Evaluating denitrifying bioreactors for edge-of-field nitrogen management in Iowa's tile-drained landscapes

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Evaluating denitrifying bioreactors for edge-of-field nitrogen management in Iowa's tile-drained landscapes

Abstract
Bioreactors show significant potential for removing nitrate from Iowa's drained fields. The investigators tested the design and management of bioreactors to see what factors can make the bioreactors operate most efficiently, and how that performance compares to other drainage water quality improvement practices.

Keywords
Agricultural and Biosystems Engineering, Corn-soybean cropping systems, Economic and environmental impacts, Water quality quantity and management

Disciplines
Agricultural Economics | Agronomy and Crop Sciences | Bioresource and Agricultural Engineering | Water Resource Management

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How can we design and operate bioreactors to optimize their nitrate removal under field conditions?

This was answered by evaluating pilot- and field-scale bioreactors to evaluate design factors (e.g., cross-sectional bioreactor shape, bioreactor length to width ratio, bioreactor volume, and retention time) and environmental factors in the field (e.g., temperature, flow rates, nitrate concentrations).

Background

The tile-drained landscape of the Midwest’s Corn Belt is one of the most productive row-cropped areas in the nation. However, the artificial subsurface drainage that fuels the region’s productivity also leads to negative water quality impacts, specifically in terms of nitrate loads. The long-term aim of the researchers is to facilitate adoption of nitrogen management and mitigation practices in Iowa and the upper Mississippi River basin. One potential route for better nitrogen control is through implementation of simple, edge-of-field practices such as denitrification bioreactors.

The project goals were to assess the performance of several denitrification bioreactors in Iowa, and to improve their applicability and cost effectiveness through advancement in reactor design and operation. Specific research objectives included:

1. Producing a bioreactor design that yields high nitrate removal from tile drainage,
2. Optimizing reactor performance under Iowa’s field conditions.

Approach and methods

The project investigators began by designing, installing and conducting experiments on three pilot-scale denitrification bioreactors, and monitoring four full-scale bioreactors. The three pilot-scale bioreactors were constructed with different design geometries to compare the effects of bioreactor shape on nitrate removal. They also were filled with two different materials (woodchips and municipal yard waste) to evaluate different potential bioreactor fill media. The four full-size bioreactors were located throughout the state and each was monitored for nitrate removal for at least two years. Project partners for this field-scale work included the Environmental Programs and Services division of the Iowa Soybean Association and the Coldwater Palmer Watershed Improvement Association.

To put this new technology in context with other water quality improvement practices, cost efficiency metrics were created for seven drainage water quality improvement strategies:

- bioreactors,
- controlled drainage,
Results and discussion

The major findings included:

• Evaluation of four bioreactors in Iowa showed that they were able to remove between 12 and 57 percent of the annual nitrate load, and when averaged over all sites and years, the four bioreactors had a total load reduction of 32 percent.
• Drainage denitrification bioreactors likely will continue to be long and narrow with woodchips used as the fill media.
• The retention time, or the amount of time the water remains in the bioreactor, is strongly correlated with nitrate removal. This information can help those who design bioreactors for the future.
• Drainage water temperature and retention time are important predictors of bioreactor nitrate-removal performance. This presents design and operational challenges that have yet to be addressed such as the high drainage flow rates and cool drainage waters in spring and early summer that are key periods of drainage nitrate loading.
• Management of bioreactor control structures can provide important flexibility, especially in management of seasonally variable flow rates.

In context of other drainage water quality improvement strategies, bioreactors are cost effective at less than $3 per kg N removed. However, bioreactors offer few additional ecosystem services unlike other practices such as wetlands, cover crops and diversified crop rotations. Bioreactors were perceived by farmers to passively accept nitrate loss (that is, bioreactors don’t retain nitrate in the field where it can be further used), and were believed to have relatively high up-front installation costs. These factors may be barriers to implementation, although bioreactors were viewed as a fairly straightforward option. No individual technology or management approach will be capable of addressing drainage water quality concerns in entirety; a number of approaches likely will be needed across the landscape to meet collective water quality goals.

Conclusions

This project has produced substantial new information to be generated and disseminated with the goal of improving the design and performance of agricultural drainage denitrification bioreactors. However, as is often the case with research, this new information has led to additional questions regarding how to further optimize nitrate removal through design and operational processes.
Key outputs of this research included (with associated status of the output):

- An improved bioreactor design for efficient nitrate removal from tile drainage: These efforts have helped establish bioreactors as a viable practice in Iowa and have highlighted the next steps for research efforts.

- A preliminary protocol for bioreactor operation and maintenance: The authors have written a review article (“A practice-oriented review of woodchip bioreactors for subsurface agricultural drainage” in Applied Engineering in Agriculture) with suggestions for design, installation and monitoring of these systems. A peer-reviewed Extension publication offers additional, albeit brief, guidance on operation and maintenance though a specific protocol, per se, is still lacking. (See: Woodchip bioreactors for nitrate in agricultural drainage. Iowa State University Extension Publication PMR 1008. Available at: http://www.leopold.iastate.edu/pubs-and-papers/2011-10-woodchip-bioreactors-nitrate-agricultural-drainage.) Additional field-scale performance data will further inform development of any such operation and maintenance protocol.

- Identification of water quality parameters for performance monitoring: The practice-oriented review article mentioned above provides this information in a format applicable to extension agents, water quality professionals in the field, and farmers.

- Information on cost-effectiveness and farmer acceptance of denitrifying bioreactors in Iowa: Cost efficiencies of bioreactors plus six other drainage water quality improvement strategies have been developed and shared with both the research and the lay communities.

**Impact of results**

In terms of design standardization, there is still much work to be done, but the authors collaborated with the U.S. Department of Agriculture-Natural Resources Conservation Service in Iowa to develop an interim design standard that allows bioreactors to be eligible for cost-sharing through the EQIP (USDA-NRCS, 2009). Important bioreactor design work continues across the Midwest and no formal consensus has been reached regarding an optimal design procedure. Since the initiation of this project, increased adoption of bioreactors in Iowa and across the Midwest is evident, though most of these installations have been for research purposes.

Results from this work have already been used to design several bioreactors in the state of Iowa. The denitrification bioreactor design model, which underwent refinement during this project, and associated resulting bioreactor designs developed by this group have been shared with researchers and USDA-NRCS engineers throughout the region including those from Iowa, South Dakota, Minnesota, Wisconsin and Canada.

It is felt that information generated through this work, specifically the development of cost efficiency metrics, may help provide more informed decision-making regarding different water quality technologies. Additionally, the Christianson and Helmers (2011) extension publication offers practical, accessible information on woodchip bioreactors.
**Education and outreach**

Peer-reviewed publications (nine): Two currently available, four in press, two under review, one in preparation

Non-peer reviewed conference proceedings and reports: Seven

Conference oral presentations: Four

Conference/symposium poster presentations: Five

Invited and Extension presentations: Fifteen

Radio, online, and print profiles: Five

**Leveraged funds**

Two additional grants were obtained through this project: a USDA-NCR SARE grant for $9,953 to study “Producer Education of Nitrate Reduction Strategies and Evaluation of Acceptance” and a $40,000 USDA-NIFA pre-doctoral fellowship grant on “Performance and Acceptance of Denitrification Bioreactors for Agricultural Drainage.”

Plan and cross-sectional views of pilot-scale denitrification bioreactors installed near Ames, Iowa. Dimensions are in meters.