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Food, Agricultural and Biological Engineering

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Nitrogen and the Hydrologic Cycle

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Water is an abundant natural resource in Ohio. Ohioans use an estimated 14 billion gallons of water per day (BGD) for various beneficial purposes. This large amount of water fulfills public, rural (domestic and livestock), industrial, and crop and turf irrigation needs. Another much used resource is nitrogen. Nitrogen (chemical symbol N) is important as a plant nutrient for food and fiber production, and for lawn and turf management. Nitrogen is abundant in its atmospheric form, N^2 (nitrogen gas), which makes up 78 percent of our atmosphere. Most plants cannot use nitrogen in this form, but N^2 can be transformed into several other compounds that plants can use. The form and movement of nitrogen are greatly influenced by components of the hydrologic cycle, which is particularly important for agriculture and the environment.

Considering the abundance and importance of both nitrogen and water, Ohioans should understand how the forms and movement of nitrogen may be affected by contact with water. Of particular public concern is the occurrence of nitrate in drinking water supplies. The purpose of this publication is to provide the reader with an overview of the nitrogen cycle and how it relates to the hydrologic cycle, and to help increase the reader's awareness of human activities that impact the quality and quantity of Ohio's water resources. Water resources terminology used in this publication is defined in *Ground- and Surface-Water Terminology*, AEX 460, which provides a listing of generally accepted water resource definitions (available through your Ohio county office of Ohio State University Extension).

The Hydrologic Cycle

The Earth holds more than 300 million cubic miles of water beneath the surface, on the surface and in the atmosphere. This vast amount of water is in constant motion in a complex cycle known as the hydrologic cycle. The hydrologic cycle describes the pathways that water travels as it circulates throughout the world by various processes. Visible components of this cycle are precipitation and runoff. However, other components, such as evaporation, infiltration, transpiration, percolation, ground-water recharge, interflow and ground-water discharge are equally important. An in-depth discussion of the hydrologic cycle is beyond the scope of this publication. However, the reader should have an understanding of the components (refer to *Ohio's Hydrologic Cycle*, AEX 461).

The Nitrogen Cycle

Just as water moves through the environment, so does nitrogen, in various forms. The nitrogen cycle is a representation of the various forms of N and how they relate to one another through many complex interactions. Figure 1, a simplified nitrogen cycle, illustrates many of the complex interactions of various forms of nitrogen, including: atmospheric nitrogen (N^2), ammonia (NH_3), ammonium ion (NH_4^+), nitrite ion (NO_2^-), and nitrate ion (NO_3^-). Each nitrogen form has characteristics that relate to plant utilization and possible impacts on water resources.

Nitrogen Availability to Plants

For nitrogen, non-leguminous plants, such as lawn and turf grasses, corn and most fruit and vegetable crops, must rely on either bacteria that live in the soil to "fix" the nitrogen (N^2) into a usable form or nitrogen from decomposing organic matter, or fertilizers. The forms of nitrogen that most plants can use are ammonium ion (NH_4^+) and nitrate ion (NO_3^-), as shown in Figure 1. Of these, the ammonium and nitrate ions are the most common forms taken in through plant roots. Ammonium is converted to the nitrite and nitrate forms rather quickly by nitrifying bacteria, such as *Nitrosomonas .sp* and *Nitrobacter .sp*, which add oxygen to the ammonium ion and convert it to nitrate. However, the legumes, for example, alfalfa, clover, soybeans and peanuts, have nodules on their roots that contain bacteria. The plants benefit by having the bacteria that fix atmospheric nitrogen into a usable form for the plant, while the bacteria benefit from the energy obtained in the chemical conversion. **Note: The ammonia and nitrite forms of nitrogen are highly toxic to humans!**

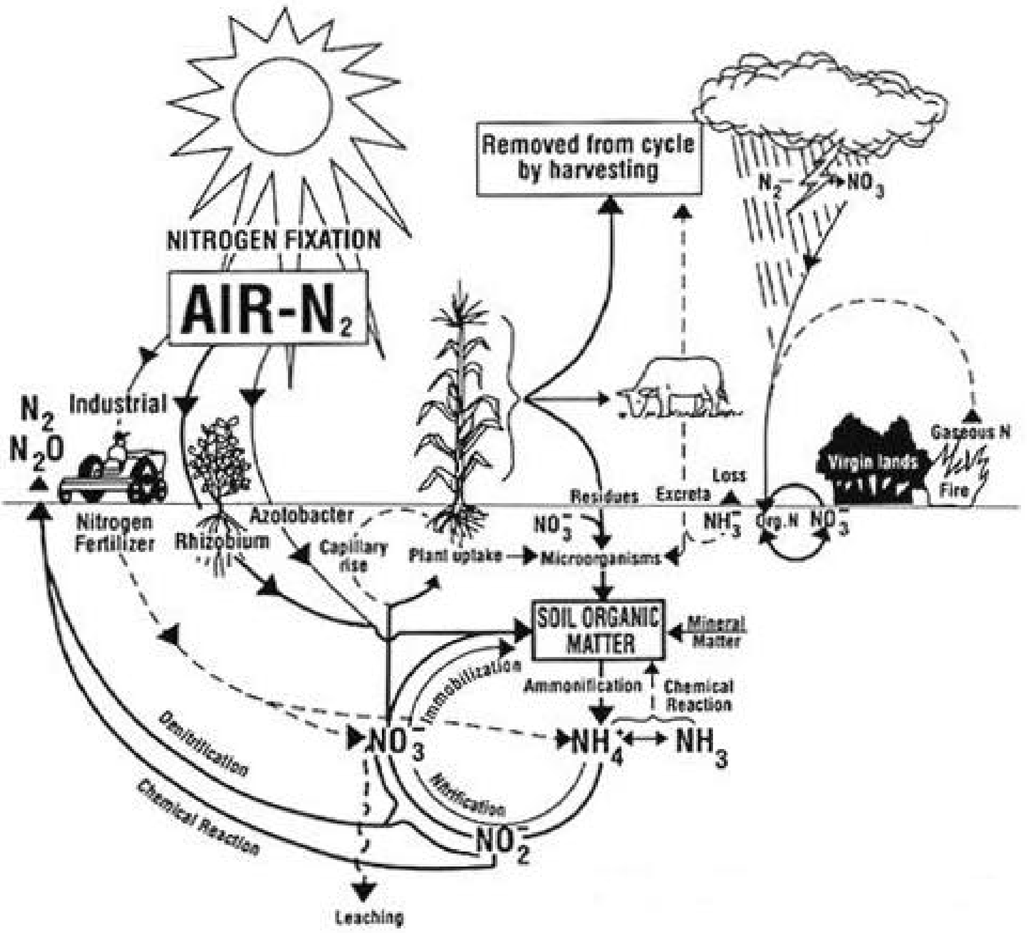

Figure 1. The nitrogen cycle in soil.

Nitrogen Loss from Availability to Plants

Nitrogen can become unavailable to plants primarily in three ways, which are illustrated in Figure 1. First, most nitrogen is lost through denitrification, which is a problem in wet or compact soils. Since these soils contain little oxygen, denitrifying bacteria remove the oxygen from nitrite (NO_2^-) and nitrate (NO_3^-) ions for their own use, releasing N^2 and/or N^2O back to the atmosphere. The second means of nitrogen loss is by nitrate leaching, which is a particular concern with the nitrate ion (NO_3^-). Leaching occurs when the water-soluble nitrate ion moves through the soil as water percolates downward beyond the reach of plant roots. Surface volatilization (conversion to the gaseous phase) is the third method of nitrogen loss. This loss occurs when ammonia (NH_3), usually in the form of urea, volatilizes and is lost to the atmosphere. Surface volatilization is usually a problem in areas with high temperatures, and with soils that have a high pH value. Soils that have been compacted by field operations and other human activities also are a problem because it may not be possible to properly mix the urea with the compacted soil. Another pathway for nitrogen loss from plant availability is the loss of the nitrogen through the process of soil erosion by water (discussed in a later section).

Nitrogen Cycle-Hydrologic Cycle: Interactions

Since nitrogen and water are so vital for all organisms, it is inevitable that components of the nitrogen and hydrologic cycles are closely related. These relations have particular importance for agriculture, and lawn and turf management. By understanding these interactions, we can better understand the effects of human activities on water resource quality.

Atmospheric Production

Nitrogen, mostly in the form of ammonium and nitrate, reaches the Earth's surface as a result of atmospheric lightning, precipitation and industrial pollution. Research in northern Ohio showed that the average annual nitrate concentration in rainfall, over a six-year period, was about 2 parts per million (ppm). This concentration translates to an average application of 17 pounds per acre per year (lb/ac-yr) for an average annual rainfall of 37 inches during the six-year study period.

Denitrification

Nitrifying organisms can only function when free oxygen (O_2) is present. In saturated soils, free oxygen is very low, suppressing the growth of the nitrifying organisms, often causing nitrogen deficiencies in excessively wet soils. This condition is enhanced by denitrifying bacteria since they thrive in an oxygen-free environment, like a saturated soil, and therefore consume nitrate at a rapid rate. Excessive rainfall promotes nitrogen loss not only by promoting nitrate leaching from the plant root zone, but also by creating wet soil conditions that favor denitrification. Evaporation works in the opposite way to remove water from the upper soil layers. Space then becomes available for oxygen, thereby making the environment suitable for the growth of nitrifying bacteria.

Surface Volatilization

In agricultural situations, surface volatilization (vaporization of urea to ammonia gas) may occur when urea is applied on crop residues, and not in good contact with soil particles. To limit volatilization of the urea, producers usually incorporate it into the soil by tillage to bring the urea into contact with the soil. Limited rainfall also helps with proper incorporation of the urea in the upper portion of the soil profile. When water and urea combine, the result is the ammonium ion (NH_4^+), which has a positive charge and attaches to negatively charged soil particles. Both tillage and rainfall can help make nitrogen available for plant use. Unfortunately, the interaction between tillage and excessive rainfall increases the potential for soil erosion. After tillage, the soil is more susceptible to being carried away by water during heavy rainfall.

Nitrogen Movement Through Soil

The nitrate ion (NO_3^-) is the most water-soluble form of nitrogen as well as the form least attracted to soil particles. Therefore, its interaction with the hydrologic cycle is very important since it moves where water moves. Precipitation, evaporation and transpiration may affect the movement of nitrate in the near-surface soil profile. Rainfall that infiltrates the soil surface may cause nitrate ions to move down through the soil profile by percolation. The more rain that infiltrates, the further down in the profile nitrate ions move. Nitrate movement below the plant root zone is called nitrate leaching. Soil texture, structure and permeability, along with other soil properties, affect nitrate leaching. Deep percolation of water through the soil profile potentially allows the movement of nitrate out of the root zone and downward, where it may pollute the underlying aquifer. In contrast to the nitrate ion, the ammonium ion has a strong attraction for soil, and therefore is considered to be immobile in most soils. However, in soils with very high sand and low organic matter contents, the ammonium ion will move in the direction of water movement.

Surface evaporation and transpiration may help nitrate move toward the soil surface within the root zone as a result of capillary movement as the plant withdraws water from the soil profile. Upward movement of nitrate occurs mainly in the summer when evaporation and transpiration exceed rainfall.

Nitrogen Movement to Surface Waters

Runoff contributes to the movement of several forms of nitrogen to surface water. Runoff results when the rainfall rate exceeds the infiltration rate at the soil surface. Runoff from agricultural and suburban watersheds carries sediment, as well as nutrients like nitrate and ammonium. Ammonium ions attach to sediments very readily, which means they move with soil, but generally do not leach. Therefore, ammonium may contribute to surface-water problems, but generally does not impact ground water.

Subsurface drainage improvements may contribute to the movement of the nitrate form of nitrogen to surface waters. Many agricultural soils with poor internal drainage require installation of drainage systems to promote a healthy environment for crop root development, and to improve nitrogen efficiency. Where nitrate is present in wet agricultural soils without proper drainage improvement, there is a great potential for nitrogen loss by denitrification if soil conditions (i.e., organic matter and temperature) are favorable. Ohio has approximately 12.5 million acres of existing cropland, of which about 50 percent has received drainage improvements. Research shows that not only can crop yields and economic stability be improved with drainage improvements on wet agricultural soils, but also that runoff and erosion rates can be reduced. In addition, rapid removal of excess water from the plant root zone decreases the potential for denitrification.

With subsurface drainage, some of the rainfall that infiltrates the soil surface is intercepted by the subsurface drainage system, and subsequently discharged to a ditch or stream. If nitrate ions are present in the soil profile, they will move with the percolating water. Subsurface drainage systems actually intercept the nitrate after it has been leached from the plant root zone, and before it has the opportunity to move by deep percolation to an underlying aquifer. Unfortunately, these systems may discharge nitrate in surface waters instead.

Subsurface drainage water generally will have a higher concentration of nitrate than runoff water, but considering the greater potential for movement of sediment, nitrate, ammonium and phosphorous in runoff, subsurface drainage water is generally of better quality. The loss of nitrate in subsurface drainage water is not a simple matter to resolve since it is related to rainfall timing and amount, soil profile characteristics, subsurface water flow rate (soil-dependent), nitrogen application rate and timing, and the extent of plant uptake of the nitrate available in the soil profile.

Nitrogen from Organic Materials

Another source of nitrogen that has potential for water resource pollution is organic materials, such as animal manure, municipal sludge, septic system sludge and plant materials (leaves, stalks, etc.). When incorporated into the soil, these materials are broken down by microbiological decomposition, which produces a number of benefits for the soil. One product is the ammonia form of nitrogen. Ammonia can be transformed easily into the ammonium or nitrate ion, both of which can be used by the plant. However, if organic materials enter a water resource, such as animal wastes from a feedlot being washed into a nearby stream during rainfall, the potential for two problems exists. First, ammonia, which is produced by bacterial decomposition of the organic material, is highly toxic to fish depending on the pH and temperature of the water. Second, as the microorganisms break down the organic materials in the water, they consume much oxygen during the process. The resulting oxygen depletion can cause a fish kill.

Ground- and Surface-Water Interactions

In many parts of Ohio, ground and surface waters are physically connected. Therefore, the potential exists for water-mobile nitrate to move from surface waters, such as lakes and streams, to aquifers through the process of ground-water recharge. Nitrate movement through ground-water recharge has a greater potential in areas of the state underlain by sand and gravel aquifers. Likewise, nitrate may move from ground water to surface-water bodies through the process of ground-water discharge, although the potential for this mode of nitrate movement is lower than for ground-water recharge.

Nitrate in Drinking Water Supplies

Nitrate has been detected in ground- and surface-water supplies in various parts of the state. Low levels of nitrate can be found in most of the surface waters of the state throughout the year. In a recent statewide survey of water wells, a small percentage contained excessive nitrate concentrations. In cases where the concentration of nitrate-nitrogen exceeds the maximum contaminant level of 10 mg/L, as set forth by the U.S. Environmental Protection Agency, water suppliers are required to issue a nitrate alert to users. The health of infants, the elderly and others, and certain livestock may be affected by the ingestion of high levels of nitrate. It is beyond the scope of this publication to fully address this important water resource issue. For more information on nitrate in drinking water, refer to *Nitrate in Drinking Water* (Bulletin 744).

Summary

Water and nitrogen are important resources in Ohio. Both are necessary for human existence, plant growth and food production. The components of the nitrogen and hydrologic cycles interact in numerous ways to affect Ohio's water supply. Many human activities (urban, rural, industrial and agricultural) have an influence on these interactions, and thus the quantity and quality of our water resources (refer to *Nonpoint Source Pollution: Water Primer*, AEX 465). To make wise decisions about the proper use and protection of these resources, we must be aware of how the various components of these complex cycles affect one another. This publication presents an overview of the nitrogen cycle and how it relates to the hydrologic cycle. The main intent of this publication is to help increase the reader's awareness of human activities that impact the quality and quantity of Ohio's water resources.

For more information on this or other water resources topics, refer to the publications listed below, or contact your Ohio county office of Ohio State University Extension.

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