioreactors using HYDRUS model. ASABE 2021 Annual International Meeting, Virtual. 12-16 July 2021. Abstract #2100826.
  2. **Maxwell, B.** and L. Christianson. 2021. University of Illinois Crop Sciences Agronomy Days 2021: Tours 4. Nitrate load reduction in tile drainage by a paired woodchip bioreactor system. 12 August 2021. ≈38 in attendance.
  3. **Wickramarathne**, N., J. Zilles, R.A. Cooke, and L. Christianson. 2021. Denitrifying bioreactor woodchip nutrient content and quality is impacted by

saturation level and time. 2021 ASA-CSSA-SSSA International Annual Meeting. Salt Lake City, Utah. 07-10 November 2021. https://scisoc.confex.com/scisoc/2021am/meetingapp.cgi/Paper/137998

4. **Díaz-García**, C., G. Johnson, R. Christianson, R.A. Cooke, and L. Christianson. 2021. Compaction and time in situ affect denitrifying bioreactor woodchip hydraulic properties. 2021 ASA-CSSA-SSSA International Annual Meeting. Salt Lake City, Utah. 07-10 November 2021. https://scisoc.confex.com/scisoc/2021am/meetingapp.cgi/Paper/138409
5. **Brunton**, A., J. Zilles, R.A. Cooke, and L. Christianson. 2021 Nitrous oxide emissions from denitrifying bioreactors with and without a soil cover. 2021 ASA-CSSA-SSSA International Annual Meeting. Salt Lake City, Utah. 07-10 November 2021. https://scisoc.confex.com/scisoc/2021am/meetingapp.cgi/Paper/138489
6. **Maxwell**, B., R. Arch, R. Christianson, S. Johnson, and L. Christianson. 2021. Cost efficiency analysis and nitrate removal performance of six Illinois woodchip bioreactors. 2021 ASA-CSSA-SSSA International Annual Meeting. Salt Lake City, Utah. 07-10 November 2021. https://scisoc.confex.com/scisoc/2021am/meetingapp.cgi/Paper/138432

- Publications during this reporting period
    1. Maxwell, B.M., L.E. Christianson, R.A. Cooke, M.E. Foltz, N.M. Wickramarathne, R.A. Chacon, R.D. Christianson. *Under revision 2021.* Nitrate removal and woodchip properties across a paired denitrifying bioreactor treating centralized agricultural ditch flows. Submitted to *Water*.
    2. Sanchez Bustamante-Bailon, A.P., A. Margenot, R.A.C. Cooke, and L.E. Christianson. 2021. Phosphorus removal in wood-based denitrifying bioreactors varies by wood type and water chemistry. Environmental Science and Pollution Research. https://doi.org/10.1007/s11356-021-15835-w

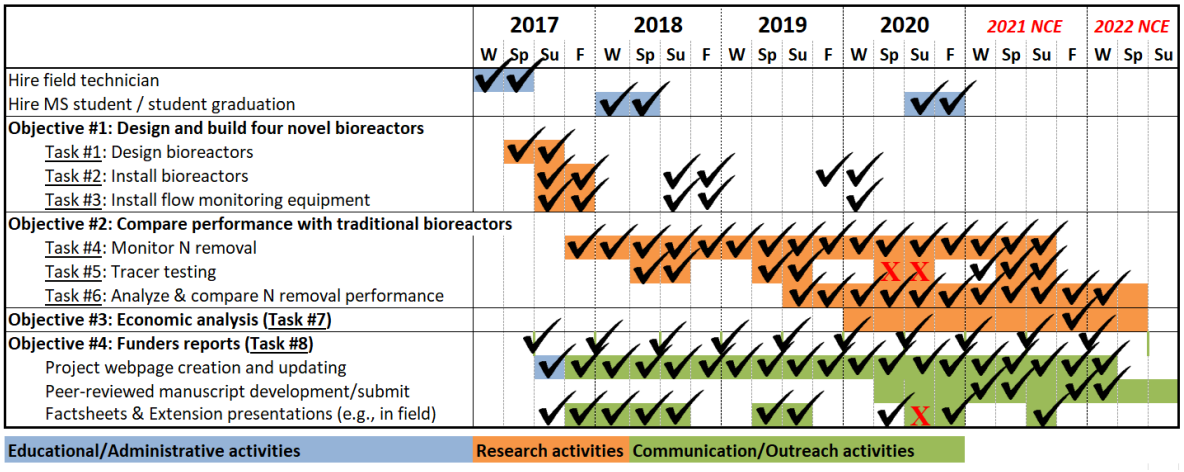
Planned activities for 2022

- Activities
    - Complete **Objective #3:** Perform an economic evaluation ($ per acre treated and $ per pound of nitrogen removed). Progress on this objective is evidenced by Dr. Bryan Maxwell presenting an early version of this work at the Tri-Societies meeting in Salt Lake City, UT (see presentations above).
- Publications (in preparation)
    - Final data analysis and manuscript drafting/submission led by Postdoctoral Associate Dr. Bryan Maxwell for:
        1. Two Ditch Bioreactors (manuscript under revision at *Water*)
        2. One High-Flow Booster Bioreactor (Monmouth Farm, UIUC)
    - Final data analysis and manuscript drafting/submission led by Postdoctoral Associate Dr. Luciano Alves for:
        1. Tracer testing paper involving Monmouth bioreactor

- Spring 2022 data analysis led by Dr. Laura Christianson:
    1. Data analysis, writing, and submission of manuscript describing *in situ* woodchip bulk density (see Figures 1 and 2).

- Defenses in Spring 2022
    1. Ms. Annie Brunton, ABE MS student
    2. Ms. Niranga Wickramarathne, CPSC PhD student

Table 1. Up-to-date timeline for "*Bioreactors for Illinois…*" project. Red Xs are COVID-19 related delays.



Original Proposed Synopsis

As substantial investments in drainage systems continue to be made across Illinois, edge-of-field practices like bioreactors will be necessary to complement in-field practices to meet Illinois Nutrient Loss Reduction Strategy goals. Considering the scale of these new goals, there is an increasing need to design bioreactors to remove nitrate more effectively under both high and low flow rates, from cool early-season drainage, and with a smaller bioreactor footprint. The major goal of this work is to test novel full-size bioreactor designs intended to maximize nitrogen removal from drainage water while limiting land removed from production. Four novel bioreactors will be designed, built (Objective #1 ***update: completed***), tested for nutrient removal and hydraulic performance over four years (Objective #2 ***update: completed***), and compared to existing "traditional" bioreactors in terms of $ per acre treated and $ per pound of nitrogen removed (Objective #3). Two bioreactors will be designed for treatment of ditch drainage ("Ditch Bioreactors"), one bioreactor will include a step-feeding system for high flows ("High-Flow Booster Bioreactor"), and one bioreactor will take advantage of solar heating to better treat low temperature drainage water ("Heat-enhanced Bioreactor"). Results will reach producers, drainage industry stakeholders, and scientists through Extension events, factsheets, a webpage, conference presentations, a peer-reviewed publication, and funder's reports (Objective #4). Ultimately, this work aims to improve the performance and increase the adoption of bioreactors to improve water quality in Illinois and across the Mississippi River Basin.