Bioreactors

EF-01

Figure 1. Construction of woodchip bioreactor at the Morden Research Station (Agriculture and Agri-Food Canada).

What do bioreactors accomplish?

The objective of a bioreactor is ***Improving Water Quality.*** Bioreactors are designed to remove nitrates from a portion of the tile water before it is discharged to surface water. Leading researchers (Christianson et al., 2016) consider bioreactors a cost-effective BMP for nitrate removal. The Minnesota Department of Agriculture (Miller et al., 2012) recommends bioreactors for nitrate (NO_3-N) reduction and anticipates a 30-40% reduction of total nitrogen load.

There is currently one experimental bioreactor in Manitoba (Figure 1), located at the Morden Research Station. Ongoing research is needed to establish bioreactor efficacy and design criteria for Manitoba conditions.

Overview of how bioreactors work

A bioreactor is an underground biological treatment system located at the edge of the field. It receives a portion of the tile drainage water before it is discharged to surface water. A lined trench, filled with woodchips and covered with soil, is connected to the tile drainage system (Figure 2). The woodchips host denitrifying bacteria that convert nitrate in the water to nitrogen gas. Anaerobic conditions, necessary for denitrification to occur, must be maintained in the bioreactor. This is achieved by controlling water flow and depth using stoplogs or similar control structures on the inlet and outlet of the bioreactor. In periods of high flow, tile water bypasses the bioreactor, by flowing over the stoplogs on the diversion structure, ensuring that field drainage performance is not impeded.

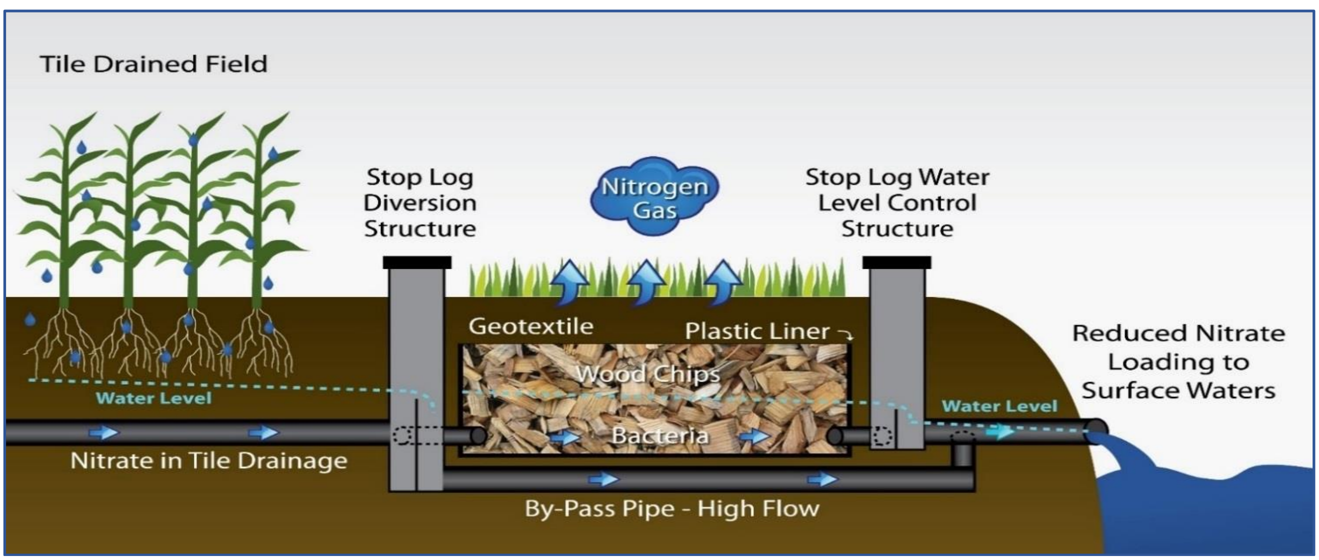

Figure 2. Illustration of woodchip bioreactor components/processes (modified from original on Ag Web by Farm Journal, 2012).

Applicability of bioreactors in Manitoba

The applicability of bioreactors is currently in the research phase in Manitoba. Agriculture and Agri-Food Canada's research bioreactor, designed to treat the tile drainage water from a 35-acre field has shown promising results. Unpublished results for 2015 (personal communication) indicate:

- Bioreactor water temperatures below 4°C can reduce the effectiveness of the bioreactor. During the 2015 season, tile water temperature rose above 4°C by May 11th-15th; about the time the tiles started to flow in earnest;
- Up to 65% of the total annual tile water volume was treated;
- Overall nitrate concentrations were reduced (Figure 3), although reduction rates were quite variable;
- Up to a 50% reduction in nitrogen load (load = volume x concentration) was achieved.

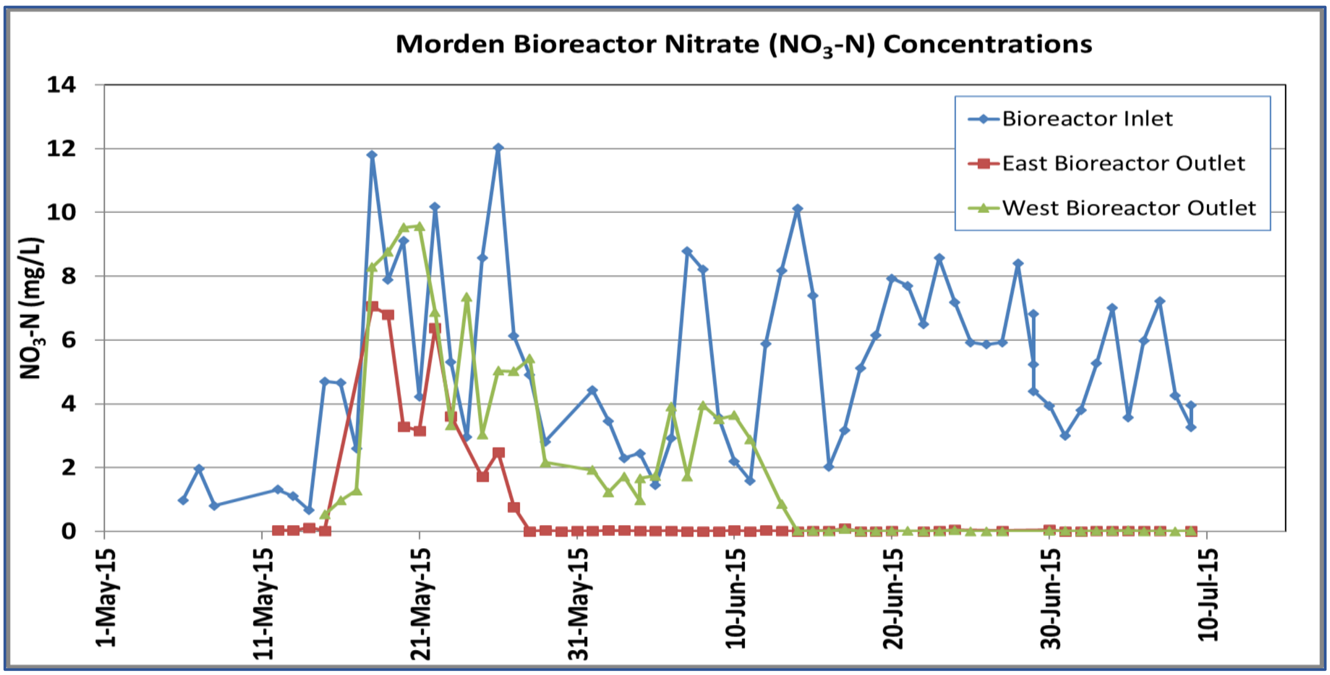

Figure 3. Reduction in NO_3-N Concentration – Bioreactor (Agriculture and Agri-Food Canada, Unpublished).

Christianson et al. (2011) noted some potential negative impacts of bioreactors. Improper operation can lead to discharge of methyl mercury, resulting from holding water in the bioreactor too long. Indication of excessive retention time is a "rotten egg" smell associated with hydrogen sulfide gas. Adjustment of retention time is accomplished with the outlet stoplogs (Figure 2). The bottom stoplog of the outlet control structure should also have a small hole drilled in it to allow the bioreactor to drain down during no-flow periods.

Research has shown that production of greenhouse gases, like nitrous oxide, is a small percentage of the nitrogen exiting the bioreactor system (Christianson et al., 2011).

What are some design considerations?

Bioreactor sizing is a function of variability in water temperature, nitrate levels and tile flow. Where possible, engineering design of a bioreactor should consider locally-measured data (e.g. flow, nitrates). Bioreactors are best designed to treat only a portion of the peak tile flow to keep them cost effective. USDA-NRCS suggests treating a minimum of 15% of peak flow and at least 60% of long-term flow volumes.

Illustrative local flow data (versus precipitation) are provided in Figure 4. A bioreactor designed to treat 1.6 mm/day (0.06 in/day) would treat all water below the arrow on Figure 4; whereas drainage flow rates above 1.6 mm/day (0.06 in/day) would bypass the treatment system.

Cold water performance should be factored into bioreactor sizing by increasing retention time.

Careful selection of media (i.e. woodchip type) will ensure treatment efficacy. Cedar should not be used as a media. Media life and replacement should be considered at the design phase.

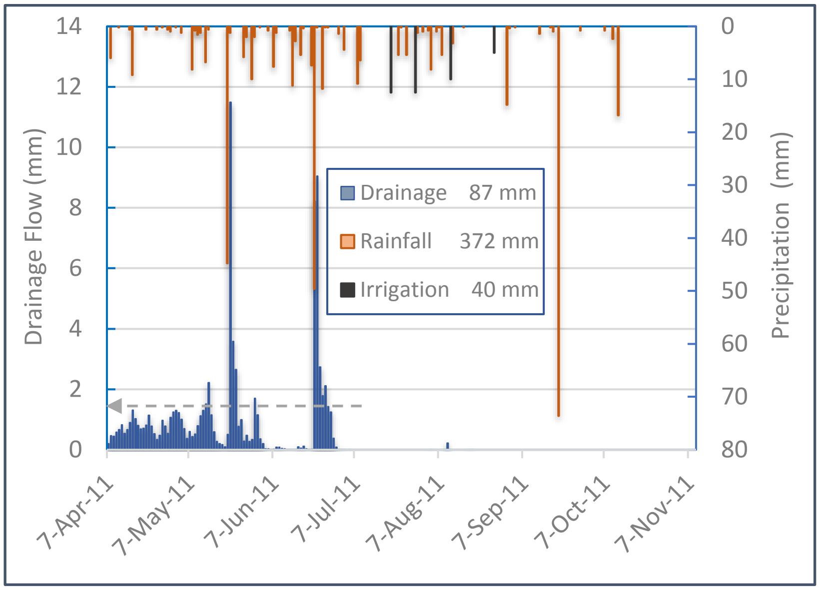

Figure 4. Typical tile drainage flow from a fine sandy loam on the Hespler Farms research plot (Cordeiro, 2013); arrow represents bioreactor sized for 25% of a 6.35 mm/day (0.25 in/day) drainage coefficient.

Outstanding questions and potential future improvements

Bioreactors should currently be considered developing technology. Additional questions that need to be addressed for Manitoba conditions include:

- To ensure that bioreactors do not contribute to climate change, denitrifying bacteria within the system must not produce greenhouse gases. Further research is required to confirm that benign nitrogen gas (N_2) are produced and not nitrous oxide (N_2O).
- Additional data is required to address questions on tile flow versus temperature, especially early season conditions. New treatment media to enhance cold water performance should be pursued (Krider, 2017).
- Manitoba design standards should be developed based on % flow treated, time of residence, nutrient concentration and drainage intensity.
- Performance monitoring criteria should be included as part of the design and operation of the system, including water sampling plans and protocols.
- Amendments to bioreactor designs have been proposed to treat other nutrients and biological constituents in tile water. Additives such as biochar, water treatment plant by-products, iron filings, mine waste products, and slag have been researched (Zoski et al., 2013; Christianson et al., 2017; Krider, 2017). Goals for additives include improved low water temperature performance, reduced residence time and bioreactor size, and treating water for phosphorus removal. Zoski et al. (2013) indicates a reduction in E. coli bacteria is possible. Where warranted, amendments could be added to bioreactor design standards and performance specifications.

Addy et al. (2016) provides the most recent compendium of research, performance review and recommendations aimed to move bioreactors towards large-scale adoption in the United States.

Complementary practices

Bioreactors are complementary to other BMPs that reduce nutrients in tile outflow or drainage volume, and hence impact bioreactors sizing:

- *IF-01 – Nutrient Management;*
- *IF-02 – Cover Crops;*
- *IF-04 – Controlled Drainage.*

Bioreactors can be an alternative to other tile water treatment or reuse practices:

- *WS-01 – Tile Water Recycling,* recycles both water and nutrients but is more expensive than bioreactors;
- *WS-02 – Constructed Wetlands,* can treat multiple tile outlets as an alternative to several bioreactors;
- *EF-02 – Saturated Buffers,* can work in very site-specific conditions, as a lower-cost alternative to bioreactors.

Design aids

Illinois Bioreactor Design Information and Tools; access on the University of Illinois Extension website under Bioreactors, Water Table Management and Water Quality.

USDA – NRCS, Conservation Practice Design Standard – Denitrifying Bioreactor Code 605; access on the USDA – NRCS website.

Additional BMP references

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Christianson, L. E., J. Frankenberger, C. Hay, M. J. Helmers and G. Sands, 2016. Ten ways to reduce nitrogen loads from drained cropland in the Midwest. Pub. C1400, University of Illinois Extension.

Miller, T. P., J. R. Peterson, C. F. Lenhart and Y. Nomura, 2012. The agricultural BMP handbook for Minnesota. Minnesota Department of Agriculture.

References

Addy, K., A. J. Gold, L. E. Christianson, M. B. David, L. A. Schipper and N. A. Ratigan, 2016. Denitrigying bioreactors for nitrate removal; a meta-analysis. Journal of Environmental Quality: 45:873-881.

Christianson, L. E., C. Lepine, P. L. Sibrell, C. Penn and S. T. Summerfelt, 2017. Dentrifying woodchip bioreactor and phosphorus filter pairing to minimize pollution swapping. Journal of Water Research: 121:129-139.

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Zoski, E. D., D. R. Lapen, N. Gottschall, R. S Murrell and B. Schuba, 2013. Nitrogen, phosphorus, and bacteria removal in laboratory-scale woodchip bioreactors amended with drinking water treatment residuals. Transactions of the ASABE: 56(4):1339-1347.