Woodchip Denitrifying Bioreactors for Nitrate Removal from Tile Drainage Water

Nitrate loss from tile drained corn-soybean fields is a major contributor to water quality problems. Woodchip denitrifiying bioreactors is a new approach to reducing nitrate losses that does not require taking cropland out of production.

Statement of the problem: Tile drainage water from corn and soybean fields typically has nitrate-N concentrations that range from 10 to 30 parts per million N, which exceeds the maximum contaminant level for drinking water and contributes to impaired water quality for the cities of Decatur, Danville and Georgetown, Illinois and Des Moines, Iowa. Additionally, the nitrate loads from tile drained regions in the Midwest disproportionately contribute to the formation of bottom water hypoxia (also known as "the dead zone") in the northern Gulf of Mexico. Careful management of fertilizer and manure nitrogen can reduce tile water concentrations and loadings and maximize farmer profits. However, economically efficient fertilizer and manure management alone is not likely to provide enough reduction to fully address these water quality problems. Even with the most finely tuned management of nitrogen fertilizer, nitrate losses from tile drained fields can be large, especially following low corn yields that may be due to factors such as drought, wind damage, disease or insect infestations. Seed corn production can produce large nitrate N losses under most conditions because harvested seed yields are usually low in comparison to the N fertilizer applied.

In addition to employing the most efficient fertilizer management practices, farmers, landowners and land managers could also consider whether denitrifying bioreactors might be compatible with their landscape and farming operations. In central Illinois, a 2,100 square foot woodchip bioreactor is expected to remove an average of about 30% of the nitrate-N in tile drainage water leaving 20 acres of tile drained corn and soybeans, if the inlet concentration averages 30 parts per million N. They are usually designed as a rectangle, so a typical design might be 30 by 70 feet.

How do they work?

Bioreactors remove nitrate by providing conditions favorable for microbes that can remove some or all of the oxygen from nitrate, converting the nitrogen into gaseous forms. This process is called denitrification and the microbes responsible for it are called denitrifiers or denitrifying bacteria. After removing the oxygen from nitrate, the denitrifiers usually emit inert and harmless di-nitrogen gas (N_2), which makes up 79% of the Earth's atmosphere. However, under some circumstances not all the oxygen is removed and nitrous oxide (N_2O) can be released, which is a potent and undesirable greenhouse gas. In field measurements made to date, little N_2O release from bioreactors has been found.

Denitrifiers require readily digestible carbon as a food source and an absence of dissolved oxygen (also called anaerobic or anoxic conditions). When oxygen and digestible carbon are in water, a wide variety of micro-organisms will feed on the carbon and utilize the dissolved oxygen for respiration. Since oxygen is not very soluble in water, an abundant supply of carbon (as found in wood chips) can quickly deplete and eliminate dissolved oxygen in water passing through the bioreactor, thereby creating anaerobic conditions. In these conditions, the denitrifying microbes utilize the oxygen portion of the nitrate for respiration, rapidly converting the nitrate to gaseous forms in the process.

The percentage of nitrate removed in bioreactors depends upon the temperature, the quality of the carbon available to the denitrifiers (fresh softwood chips are more readily available than hardwoods) the nitrate concentration of the drainage water, and how long the water resides in the bioreactor (called residence time). The residence time will vary depending on the volume of the bioreactor and the rate of incoming drainage water. Residence times are shorter when inflow rates are higher, and thus a smaller percentage of nitrate will be removed during these events. Rainfall events that produce low rates of drainage will result in longer residence times, and thus a greater percentage of nitrate removal. At high flows bioreactors are designed to allow the tile water to bypass the woodchip bed. This allows for efficient tile drainage, but limits nitrate removal. In a given year, the percentage of nitrate removed will vary depending on the timing and amount of rainfall and drainage events.

The activity of the microbes and the rate of nitrate-N removal also depends upon the water temperature. Consequently nitrate removal rates in winter and early spring tend to be much lower than in late spring and summer.

What are appropriate locations for bioreactors?

Bioreactors for treatment of tile drainage water are most conveniently located in a vegetated riparian buffer near a tile drain outlet so as to not interfere with the existing crop management practices.

How are bioreactors designed and constructed?

Bioreactors are essentially shallow water holding basins filled with wood chips. By considering the drainage area, soil types and rainfall frequencies, the bioreactor can be designed so that the average water residence time achieve a desired percentage of nitrate removal. Technical design procedures are described on the University of Illinois web site: http://web.extension.illinois.edu/bioreactors/design.cfm.

Earthmoving is required to excavate a pit and install a water level control structure.

How much do they cost?

The costs of bioreactors include construction, additional tile, control structures and wood chips. If cropland is not taken out of production, which is often possible, there would be no costs for land or lost crop revenues. The cost of excavation and woodchips will depend upon the specific design and local markets.

What management is required?

Periodic inspections are needed to ensure that water and wood chip levels are appropriate. The wood chips will decompose over time and additional wood chips should be added to maintain the supply of carbon for the microbes.

Do bioreactors provide any benefits besides nitrate removal?

Bioreactors generally do not provide any benefits besides nitrate removal. If wildlife benefits are of interest, constructed wetlands should be considered, but these require more land area, which contributes to higher costs if high yielding cropland is taken out of production.

Are there any problems caused by bioreactors?

Bioreactors may contribute to increased losses of phosphorus, which often promotes unwanted algae growth. There is also little or no oxygen and an initial flush of dissolved carbon in the outflow from bioreactors. More research is needed on these topics. Bioreactors are a relatively new technology and ongoing research is likely to provide more effective designs in the future.

Where can I find out more information?

Illinois Loss Reduction Strategy

http://www.epa.illinois.gov/topics/water-quality/watershed-management/excess-nutrients/nutrient-loss-reduction-strategy/index

USDA NRCS https://efotg.sc.egov.usda.gov/references/public/IL/605_6-20-16.pdf

University of Illinois Extension http://web.extension.illinois.edu/bioreactors/bioreactors.cfm

http://www.wq.illinois.edu/DG/Equations/trifold_Bioreactor.pdf

Iowa State University Extension http://www.extension.iastate.edu/article/tool-nitrate-treatment-highlighted-new-fact-sheet

Purdue University Extension https://engineering.purdue.edu/watersheds/conservationdrainage/bioreactors.html

This fact sheet is based on research partially supported by the National Institute of Food and Agriculture, USDA, under Agreement No. 2011-039568-31127 to the University of Illinois at Urbana-Champaign.