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# Woodchip Bioreactors for Nitrate Removal In Agricultural Land Drainage: A Review

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***Abstract:-*** **Subsurface agricultural drainage can allow large gains in agricultural productivity in the Midwestern United States. There is, however, concern about pollutants moving through these systems. One specific water quality concern is nitrate, a form of nitrogen that moves readily through the soil and often can be present in high amounts in clear drainage waters. The water quality of our local streams, rivers, and lakes can be negatively impacted by nitrate in tile drainage. Moreover, because many streams and rivers in this region lead to the Mississippi River, nitrate in mid-western agricultural drainage also contributes to the hypoxic zone (or Dead Zone) in the Gulf of Mexico. Fortunately, there are a number of practices that can reduce the amount of nitrate in drainage water. Woodchip bioreactors are a new option to reduce the amount of nitrate in drainage before it gets to local surface waters. This technology describes key questions relevant to this innovative approach to water quality. A woodchip bioreactor is made by routing drainage water through a buried trench filled with woodchips. Woodchip bioreactors also are known as DE nitrification bioreactors, a name that is slightly more descriptive of the actual process occurring inside the bioreactor. DE nitrification is the conversion of nitrate (NO3-) to nitrogen gas (dinitrogen, N2) that is carried out by bacteria living in soils all over the world and also in the bioreactor. These good bacteria, called denitrifiers, use the carbon in the woodchips as their food and use the nitrate as part of their respiration process. Because these bacteria also can breathe oxygen, providing anaerobic conditions through more constantly flowing tile water helps ensure that the bacteria utilize the nitrate. Providing these denitrifiers an ample supply of carbon to eat and giving them anaerobic conditions in the bioreactor offers them a perfect environment to remove nitrate from drainage, and in this way we can get rid of the nitrate from the drainage water which ultimately joins other water bodies and can create serious health hazards like the most coveted Blue baby Syndrome. A typical woodchip bioreactor can treat 30 to 80 acres of nitrate infested fields with an annual nitrate load reduction of about 10 percent to greater than 90 percent depending on the bioreactor.**

***Key Words*: Woodchips, Nitrate, De nitrification, Agricultural Drainage**

## INTRODUCTION

Nitrogen (N) is necessary for all life as the primary constituent of nucleotides and proteins (Robertson and Vitousek, 2009). However, more than 99% of N on earth is dinitrogen gas (N2), which is unavailable to more than 99% of organisms (Galloway et al., 2003), thereby limiting autotrophic production and affecting ecosystem structure (Robertson and Vitousek, 2009). The need to overcome N limitation in agricultural food production to meet the demands of growing global population has led to increased cultivation of N fixing plants and development of the Haber–Bosch process, which converts N2 to ammonia (NH3), the main fertilizer for agricultural systems (Galloway et al., 2003; Seitzinger et al., 2006). While there are significant benefits of increased production with increased N inputs, excess N from agricultural systems enters groundwater and surface waters, and eventually flows to downstream water bodies. ExcessNin the aquatic environment has led to many environmental problems including acidification of freshwater bodies, eutrophication and associated hypoxic zones, adverse health effects for humans and aquatic organisms, and N2O production, a greenhouse gas (Camargo and Alonso, 2006). It is important to remediate N at the source in order to avoid multiple adverse impacts as N travels to downstream water bodies (Galloway et al., 2003).Denitrification is the process by which nitrate (NO3−) is reduced by microbes to the inert N2 gas (Seitzinger et al., 2006). It is the primary removal mechanism of N from ecosystems (with the exception in some cases of anammox; Burgin and Hamilton, 2007),and therefore is extremely important in terms of maintaining water quality. All other transformation processes keep reactive N(biologically active N species) within the terrestrial or aquatic system(Myrold, 2004). The

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primary controls on denitrification are availability of $NO_3^-$ and labile C to act as an energy source, and an absence of oxygen ($O_2$) (Teidje, 1988; Seitzinger et al., 2006).Denitrification tends to be constrained in most modern agricultural systems because agricultural practices are aimed at keeping the root zone aerobic, which indirectly reduces denitrification(Seitzinger et al., 2006). The result can be high levels of $NO_3^-$ leaching into groundwater and drainage waters, making approaches for enhancing denitrification in agricultural groundwater and drainage waters critical. Denitrification walls have been shown to maintain high levels of$NO_3^-$ removal for at least 7 years (Robertson et al., 2000; Schipper et al., 2005), while Moorman et al. (2010) showed that a denitrification wall constructed in central Iowa, USA (Jaynes et al., 2008) sustained $NO_3^-$ removal for 9 years. The only decadal study of $NO_3^-$ removal in a denitrification wall was performed in Canada, which showed continued effectiveness in $NO_3^-$ removal after 15 years (Robertson et al., 2008). This study used laboratory column tests of the 15-year old wall material rather than direct field sampling of changes in groundwater $NO_3^-$ concentrations. Therefore, long-term field studies remain sparse for establishing long-term effectiveness of denitrification walls.

## II. WOODCHIP BIOREACTOR BASICS HOW DO BIOREACTORS WORK?

A woodchip bioreactor is made by routing drainage water through a buried trench filled with woodchips. Woodchip bioreactors also are known as denitrification bioreactors, a name that is slightly more descriptive of the actual process occurring inside the bioreactor. Denitrification is the conversion of nitrate ($NO_3^-$) to nitrogen gas (dinitrogen, $N_2$) that is carried out by bacteria living in soils all over the world and also in the bioreactor. These good bacteria, called denitrifiers, use the carbon in the woodchips as their food and use the nitrate as part of their respiration process. Because these bacteria also can breathe oxygen, providing anaerobic conditions through more constantly flowing tile water helps ensure that the bacteria utilize the nitrate

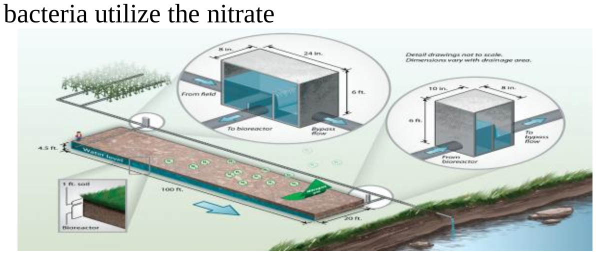

*Fig.1.Descriptive illustration of a woodchip bioreactor*

*Fig.2.Woodchips commonly used in woodchip bioreactors*

Providing these denitrifiers an ample supply of carbon to eat and giving them anaerobic conditions in the bioreactor offers them a perfect environment to remove nitrate from drainage. Fig 1 and Fig2

**HOW BIG ARE WOODCHIP BIOREACTORS?**

Most installations in Iowa to date have been approximately 100 to 120 feet long and 10 to 25 feet wide. Typically, no land is taken out of production for a bioreactor. Because bioreactors tend to have an orientation that is long and narrow, they fit well in edge-of-field buffer strips and grassed areas.

**DOES THE TYPE OF WOODCHIP MATTER? CAN WE USE MATERIALS OTHER THAN CHIPS?**

Not all woodchips are created equal. To allow the good, denitrifying bacteria time to remove the nitrate from the water, bioreactors are designed based on a specific flow rate of water that the woodchips allow (that is, hydraulic conductivity of the woodchips). Using chips that have many fine materials, shredded materials, dirt, and gravel can change this allowable rate of water flow, meaning the bioreactor may not work as intended. Currently chips used in bioreactor research have had the majority of the chips falling within the ¼-inch to 1-inch size range. Chips made from treated or preserved wood are not recommended because this limits the bacteria's ability to use the carbon in the wood. Also, including green material such as leaves or conifer needles is not recommended due to their relatively high nitrogen content and their potential to quickly be degraded. A number of other carbon source materials such as corn cobs, corn stalks, wheat straw, cardboard, and

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newspaper have been investigated, but research has recommended woody material because it provides a sustainable carbon source that lasts longer.

**WHAT IS THE LIFE OF A BIOREACTOR?**

Research has estimated bioreactor lifespans of 15 to 20 years, after which the woodchips would be replaced if treatment was to be continued. Because it is a new practice, no bioreactors have been in the ground long enough to have direct evidence of longevity. The oldest working denitrification system that treats septic wastewater was 15 years old in 2010.

**HOW MANY ACRES OF DRAINAGE CAN WE TREAT?**

Most current bioreactor designs have been successful at reducing the amount of nitrate in drainage from 30 to 80 acres. Some larger designs have been installed and are being watched closely for performance.

**INSTALLATION/OPERATION**

**ARE CERTAIN AREAS BETTER THAN OTHERS FOR WOODCHIP BIOREACTORS?**

Bioreactors are specifically designed to treat subsurface drainage water that contains high amounts of nitrogen as nitrate and that has relatively little sediment. These systems are not intended to treat runoff or water collected along terraces, and they work best in drainage systems that have few surface intakes. Many bioreactors in Iowa have been targeted for watersheds identified as having high nitrate in surface waters and having a large percentage of land drained. Though some bioreactors are lined, they may not be as effective in sandy areas because the drainage water being treated may leak into the surrounding soil and escape treatment. Also, considerations should be made for possible contaminants like the initial flushing of organics at each bioreactor regardless of location Fig 3 and 4

*Figure 3. Filling an excavation with woodchips for a bioreactor installation (courtesy of the Iowa Soybean Association Environmental Programs and Services)*

*Figure 4. Covering the woodchips with ageo-textile fabric before laying the soil cover at a bioreactor installation (courtesy of the Iowa Soybean Association Environmental Programs and Services)*

**HOW DO WE MANAGE THE BIOREACTOR? HOW MUCH MANAGEMENT IS REQUIRED?**

It is estimated that at minimum, twice per year the outlet control structure needs to have gates either raised or lowered. In the spring and early summer, when drainage water is typically flowing faster and in greater quantities, more gates should be lowered into the outflow structure to retain water for a longer time in the bioreactor. Later when drainage flow rates decrease, typically mid-July, these gates in the outflow structure should be removed so water can flow unimpeded through the bioreactor. The gates should be reinserted in late fall prior to spring drainage events or in anticipation of the possibility of late fall drainage. Management at each location will be site-specific and can vary from year to year. Ideally, periodic samples would be taken at the site to confirm bioreactor performance and help guide management decisions.

**WILL THE TILE BACK UP BECAUSE OF MY BIOREACTOR?**

The slope of the site will have the biggest impact on whether this is a significant issue. A small amount of backup will occur, especially at flatter sites due to the way the inflow control structure diverts water into the bioreactor. This has not been a significant issue at the installations in Iowa thus far. Landowners will get a feel for the number of gates or stop logs that can be

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comfortably lowered into the inflow control structure, and if they feel that the site is not draining properly, these gates can be removed.

**WILL THIS WORK ON AN EXISTING DRAINAGE SYSTEM?**

They are easy to install on existing systems, but the tile depth, diameter, and slope as well as tile connectivity need to be known. It also is helpful to have a good estimate of the drainage area for the system. All the bioreactors in Iowa to date have been installed on existing drainage systems.

**IS THERE A YIELD OR SOIL IMPACT, AND WILL A BIOREACTOR WORK WITH OTHERCONSERVATION PRACTICES?**

Because this is an edge-of-field practice, in-field yields will not be affected. Likewise, bioreactors will have no impact on soil quality. Other practices such as cover crops and adding perennials to a crop rotation can improve water quality while also maintaining or enhancing soil quality. One of the biggest benefits of bioreactors being on the edge of the field is that they are minimally impacted by what is done in the field. This means that other conservation practices such as no-till, cover crops, and improved nutrient management can be done in the field, and the bioreactor will continue to treat the remaining nitrate that is lost in drainage. Water Quality

**HOW MUCH NITRATE WILL A WOODCHIP BIOREACTORREMOVE? HOW BIG AN IMPACT WILL IT HAVE?**

A bioreactor's annual nitrate load reduction can range from about 10 percent to greater than 90 percent depending on the bioreactor, the drainage system, and the weather patterns for a given year. Based on research from Iowa, Illinois, and Minnesota, most bioreactors show performance of about 15 to 60 percent nitrate load removed per year. It may be best to target fields or watersheds that have higher nitrate loads in order to have the biggest impact.

**How do bioreactors compare to wetlands and other nitrate reduction strategies?**

Bioreactors and wetlands often are compared because both technologies provide edge-of-field or off-site treatment. In terms of percent reduction of nitrate loads, wetlands have been shown to have nitrate removal of 40 to 70 percent. Bioreactors have far smaller surface footprints than wetlands, but also receive drainage from far smaller areas; bioreactors will treat drainage from a field-sized area while wetlands will receive drainage from several thousand acres. Also, wetlands can be effective for other water pollutants such as sediment and can have many additional benefits for wildlife habitat and flood regulation. A number of other practices in addition to bioreactors and wetlands can help reduce nitrate export in drainage water. Several of these other options include improved nutrient management, cover crops, crop rotations that include perennials, and controlled drainage. In systems that are not tile-drained, nitrate could be moving to the stream via shallow groundwater flow. In those cases, buffers or prairie strips can help reduce nitrate export to the stream. The acceptability of any water quality practice will vary by individual producer and individual farm, and it is likely that a variety of practices applied across the landscape will be necessary to meet overall water quality goals.

**WILL THE BIOREACTOR REMOVE OTHER CHEMICALS?**

Woodchip bioreactors are specifically designed to reduce the amount of nitrate in drainage, and may not be effective for other pollutants such as phosphorus, pesticides, herbicides, and pathogens. However, the potential of bioreactors to remove some of these pollutants is an area of ongoing research.

**ARE THERE NEGATIVE SIDE EFFECTS?**

One of the first things a bioreactor owner may notice after installation is that the outflow water is tea-colored. This is because these first waters contain some of the most readily dissolvable organic material that will wash out in the initial weeks. This has been noted at nearly every site and could be minimized by holding back some drainage water in the field with the inflow control structure, and then allowing this accumulated water to flush through the bioreactor as quickly as possible. Another possible side effect is the export of methyl mercury. If the water stays in the bioreactor too long, all the nitrate will be removed through denitrification and other processes may begin. One of these processes involves the transformation of sulfate, which is naturally present in drainage water, to hydrogen sulfide gas. The bacteria that perform this process also are involved in transforming mercury in the water or the chips to a toxic form called methyl mercury. This concern can be minimized be managing the bioreactor closely during low flow periods and monitoring for a rotten egg smell (hydrogen sulfide); if this smell is detected, the outflow control structure should be lowered to allow water to move unimpeded through the bioreactor. The last concern may be the production of

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nitrous oxide, a greenhouse gas, which is a natural by-product of this denitrification process. Research suggests that nitrous oxide emissions from bioreactors are a very small percentage of the nitrate entering the systems. Though it is thought these concerns may be minimized through good design and management, research still is ongoing.

**HOW MUCH DO THEY COST? WHO WILL HELP PAY?**

Most bioreactor installations in Iowa have been in the range of $7,000 to $10,000 in order to treat drainage from about 30 acres to over 100 acres. In Iowa, the Environmental Quality Incentive Program (EQIP) allows cost sharing for about half the installation cost of this water quality practice. In 2011, the EQIP practice code
747 for denitrifying bioreactors specified $3,999.50 as a one-time installation payment. Also, location within a watershed that has an organized watershed group may help increase a landowner's chances of finding other funding.(Fig 5).

***Figure 5. Woodchip bioreactor after installation; circular sumps and PVC wells used for research monitoring (Northeast Iowa Research and Demonstration Farm)***

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