

Removal of Nitrogen and Phosphorus From Tile Drainage Water

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Seminar Outline

Today's seminar will cover the following topics, which influenced my decision to choose a Learning Module for my Creative Component:

- Background information
- Why a Learning Module
- Module Contents
- Sample Quiz Questions
- Questions/Open Discussion



Spring tillage, April 2016



Over seeding hay fields with a no-till drill
August 2014

Background Information

Owner, operator of Alfisol Acres, LLC

- Based in Morrisville, NY
- 300 acre crop/livestock farm
- 240 acres of hay
- 60 acres of oats
- 450 taps for maple syrup production
- 30 head, commercial cow/calf Hereford/Angus beef herd
- Converting to grass fed cow/calf/finish operation
- Incorporating no-till while phasing out all tillage operations
- Grid sampling for soil testing
- Tile drainage in use



Tile installation, November 2015



Baling hay, May 2014

Background Information

Credit Representative, Farm Credit East, ACA

- \$67MM Loan Portfolio
- Specializing in credit delivery and loan underwriting
- Serving over 400 farms in Madison, Chenango, Otsego, and Herkimer Counties in Upstate New York
- 60% dairy
- 17% cash field
- 11% livestock
- 5% timber
- 7% other



Why a Learning Module

A learning module provides a useful tool for others to learn from and expand their knowledge on the topic of nitrogen and phosphorus losses in tile drainage. Although my farm only uses spot tiling in areas of sporadic flow that are not conducive to bioreactors, water quality is becoming an increasingly scrutinized aspect of modern agriculture and therefore, this module can help myself and other producers make informed decisions when tiling and fertilizing cropland in order to reduce our impact on the environment. Lastly, this module will provide a lasting reference that can be used by anyone interested in learning about nutrient losses in the field.



A view of the farmstead, August 2015

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Picture demonstrates several conservation practices, including contour farming, terraces which follow the topography of the land, riparian zones and grass waterways. These practices are designed to prevent soil erosion by slowing surface waters and filtering soil before it reaches surface waters. Photo courtesy of Iowa State University.

Introduction

Agricultural tile drainage plays an important role in managing soil water for optimal crop growth by artificially lowering the water table in the field.

Leaching of water soluble nutrients, such as nitrogen (N) and phosphorus (P), can lead to excessive concentrations in tile drainage discharge water.

Soil is able to store nutrients based on the charge exhibited by the nutrient and to release them based on the nutrient saturation level and through biological and chemical processes that can change the chemical state of the nutrient.



The above picture shows a farmer topdressing granular urea fertilizer at approximately V5 corn stage with the use of a nitrogen stabilizer, specifically a urease inhibitor, to slow the conversion of ammonia to nitrate and allowing the corn plant to utilize more of the nitrogen. Nitrate is the most susceptible form of nitrogen prone to leaching and reaching tile drainage discharge water. Courtesy of Michigan State University and USDA NRCS.

Introduction

The two primary nutrient pollutants that are reaching surface waters via agricultural drainage tile are **nitrogen** and **phosphorus**. In high concentrations, these nutrients stimulate algae growth which also consumes the available oxygen in these aquatic systems.

One of the most recognized instances of this situation is the “**dead zone**” in the Gulf of Mexico. This is due to the massive watershed that the Ohio and Mississippi River basins drain and subsequently terminate in the Gulf of Mexico.

This “dead zone” is a hypoxic environment which does not support aquatic marine life, of which many species are relied upon for commercial fishing.



The above picture was taken by NASA from a satellite in space showing the hypoxic zones in the Gulf of Mexico due to excessive nutrient discharges from the Mississippi River. Notice the green algae blooms near the coast compared to the normal deep blue water color as your progress further from the shore line. Courtesy of University of Nebraska at Lincoln (2013). Image by NASA.

Introduction

This module provides a brief background on the principles of agricultural tile drainage, the conditions in which nutrients are most susceptible to leaching, and strategies to reduce nutrient losses. The primary topic of discussion will be the use of denitrifying bioreactors and phosphorus sorption technologies for removing these nutrients from tile drainage water before it is discharged into surface waters.



Woodchip denitrifying bioreactors are an available tool for farmers to use in the reduction of nitrates from tile drainage water. The above picture demonstrates the construction of a bioreactor in a farm field. Photo courtesy of Iowa Soybean Association Environmental Program and Services.

Objectives:

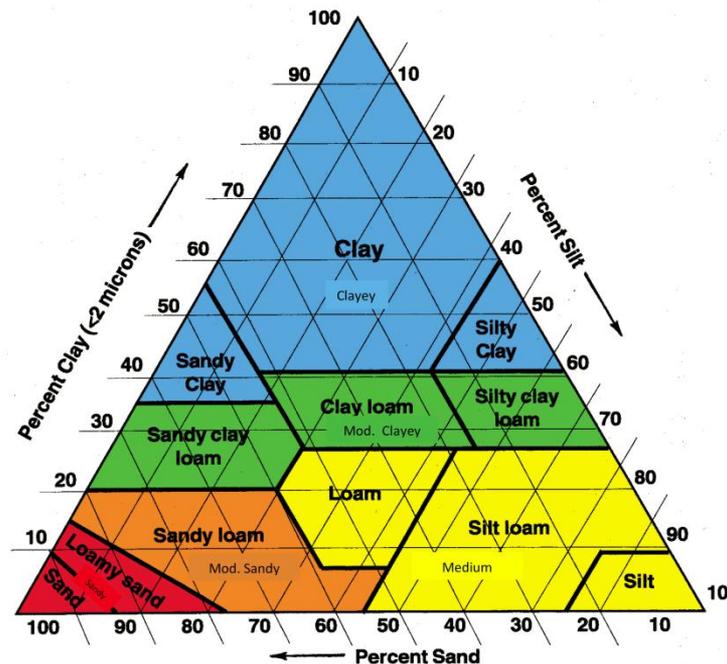
1. To describe how soil properties, nutrient type, and field water influence nutrient stability and availability in the soil profile.
2. To differentiate the chemical and biological processes used to remove nitrogen and phosphorus from tile drainage water (denitrifying bioreactors and phosphorus sorption beds).
3. To become familiar with best management practices to reduce the likelihood of nutrient loss and improve crop nutrient use efficiency (4R concept).

Soil

Soil Characteristics

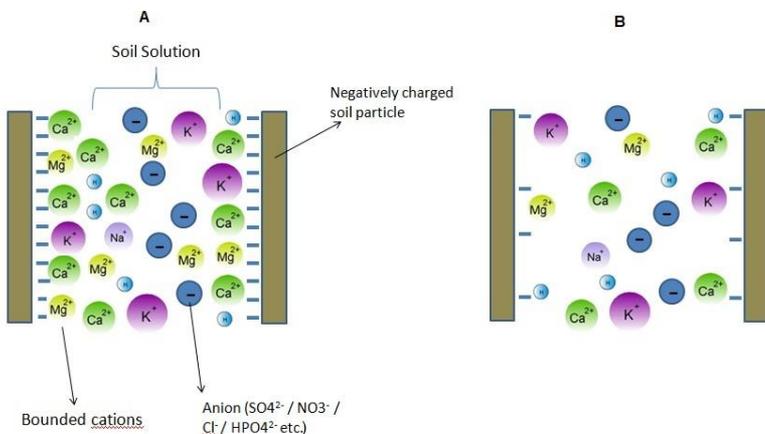
Soil texture is characterized by the percentage of clay, silt, and sand present in a soil sample.

Clay and **organic matter** both carry a net negative charge which attracts nutrients with a positive charge. This is what gives soil its nutrient holding capacity and is described as **CEC (Cation Exchange Capacity)**. Nutrients that carry a negative charge will be repelled by soil particles and are thus, mobile in the soil.



A soil triangle is used to describe soil textures. Courtesy of <https://ag.purdue.edu/agry/agryclub/PublishingImages/Textural%20Triangle%20Final.jpg>

CEC (A) > CEC (B)



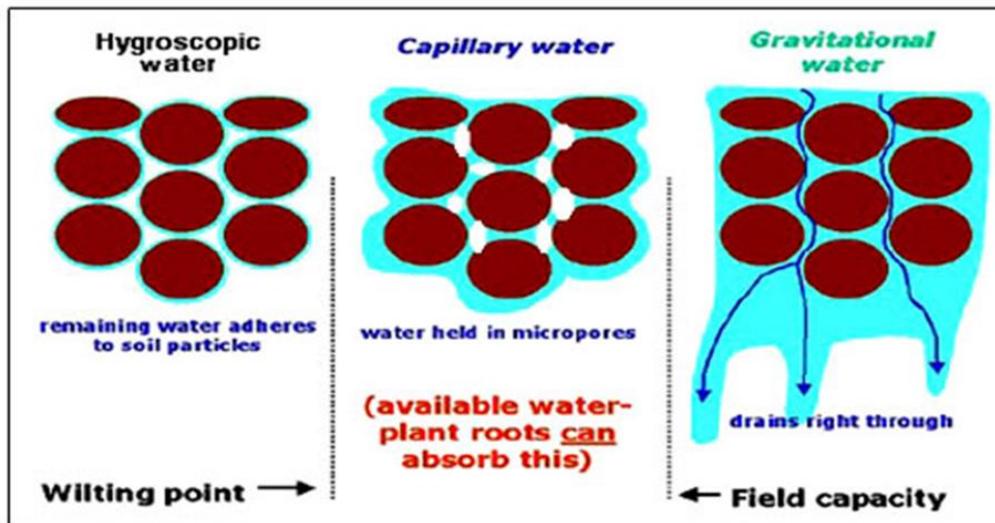
Soils with different CECs will bind the positively charged cations on to negatively charged soil particles. Negatively charged anions of sulfur (SO_4^{2-}), nitrogen (NO_3^-), and phosphorus (HPO_4^{2-}) will not bind to the negatively charged soil particles, but will move through the soil. Soil A has a higher CEC (more negatively charged sites on the clay) so more of the positively charged cations will bound to that soil compared to soil B which has a lower CEC – fewer negatively charged soil particles.

Soil

Soil Water Characteristics

Water moves in soil based on concentration gradients.

Hygroscopic water is plant unavailable due to the tight adhesive bond it forms with soil particles. As water content increases in the soil, water molecules form **cohesive bonds** with each other which overcome the **adhesive bonds** with soil particles. This **capillary water** is held in the **micropores** between soil particles and is plant available. When soils become saturated with water, gravity overcomes both adhesive and cohesive forces pulling water deep into the soil profile (**gravitational water**).



Picture from: www.growflow.com.au

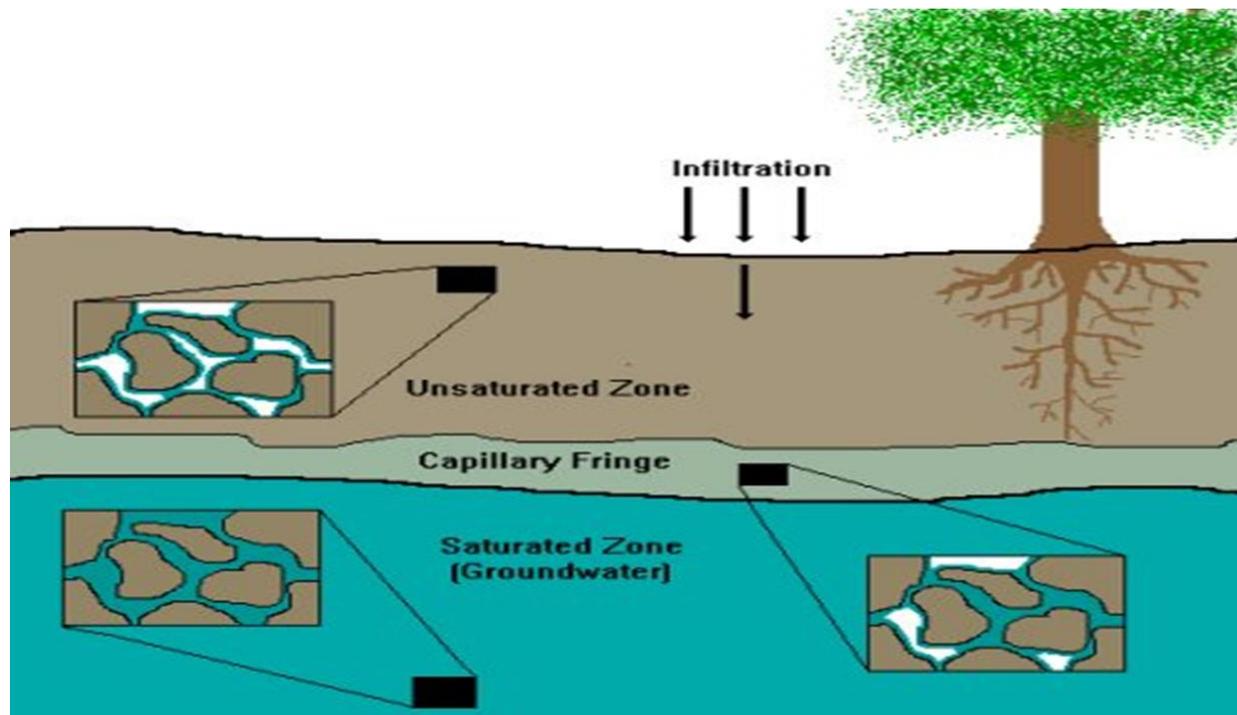
Soil

Soil & Water Profile

The picture shows the typical profile of water in soil. The **capillary fringe** is the point where **diffusion** causes water movement from the **saturated zone** (high water concentration) to the **unsaturated zone** (low water concentration).

Tile acts much the same way as water moves towards the dry zone around the tile. Restrictive layers, such as bedrock, a plow pan or a clay hard pan, can stop water movement in the soil profile.

Soil particle size influences water holding capacity and movement. Small particles, such as clay, have more surface area, therefore they hold more water.



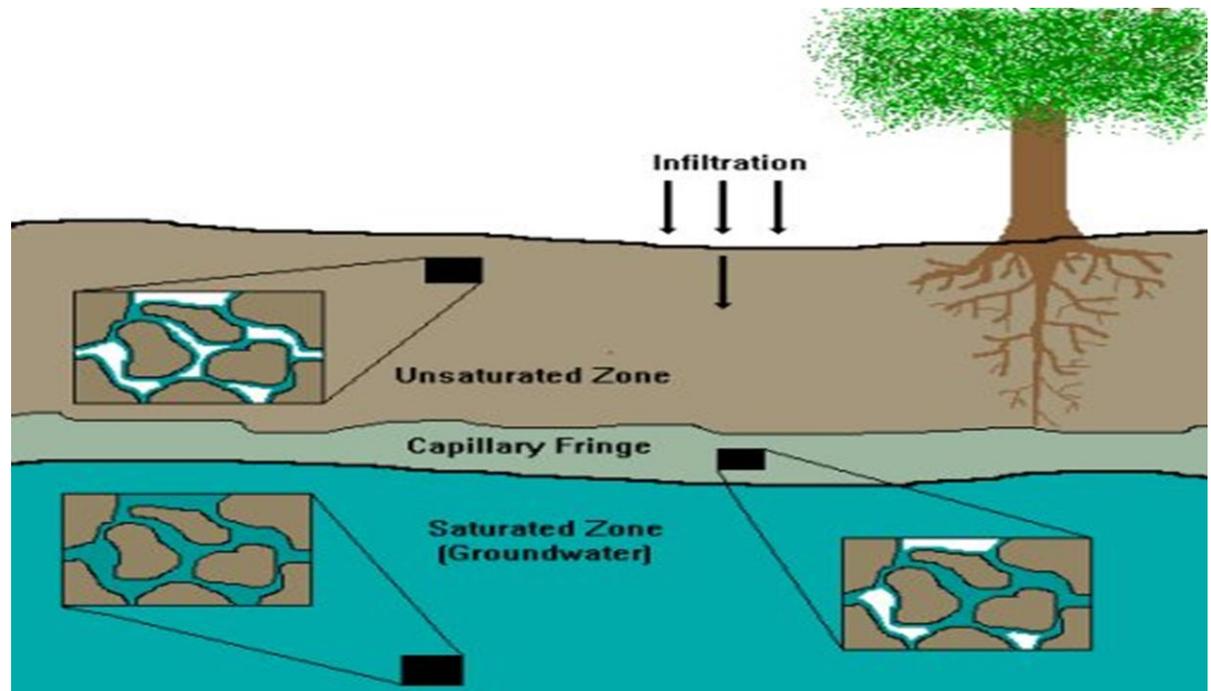
Soil

Soil & Water Profile

Water from precipitation enters the soil through **infiltration** via the macro-pores in the soil. The **unsaturated zone** exists when the macro-pores between soil particles are not completely filled with water. Below the unsaturated zone is the **saturated zone** - the area where all soil macro-pores are filled with water. This is where the **water table** is located.

Between the two zones lies the **capillary zone** - the area where water moves via diffusion from the area of high water concentration (saturated zone) towards the surface into the unsaturated zone.

This concentration gradient is why water moves against gravity into the unsaturated zone.



Soil

Soil Drainage Classes

Soil drainage classes are designated 1-7, 1 being very rapidly drained to 7 being very poorly drained: (click on each of the soil drainage classes to read the USDA's Soil Taxonomy for each - <http://www.css.cornell.edu/courses/260/Lab%20Hydric%20Soils.pdf> .

1. Excessively drained
2. Somewhat excessively drained
3. Well drained
4. Moderately well drained
5. Somewhat poorly drained
6. Poorly drained
7. Very poorly drained

The diagram on the following slide starts at class 3 (well drained) and shows how soil color and texture can be indicative of drainage.

Understanding the soil drainage class of your soil type influences the type of drainage chosen, including the spacing of tile lines. Standing water kills roots due to a lack of oxygen, so understanding drainage class is very important when choosing what crops to plant and how drainage will affect yield.

Soil

Soil Drainage Classes

The **depth of the root zone** is clearly influenced by the depth of the water table in the soil profile. Roots will not grow past the water table due to a lack of oxygen in the soil profile. The lack of oxygen forms a **hypoxic zone** (lacks oxygen) and causes chemical reactions with the soil, as noted by the change in color.

This is the result of chemical reactions in the soil in which certain elements, such as iron (rusty stain) and clays tend to form horizons in the soil.

The clay becomes grayed and exhibits a dark brown to gray color as it forms a separate layer or horizon in the soil.

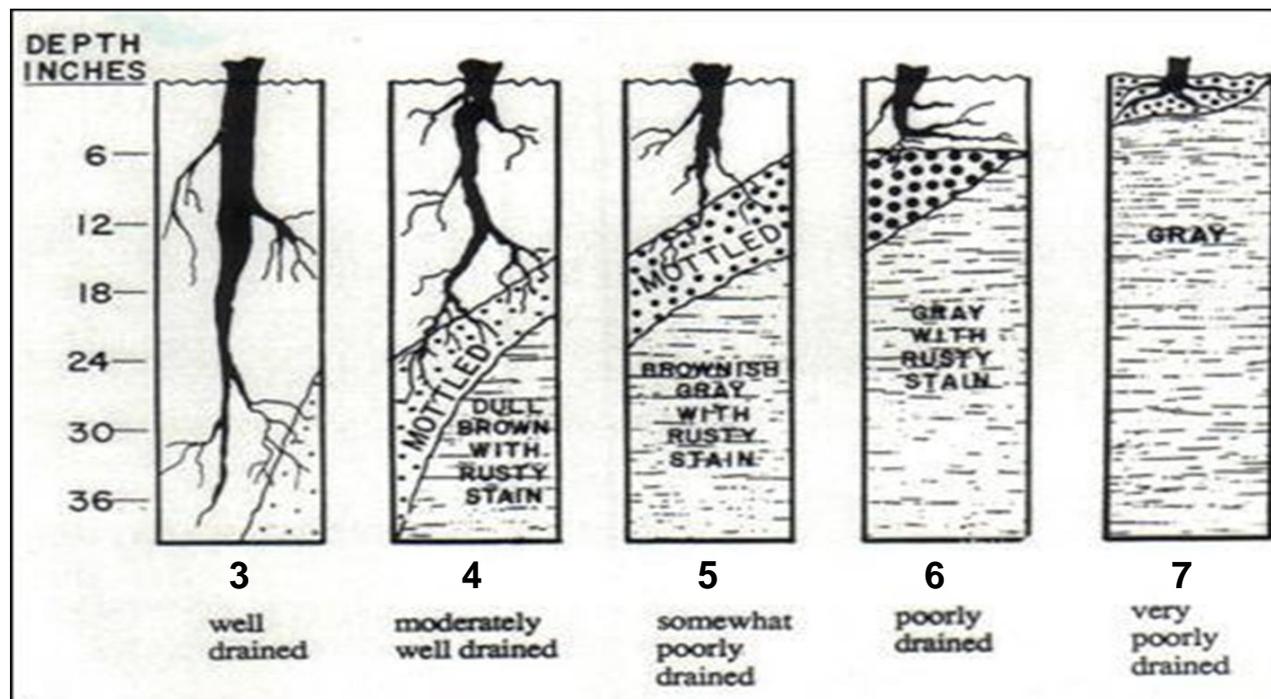


Image source: NRCCA Soil Water Management Study Guide. Cornell University - <http://nrcca.cals.cornell.edu/soil/CA3/>

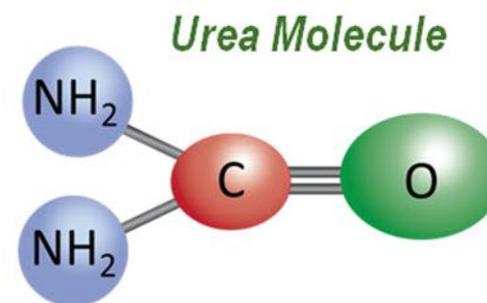
Soil Nutrients

Nitrogen

Nutrients such as **nitrogen** can change form through chemical and biological processes. By understanding the type of charge each form of nitrogen fertilizer carries, one can choose the appropriate form to reduce the likelihood of **leaching**, **denitrification** or **volatilization**.

It is important to understand the charge on nitrogen molecules, as this dictates the pathway towards plant uptake or losses into the environment.

Positively charged molecules, such as ammonia (NH_4^+), can bind with negatively charged soil particles which reduces losses. Negatively charged molecules (nitrate – NO_3^-) can be lost into the environment as gases (nitrogen gas - N_2) or via soil water.



Urea molecule containing two nitrogen atoms.
Dupont Pioneer. 2016

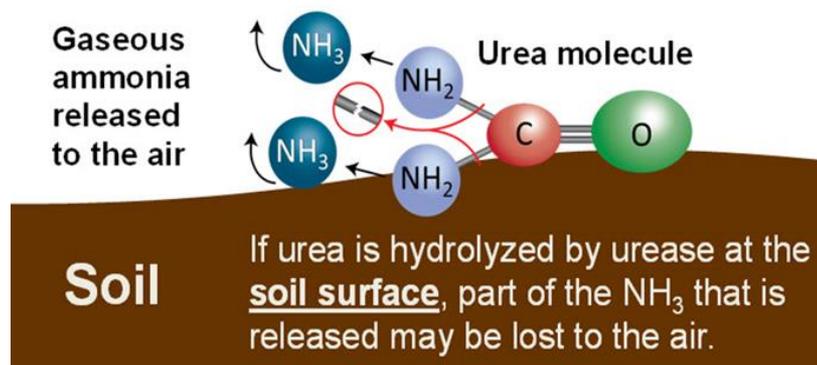
Soil Nutrients

Nitrogen

Mobile nutrients in the soil are water soluble and will have a tendency to leach as water moves through the soil profile. Nitrate (NO_3^-) losses from leaching into tile drainage can amount to 10-40 lbs/A/yr in humid, high rainfall environments (>25 inches/yr.) which stresses the need to apply the correct form of nitrogen fertilizer at the right time in order to minimize losses (The Fertilizer Institute, 2013).

Nitrogen can be lost to the environment through several processes depending on the type nitrogen molecule. Anhydrous ammonia is a commonly used nitrogen source due to its low cost and high nitrogen content. In order to minimize the escape of gaseous NH_3 into the air, this fertilizer is typically injected into the soil at a depth of 6-8 inches where it quickly reacts with soil water to form ammonium (NH_4^+) ions.

The positively charged molecule (NH_4^+) can then bind with negatively charged clay or organic matter particles where it is stored in a plant available form and is not susceptible to leaching. Conversely, urea reacts to form **gaseous ammonia** or NH_3^- which is either taken up by plants or lost into the atmosphere as a **gas** (NH_3^-) or into the **ground water** (NH_3^-) due to the negative charge which prevents it from binding with soil particles.



Pictured above: Volatilization of urea into ammonia gas. From Dupont Pioneer.

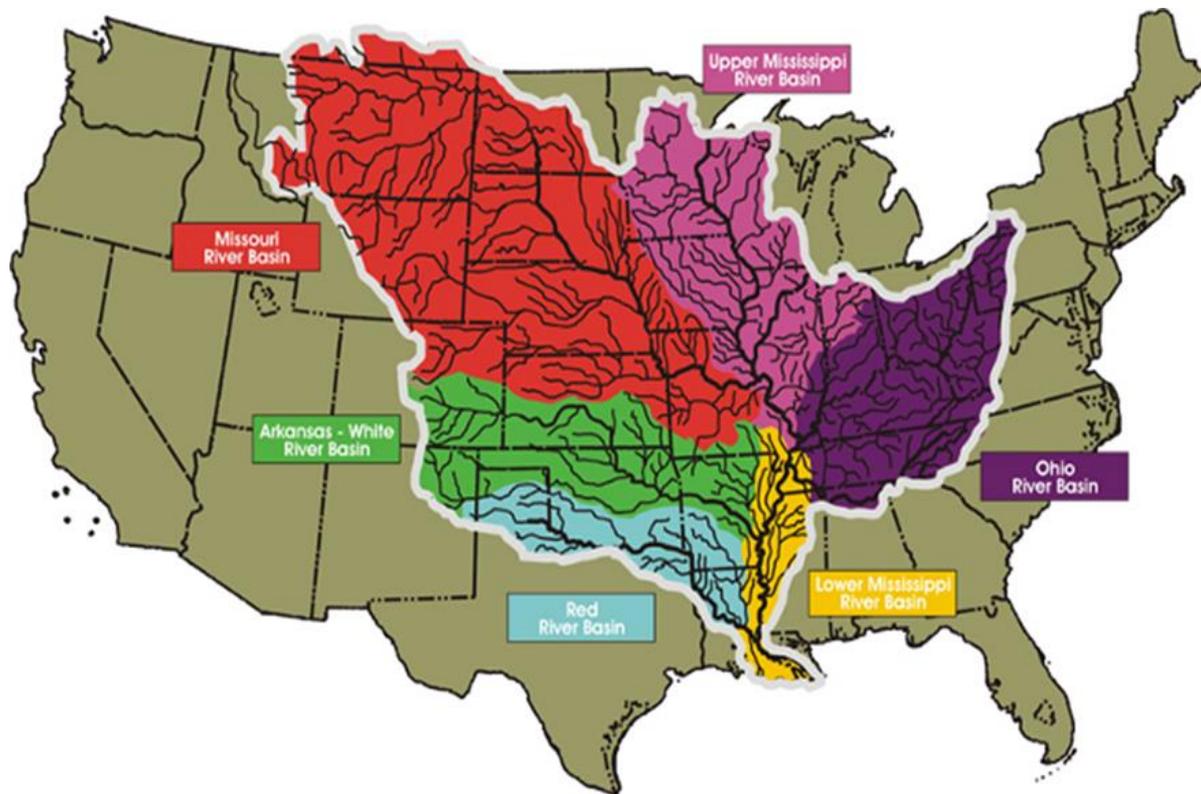
Soil Nutrients

Phosphorus

It is important to understand the primary pathway of **phosphorus** loss is **soil particles**.

Phosphorus is fixed to soil particles and it is the loss of soil particles due to erosion that transports sediments, and thus phosphorus, to waterways.

A common misconception with phosphorus is the pathway it takes. Phosphorus is bound to soil and considered immobile. This means it is not suspended in soil water and the primary pathway for losses is erosion as it moves with soil particles.



The above picture shows the Missouri River, Arkansas-White River, Red River, Upper Mississippi River, Lower Mississippi River and Ohio River Basins which feed into the Mississippi River, eventually terminating in the Gulf of Mexico. This vast area of land drainage shows the impact of agricultural practices on the Gulf of Mexico and the importance of environmental stewardship by farmers. Courtesy of U.S. Army Corps of Engineers. 2016.

Soil Nutrients

Phosphorus

Since the primary loss of phosphorus is due to soil loss, erosion control is the best defense against phosphorus losses. This can be accomplished through practices, such as no-till, minimum tillage, high residue practices, vegetative filter strips, grass waterways or sediment ponds. This prevents the soil particles from reaching surface waters.

Practices that reduce soil loss due to erosion will have the biggest impact on reducing phosphorus losses. Practices that reduce soil disturbance and the likelihood of erosion should be implemented as **Best Management Practices (BMP)**. Tillage destroys soil structure because it breaks up soil aggregates which stabilize the soil structure and hold nutrients. Good soil aggregation leads to increased infiltration and reduced runoff since water enters the soil profile instead of staying on the surface and eventually reaching surface waters.



No-till soybean in corn residue where a significant amount of crop residue remains on the soil surface, protecting the soil from water erosion and improving soil tilth.

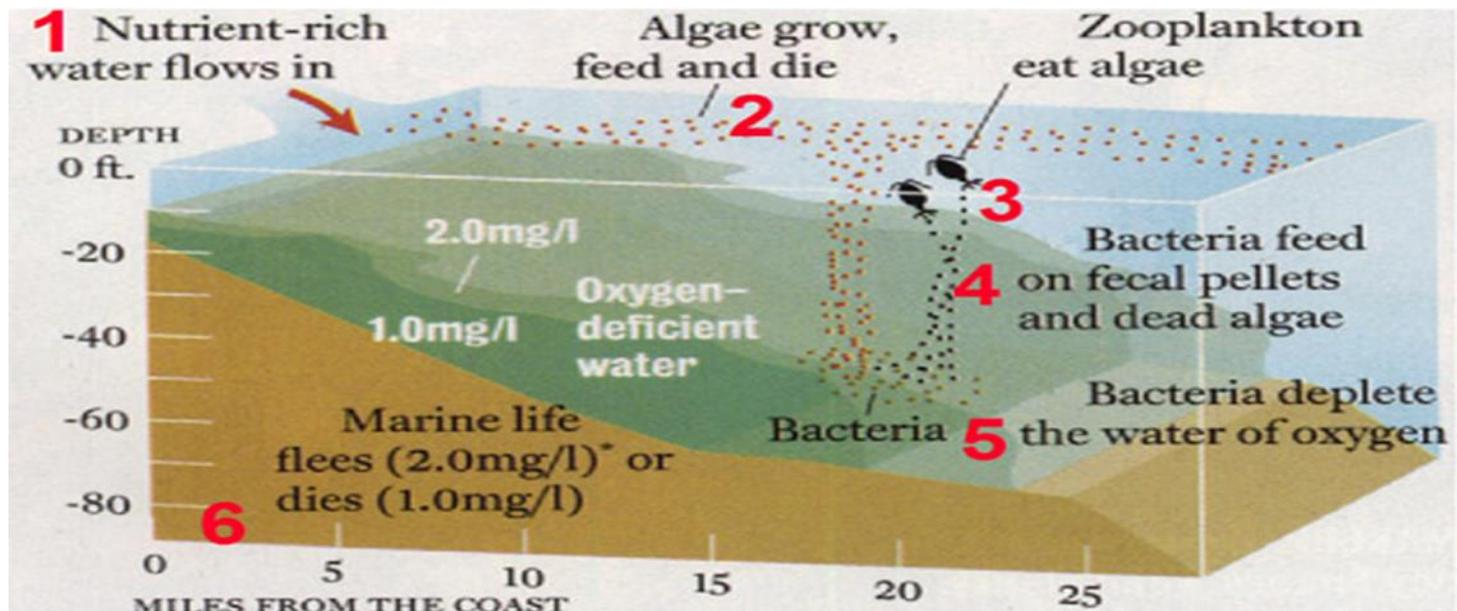


Grass waterway protects soil from eroding.
<http://www.iasoybeans.com/Waterquality/images2/Grassed%20Waterway-1sm.jpg>

The “Dead Zone”

Excessive concentrations of nitrogen and phosphorus being discharged by the Mississippi River into the Gulf of Mexico have led to large, oxygen-depleting algae blooms which consume these nutrients and then either are consumed by zooplankton or die and settle at the bottom of the seafloor.

Bacteria consume the dead algae and fecal waste pellets of the zooplankton which requires large amounts of oxygen and subsequently results in **hypoxia**, or low dissolved oxygen in the water (GulfHypoxia.net, 2013).



Nutrient-based hypoxia formation from <http://www.gulfhypoxia.net/Overview/>.

The “Dead Zone”

Economic Impact

The commercial fishing industry is worth over \$650MM to the U.S., with brown shrimp being one of the most valuable. One study indicated up to a 25 percent loss of shrimp habitat on the Louisiana shelf in the Gulf of Mexico (Iowa State University, 2008).



Brown shrimp.

http://gulffishinfo.org/DesktopModules/DNNTaskManager/Images/54/54BrownShrimp_Added1_900.jpg



Shrimp trawler. Photo courtesy of Robert K. Brigham, NOA A Photo Library.



The “Dead Zone”

Nutrient Management with Drainage

Soil nutrients that leave the field can be managed in many ways to prevent them from entering surface waters.

- **Wetlands** are nature’s natural water filters.
 - Provide a natural filter for surface waters as they reduce flow velocity, allowing soil to settle out, in addition to supporting plants which absorb excess nutrients.
- **Grass waterways** and other vegetation filter soil and nutrients.
 - Reduce flow velocity and provide settling points for soil.
 - Vegetation (plants) take up the nutrients and in many cases the grass can be cut for hay during dry periods in the summer.
- **Carbon based bioreactors** remove nitrogen.
 - Bioreactors are installed at the outlet of drain tile and use woodchips. Bacteria require nitrogen to break down the carbon in the woodchips, thereby removing it from the water. They rely on the C:N ratio of the woodchips (C) and drainage water (N).
- **Lime beds** to filter phosphorus.
 - Phosphorus binds with calcium in the lime and is immobilized. It then settles out as a solid.

The “Dead Zone”

Compliance Issues Pertaining to Drainage

- Always check with your local NRCS agent before starting a drainage project.
- Draining of wetlands is highly regulated and in most cases prohibited.
- Nutrient discharge is becoming increasingly scrutinized.
- Waters of the U.S. are presenting major problems for farmers due to its overreaching definition of “navigable waters of the U.S.”

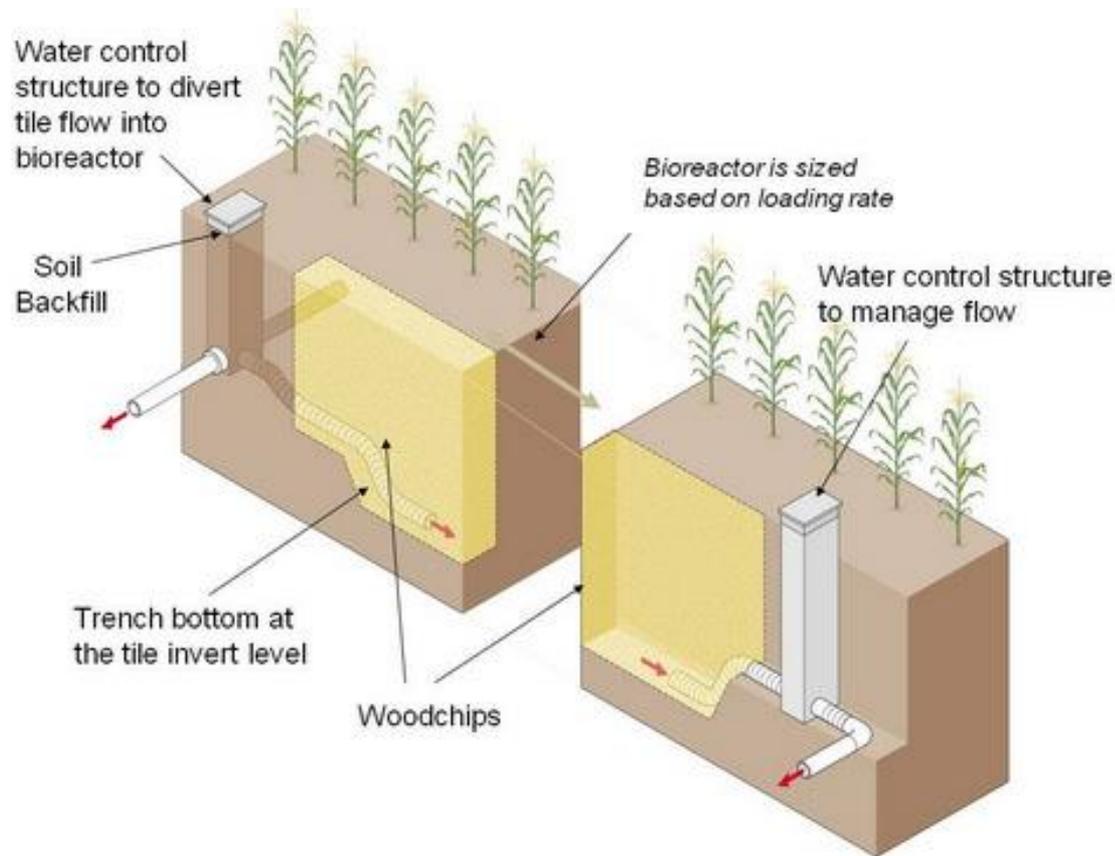
Your local NRCS agent can aid in the planning and implementation of a drainage project. If you start a project and are found to be in violation of laws regulating drainage, you could face large fines. Wetlands are highly regulated and their conversion to cropland is prohibited almost in entirety. Nutrient discharges from farms are becoming increasingly scrutinized by the EPA, and could become a compliance issue in the near future as a non-point source pollutant.

Denitrifying Bioreactors

Denitrification is a natural process and denitrifying bioreactors aim to raise the rate of denitrification above normal background rates.

Bioreactors contain large volumes of **carbon** (wood chips) which bacteria breakdown.

Bacteria rely on nitrogen for this process and the result is a significant reduction in nitrates in drain tile water.



Courtesy of Purdue University. 2016.

Denitrifying Bioreactors

Primary Carbon Choice

Woodchips are the primary carbon choice to be used in the bioreactors and the size and variety of wood used influences the rate of flow for water through the reactor and the efficiency of the bacteria.

The recommended size for the woodchips is $\frac{1}{4}$ to 1 inch in size. Smaller woodchips provide more surface area for bacteria to attach to, but will decompose faster, thus the reasoning for a variation in size is to allow for a longer useful lifespan of the bioreactor.

The variation in woodchip size also allows for improved water flow through the material.



Woodchips commonly used in woodchip bioreactors. Photo courtesy of Iowa State University.

Denitrifying Bioreactors

Bioreactor Development

To build a bioreactor, a pit is excavated and filled with woodchips with tile drainage water flowing through the woodchips. A typical reactor is 100-120 feet long by 10-25 feet by 3-6 feet deep and will typically support 30-100 acres of drained land. The pit is lined with plastic fabric in order to contain the drainage water in the reactor. Lastly, an inflow gate is added to divert water into the reactor while allowing a bypass for high flow events. An outflow gate controls the depth of the water and retention time in the reactor.



Excavating the bioreactor bed with the control box installed in the foreground.



A final layer of plastic is installed over the woodchips and will be backfilled with dirt to complete the bioreactor.



The bioreactor is lined with plastic and woodchips are filled and packed with a bulldozer.

All photos courtesy of Iowa Soybean Association.
http://www.iasoybeans.com/environment/sites/default/files/IMG_0201.JPG

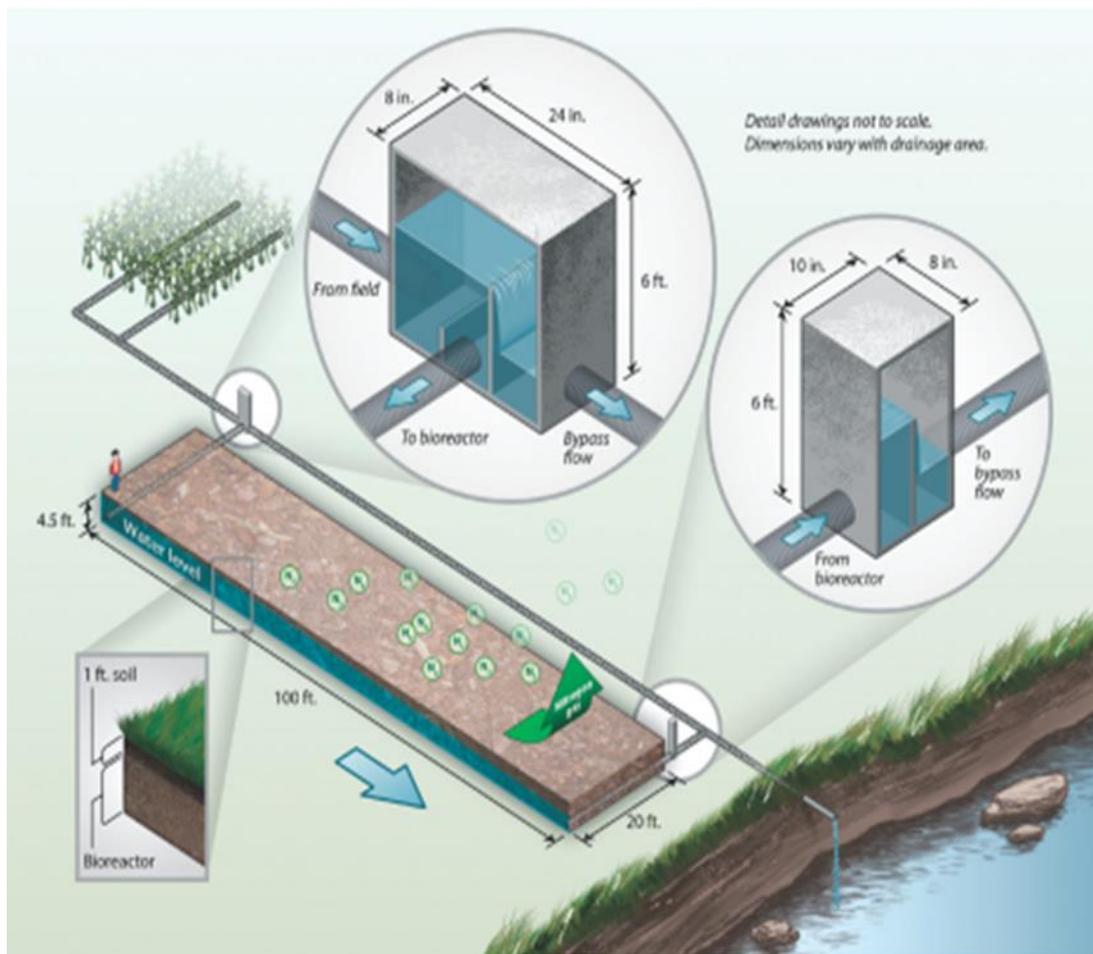
Denitrifying Bioreactors

Control Boxes

The use of a **control box** can help manage water table levels at different times of year in the fields. This can allow the operator to adjust the water table higher or lower in the fields.

These control boxes also become important in periods of high flow because they allow some water to bypass the reactor and prevent water from backing up into the fields.

This picture shows how the water level is controlled with gates in the control boxes, allowing diversion into the reactor and bypass of drainage water during high flow events.



Picture courtesy of Iowa State University Extension. Image by John Petersen.

Denitrifying Bioreactors

Cost of Bioreactors

Costs of bioreactors and their useful life vary depending on the resources available to the farmer and the design of the bioreactor. Cost per cubic foot ranges are \$0.35-\$0.55 depending on whether the farmer has to rent a backhoe for constructing the reactor and other incidental costs.

The primary factor determining the useful life of the reactor is the saturation of the woodchips with the tile drainage water. The immersion of the woodchips in water prevents degradation of the woodchips by reducing their exposure to oxygen. The typical lifespan of bioreactors is 10-25 years depending on the size of the woodchips, saturation periods in the reactor, and the nitrate content of tile water.



The above pictures show the movement of woodchips to the bioreactor. These photos are courtesy of Iowa State University; Ag Water Management Research Group.

Denitrifying Bioreactors

Site Considerations

Generally, fields with constant flow of tile water in lines with a diameter of 6-10” are treated with bioreactors. Constant flow is important to keeping the woodchips submerged in tile water. Tile lines with sporadic flow are not good candidates for bioreactors since the woodchips will be exposed to air during times of low or no flow, reducing the useful lifespan of the reactor.

The bioreactor should be located in areas with a naturally low water table. In areas with a high water table (less than 3 feet from the surface), the bioreactor can be flooded with groundwater, forcing tile water to bypass the system. This negates the intention of the bioreactor. Though more costly, sealed concrete reactors can be used in these sites, but at a much greater construction cost.

Lastly, the site of the reactor should have minimal change in elevation in order to ensure the diversion of water in and out of the bioreactor.

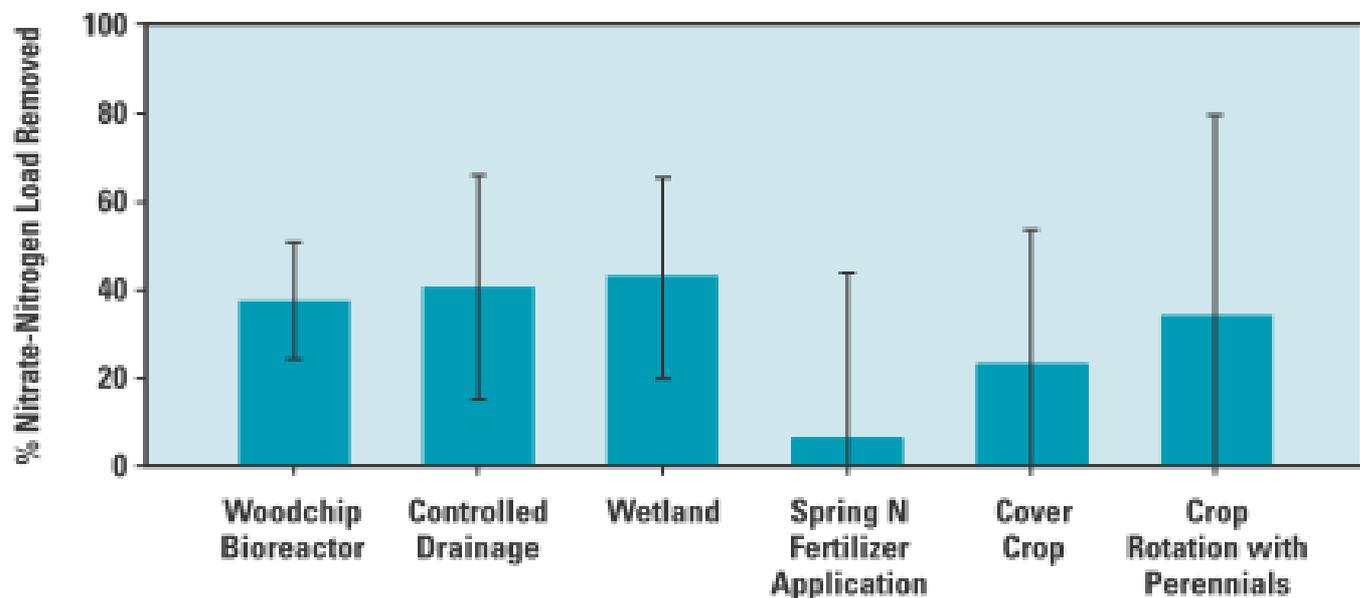


The above picture shows a completed bioreactor at the Northeast Iowa Research and Demonstration farm. This reactor has wells to allow for sampling water in the reactor and they otherwise would not be in a typical bioreactor. Note the nearly level grade of the bioreactor site. Photo courtesy of Iowa State University.

Denitrifying Bioreactors

Water Quality Results

Woodchip bioreactors have the potential to remove 15-60 percent of nitrate loads in tile drainage water per year. Fields and watersheds with a higher nitrate load are generally the best candidates for bioreactors and should be high priority sites. A combination of woodchip bioreactors and controlled drainage provide the best results and can easily be managed together.



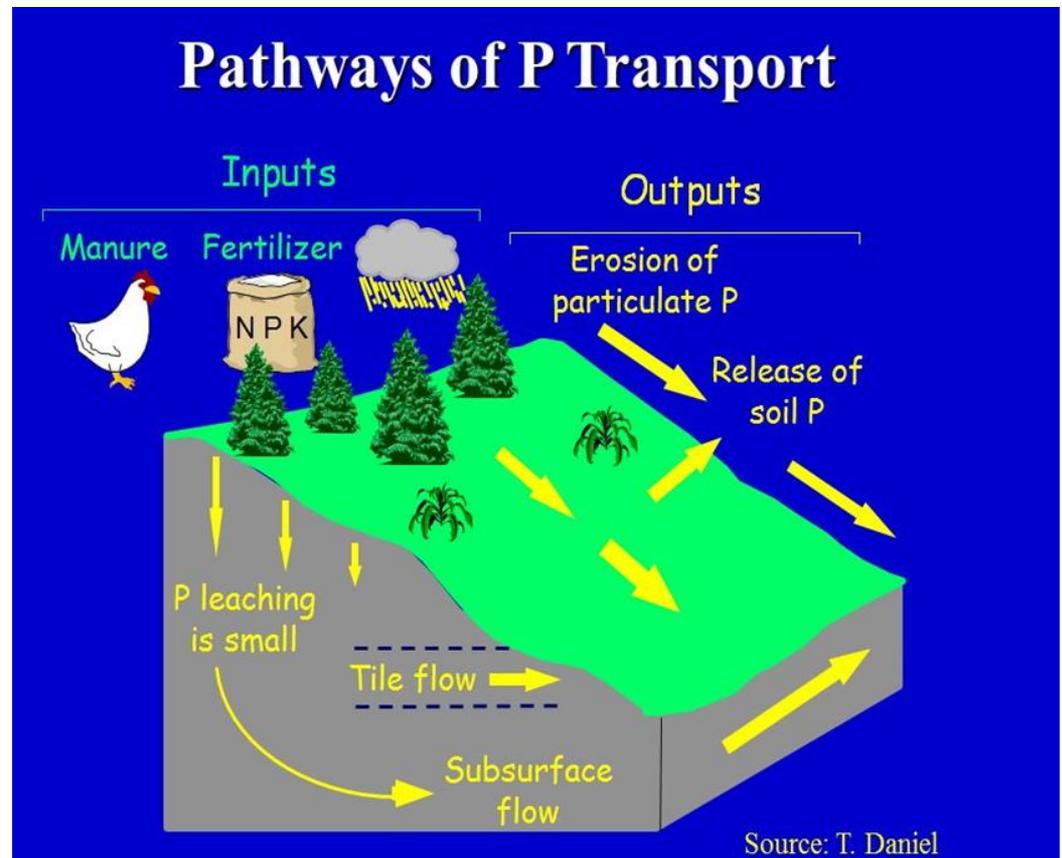
The above graph shows the comparison of nitrate removal from bioreactors, controlled drainage, wetlands, timed fertilizer applications, and various cropping practices. The blue bar shows the average removal of nitrate loads and the whisker within each bar shows plus and minus one standard deviation. Photo courtesy of Iowa State University Extension.

Phosphorus Sorption Beds

The largest and most common loss of phosphorus (P) is particulate loss from soil erosion. The phosphorus is attached to soil particles and is plant unavailable.

Dissolved P is plant available due to its suspension in soil water. Leaching of dissolved P is much more difficult to target due to the difficulty of measuring the levels of dissolved P in soil, as well as effective ways to remove it from soil water, especially in tile discharge water.

Phosphorus sorption beds are a new technology targeted at solving this problem.



The above picture from Ohio State University shows the pathways of phosphorus transport from fields such as soil particulate erosion and leaching of soluble Phosphorus into groundwater. Soluble P is plant available, particulate P is not. <http://www.slideshare.net/LPELC/removing-phosphorus-from-drainage-water-the-phosphorus-removal-structure>

Phosphorus Sorption Beds

Phosphorus sorption beds work based on molecular charge and permeable reactive filter barriers and must take into account the saturated hydraulic conductivity of the soil and filter material. They can remove both particulate P and dissolved P.

Dissolved P carries a negative charge, while the Phosphorus Sorption Materials (PSM) carry a positive charge. The reaction of these oppositely charged particles forms solid materials which settle out in the phosphorus sorption beds.

Several common materials used for P sorption are flue gas desulfurization (FGD) gypsum, and iron coated sand.



Fly ash.



Photo Credit: K.D. Chamberlain

Gypsum waste.

Photos courtesy of Ohio State University.

Phosphorus Sorption Beds

P sorption technologies are still in their infancy but are proving to be viable options for P removal in tile water. Costs range from \$5,000 to \$15,000 depending on size, PSM material type and availability.



Above: this structure allows for high flow during times of large rainfall due to its large surface area and shallow depth.

Left: This picture shows tile lines that are buried in the PSM material and works well on large scale projects draining many acres of land.

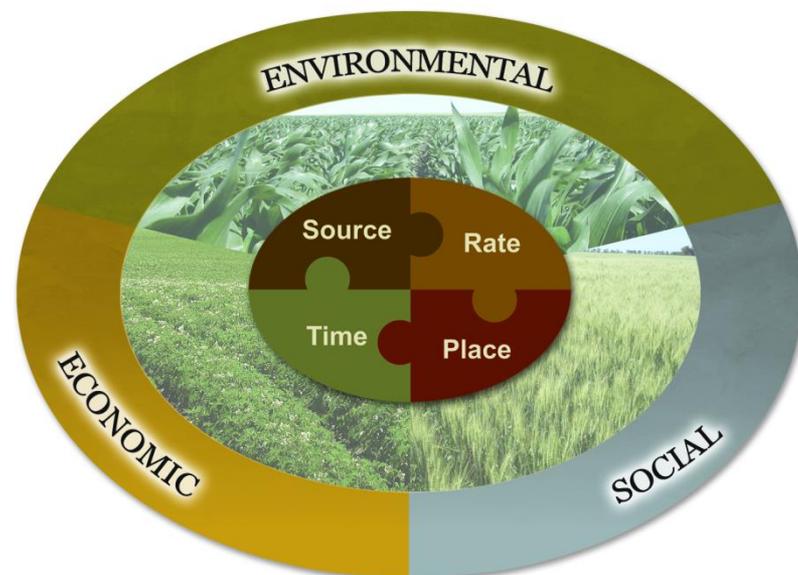
Photos are courtesy of Ohio State University.

4R Nutrient Stewardship Concept

The goal of fertilizer BMPs is to match nutrient supply with crop requirements and to minimize nutrient losses from fields.

- ✓ Choosing the **right fertilizer** source is important when determining how the soil is able to store the fertilizer and plants are able to utilize it.
- ✓ Choosing the **right rate** is the result of soil sampling, expected nutrient removal rates based on the crop type, yield, and plant tissue testing.
- ✓ Choosing the **right time** of year to apply nutrients can influence losses greatly.
- ✓ Choosing the **right place** to apply the nutrients on or in the soil profile in order to make them most available to crops for use.

It is important to understand the type of nutrients you are using, in addition to the rate, time, and place of application. When the 4R Concept is followed, farmers can increase nutrient use efficiency which lowers costs, increases yields, and has the least impact on the environment. This provides the best economic return while acting as a steward of the environment.



4R Nutrient Stewardship Logo. Courtesy of the International Plant Nutrition Institute (IPNI).

Summary

Nutrient losses from agricultural fields continues to be an ever increasingly scrutinized aspect of modern agriculture, specifically concerning water quality.

By using Denitrifying Bioreactors and Phosphorus Sorption Beds, farmers can significantly reduce the impact of nutrient losses in tile drainage water.

Nutrients are mobile in water (solution); therefore, losses to leaching can be significantly reduced by lowering the water table through the use of tile drainage.

Furthermore, water control gates in the tile line can allow producers to actively manage the depth of the water table in their fields to reduce environmental impact while increasing crop yields.



The above picture shows the collection of water samples at tile outlets which will be sent to the lab for analysis. Courtesy of Iowa State University.

Summary

Conservation practices such as no-till, minimum tillage, high residue farming, grass waterways, and constructed wetlands can further enhance the practices of controlled and filtered drainage on farms.

By understanding how nutrients are used by crops and lost to the environment, farmers and agronomists can make informed decisions on how, when, and what type of fertilizer to apply to cropland.

By actively managing water and nutrients in the field, agricultural producers can greatly reduce their environmental impact, while increasing yields and profitability. Denitrifying bioreactors, phosphorus sorption beds, and Best Management Practices provide effective tools for managing tile drainage water in order to improve water quality and reduce agriculture's impact on the environment.



The above picture shows an Iowa State student analyzing water samples from tile water. This confirms the amount of nitrogen and phosphorus removed from tile water.

Quiz Questions

1. Nutrient fixation and losses are based on:
 - a. Soil pH
 - b. Growing Degree Days
 - c. Nutrient and soil particle charges (+ or -)**
 - d. Crop variety

2. Nitrogen and Phosphorus losses occur in tile drainage water because these nutrients are:
 - a. Water soluble**
 - b. Utilized by crops
 - c. In a gaseous state
 - d. In a solid state

Questions



A sunset on the farm, September 2015