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Denitrifying Bioreactors Reduction of Agricultural Nitrogen Pollution at the Watershed Scale

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Abstract

Denitrifying bioreactors have the potential to reduce nitrogen loading to streams in agricultural watersheds. By passing the nitrate-rich waters of tile-drained fields through a system engineered for denitrification, the total nitrogen loading is reduced before entering sensitive aquatic ecosystems. In this project we found that intense summer storms impact nitrate removal rates in these reactors, causing in some cases for the removal rate to sharply drop for a period of time post-storm. Denitrifying bioreactors placed in existing tile-drained fields could reduce 4.5% of the total nitrogen export from the Upper Susquehanna River Basin. As a low-cost, low-maintenance strategy, denitrifying bioreactors can be expected to reduce agricultural impact on water resources. More research and design modifications are recommended to address performance during storm events.

- **Denitrifying bioreactors removed on average 7.5 g N per m^3 per day.**
- **Storms caused flow fluctuations and increased the variability in removal rate.**
- **Denitrifying bioreactors have the potential to remove 252,000 kg of nitrate in an average growing season.**

Keywords
Denitrification – Nitrate – Bioreactor – Tile Drainage – Watershed

Introduction

Nonpoint source nutrient pollution is a continuing problem for water quality in the United States, especially in highly agricultural watersheds. Nitrogen (N) is a main component of this due to high levels in fertilizers and manure (Vitousek et al, 1997). Storm-driven runoff and subsurface flow from agricultural fields is commonly high in nitrate (NO3) which leads to eutrophication in downstream freshwater systems (Carpenter et al, 1998). While this NO3 can be reduced through denitrification, the drainage of wetlands, additions of tile drains, and reduction of riparian buffers minimize locations where this can naturally occur in the landscape (Vitousek et al, 1997).

Denitrifying bioreactors have been developed to combat this NO3 problem. Bioreactors consist of pits of saturated woodchips that intercept tile drainage (Schipper et al, 2001). This provides the ideal environment for naturally-occurring denitrifying microbes to thrive and reduce the NO3 in the bioreactor influent to an inert gas. Previous research has shown rates of removal between 2.9 and 7.3 g N m-3 d-1 and reduction to natural concentrations of NO3 in the bioreactor effluent (Addy et al., 2016; Bell et al, 2015).

These studies have relied predominately on discrete grab sampling to develop average reduction rates (Addy et al 2016). However, these systems are continuously flowing and are likely more complex than grab sampling may suggest during certain times, such as storm events (Williams et al., 2015). This is especially relevant given that residence time in the bioreactor is a strong controlling variable and is inversely related to the flow rate (Addy et al 2016). Hydrology of soils with tile drainage can lead to rapidly-changing and highly-variable flow rates and therefore variable residence times that may not be evenly represented with grab samples (Williams et al., 2015).

This study proposed to use automated sampling to facilitate higher resolution of sampling to determine the effects of sampling on calculated removal rates. The purpose was to compare the high-resolution removal rate with grab sample removal rates at the watershed scale. This will help provide more appropriate estimates of the potential NO3 reduction that can be achieved in a watershed with widespread denitrifying bioreactor application.

Results & Discussion

We were able to monitor 18 different periods throughout the growing season of 2015– 13 at the Tompkins County site and 5 at the Chemung County site. While many of the high-resolution sample periods had constant inflow and temperature conditions, several sample periods captured storm events that demonstrated more variable processes in the bioreactors. Figure 1 shows the increased range of removal rates in the bioreactors during storm events, including negative values that indicate the outflow load of NO3 is greater than the inflow. Mean removal rates in the storm events were greater (M=10.9, SD=26.7) than the removal rates during baseflow conditions (M=5.63, SD=4.25), $p<0.05$. A Brown-Forsythe test indicated the variances to be unequal (F=39.3), $p<0.0005$.

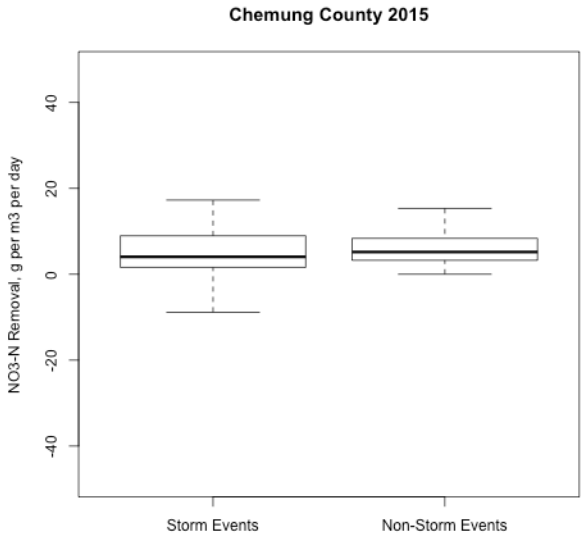

Figure 1: Comparison of removal rate of NO3 in bioreactors at the Chemung County site between storm events and non-storm, baseflow conditions.

With the high frequency sampling, we analyzed individual storm events to determine the cause of the high variability. One particularly interesting event is shown in Figure 2. Prior observations had a similar pattern to this, where the beginning of the storm shows apparently large removal rates followed by a significant drop later in the storm. It is likely that the first portion is due to the flushing of highly reduced water while in the

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inflow is particularly high. Once the bioreactor has been flushed, the outflow is stormwater that has had minimal time for reduction. The flow variability may disrupt stable community structure or wash away dissolved carbon or biofilms necessary for denitrification. The high flow rates accentuate these changes leading to large swings in removal rate.

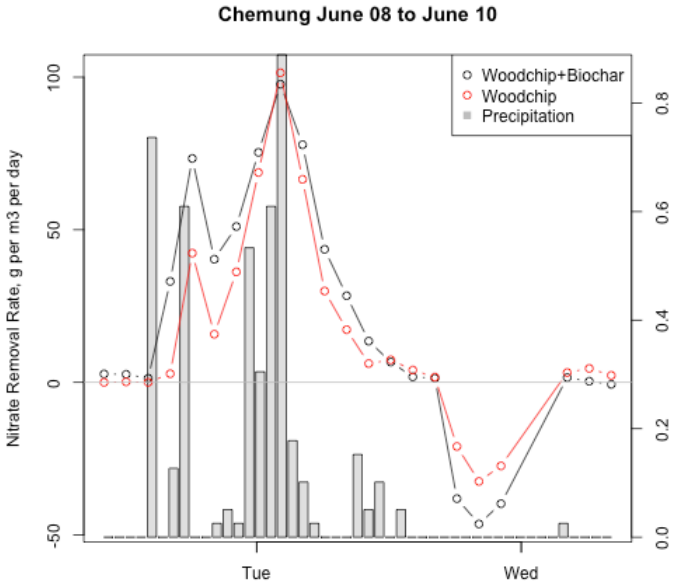

Figure 2: Precipitation data and instantaneous removal rate based on high frequency sampling of a storm event at the Chemung County site.

The potential for nitrate reduction using bioreactors was estimated for the Upper Susquehanna River Bain using the storm and non-storm data collected in this project. With 2% of the watershed area under tile-drainage (Jaynes & James, 1992), bioreactors have the potential of removing 252,000 kg of nitrate from tile-drainage water entering the stream during the average growing season (135 days). On an annual basis, bioreactors placed in all tile-drained fields could remove approximately 4.5% of the streamflow total nitrogen exported from the Upper Susquehanna River Basin (Woodbury, Howard, & Steinhart, 2008).

Policy Implications

The main take-away from this study is that bioreactors are a relatively inexpensive yet highly effective best management practice for reducing n in agricultural tile drainage. Based on these results, New York State should strongly encourage or even begin to require the installation of bioreactors to certain percentages of farmland. Cost-sharing may be possible for watersheds draining into water bodies of concern, such as the Chesapeake and Hudson Bays. This could be even more effective because treating N pollution is more easily achieved closer to the source, when volumes are small, than once it reaches the outlet.

New York State also must soon adopt or adapt the design standards for bioreactors installed on agricultural lands recently published by the NRCS. Given the findings from this study, it is important to include storm conditions in designs. However, the NRCS designs already require design based on a 10-year storm. Our current data does not show whether this is an adequate design

Methods

This project had two major portions: the first was high-frequency field sampling and the second was removal rate and scaling comparisons. Field data was collected at two sites in central New York State. Each site featured paired bioreactors, one of which was filled with woodchips while the other contained woodchips and biochar in a 9:1 ratio. The paired bioreactors used a shared inflow that was diverted into each bioreactor using a control box. Control boxes on at the outlets determined saturated volume and helped determine flow and residence time.

The bioreactors at the Tompkins County site were constructed in October 2012, draining a total of 4 ha of vegetable fields, and were approximately 35 m^3 each. The Chemung County bioreactors were built in June 2013 to treat water draining from 5 ha of dairy farmland, and were about 40 m^3 each.

High-resolution sampling was conducted using three ISCO 3700s placed at the shared inlet and the outlet of each bioreactor. ISCOs collected samples every 30 minute, compositing 4 samples per bottle for a two-hour resolution. This allowed for 48 hours of continuous monitoring. Bottles were pre-acidified and samples were filtered within 72 hours of collection. Samples were analyzed calorimetrically for NO3 and ammonium. Average removal rate was calculated for each outflow sample using the equation:

$$RR = \frac{Q\ (C_{in} - C_{out})}{V}$$

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where Q is the flow rate, Cin and Cout are the concentrations at the in and out control boxes, and V is the total saturated bioreactor volume.

Outreach Comments

The field site for this research continues to provide an example for Soil and Water Conservation Districts working with the Upper Susquehanna Coalition. Based on this partnership, we continue to construct new research bioreactors in farms throughout the state as demonstrations of an effective treatment strategy.

The video prepared as part of the project will be used as an outreach tool. This video provides basic knowledge of what denitrifying bioreactors do and how they can be used to reduce environmental impact from agriculture. The video targets both conservation groups and farmers to address the broad range of those impacted by excess nutrients in water.

Student Training

Two doctoral students in Water Resources Engineering at Cornell University led the research for this study. Their work involved the idea and method development and the analysis and conclusions. Several undergraduate researchers worked on the project, specifically with sample collection in the field and lab analysis. The undergraduate students were also trained on basic data analysis and cleaning for use in the model portion of the research.

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