UNIVERSITY OF ARKANSAS
DIVISION OF AGRICULTURE
Cooperative Extension Service

Agriculture and Natural Resources

The Nitrogen and Phosphorous Cycle in Soils

Leo Espinoza
Extension Agronomist - Soils

Rick Norman
Professor, Soil Fertility

Nathan Slaton
Associate Professor, Soil Testing

Mike Daniels
Extension Environmental Management Specialist - Agriculture

The Nitrogen Cycle

Nitrogen exists in soils in many forms and constantly changes from one form to another. The paths that the different forms of nitrogen follow through the ecosystem are collectively called the **nitrogen cycle** (Figure 1). Understanding how the different pools of nitrogen interact and the processes by which these forms enter and leave the cycle is the subject of continuing study. Nitrogen is found in both inorganic and organic forms. Soil organic matter is composed primarily of amides (NH_2) and accounts for more than 90 percent of the total nitrogen present in most environments. In general, nitrogen is not found associated with soil minerals, as is the case with phosphorus. Some clay minerals may tie up small amounts of nitrogen in the ammonium form (clay fixation) but not in the same magnitude as phosphorus.

Organic Nitrogen

Soil organic matter is the major storehouse of many plant nutrients in soils, including nitrogen, phosphorus, sulfur, calcium and magnesium. Soil organic matter is composed of a stable material called **humus**, an easily decomposed material (litter), soil microbes and some other organic molecules. Typically, humus will contain 45 to 55 percent carbon and about 5 percent nitrogen. In other words, soil humus typically has a carbon to nitrogen ratio (C:N ratio) of approximately 12:1 for surface soils and 8-10:1 for subsurface soils.

Mineralization

Nitrogen that is present in soil organic matter, crop residues and manures is converted to the inorganic

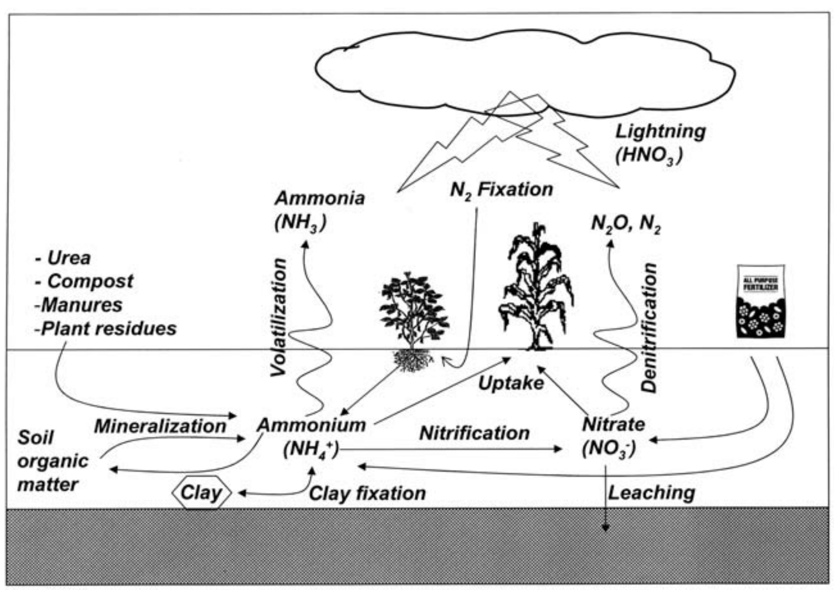

Figure 1. Nitrogen cycle in upland soils

Arkansas Is Our Campus

Visit our web site at:
http://www.uaex.edu

form by the process of **mineralization** (Figure 2). Initially, larger organic matter molecules are broken down into smaller ones, with soil microorganisms attacking these remaining materials by producing specific enzymes. The transformation of organic nitrogen to the ammonia (NH_3) and ammonium (NH_4^+) forms is referred to as **ammonification**. The resultant ammonium can then be transformed to the nitrate form (NO_3^-) by a process called **nitrification**. Since the decomposition process is carried out by living organisms, it is affected by several environmental variables, including soil moisture, temperature, pH, the C:N ratio and the type of organic materials in the residue. Cotton and grain sorghum stalks and small grain residues are relatively high in carbon and low in nitrogen (having C:N ratios greater than 30:1). Soil organisms may need additional nitrogen to decompose these residues. When the nitrogen supply is limited, soil microbes compete with plants for fertilizer N in a process called **immobilization**. When these microbes die, nitrogen tied up in the decomposition process again becomes available for crop use.

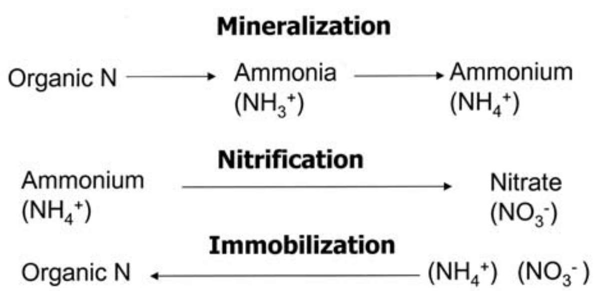

Figure 2. Nitrogen mineralization/immobilization process

Biological Nitrogen Fixation

Atmospheric nitrogen (N_2) is basically an endless source of N, but this nitrogen cannot be used directly by most plants. Legumes such as alfalfa, soybeans and clovers form a **symbiotic association** (mutually beneficial) with specific bacteria to convert atmospheric N_2 to a form plants can use. The plant provides nutrients and other compounds to the N_2-fixing bacteria, and in return, the plant benefits from the N fixed by the microorganisms. The amount of N fixed varies among plants and growing conditions (Table 1). The symbiotic association is highly specific; thus, the bacterial species that fixes N_2 with soybeans is not effective for fixing N_2 with alfalfa. The site of the N_2-fixing process is a root nodule that forms on the root system and has a pink color if actively fixing N_2.

The biological nitrogen fixation process is catalyzed (accelerated) by the nitrogenase enzyme, which is affected by a number of soil and weather factors. The association does not work well in soils with very low pH or when high levels of available mineral nitrogen are present. The absence of the right type of inoculum (bacteria) in the soil also will limit nodulation and N_2 fixation.

Table 1. Typical Amount of Nitrogen Fixed by Selected Legumes

Crop	Amount fixed (lb/A/year)
Alfalfa	170-270
Soybeans	70-170
Clovers	120-170
Vetch	70-150

Source: M. Alexander, *Introduction to Soil Microbiology,* 1977

Some other soil organisms are capable of fixing N_2 via **non-symbiotic** associations. This process is of little significance in most agricultural systems, with the exception of blue-green algae which live in rice systems. Some nitrogen also is fixed by lightning, but in considerably smaller amounts than biologically fixed N_2.

Leaching

Nitrogen in the nitrate form is very mobile and highly soluble in water. Rainfall moving through the root zone may wash nitrate downward, reaching tiles or drainage channels and potentially reaching groundwater or surface waters. Leaching is a more serious problem in highly permeable sandy soils than in clayey soils. The magnitude of nitrate loss through leaching depends on the amount and intensity of the rainfall or irrigation water and the amount of nitrate present in the soil.

Loss of nitrate by leaching is of concern for two important reasons. Nitrate below the root zone is no longer available for plant use, representing an important loss of resources. Water quality problems caused by excess nitrogen leaving fields may result in the deterioration of drinking water sources and wildlife habitat.

Volatilization as NH_3

A significant amount of nitrogen fertilizer can be lost through the process of volatilization if not properly applied. Many commercial fertilizers contain ammonium or convert readily to ammonium, such as urea. Under alkaline pH conditions (pH > 7), a percentage of the ammonium (NH_4^+) can be converted to ammonia gas (NH_3) and escape to the atmosphere. In addition to soil pH, high soil temperature, excessive soil moisture and strong winds will contribute to such loss.

Ammonia volatilization also can occur under neutral and acidic soil pH conditions. During the transformation of urea to ammonium (NH_4^+), the pH of soil adjacent to the fertilizer can increase to levels that promote ammonia formation. This effect is more pronounced in sandy and silt loam soils, which lack the ability to resist pH changes (i.e., low pH buffering capacity).

Denitrification

The process of denitrification is a form of respiration carried out by microorganisms under low oxygen conditions. Specific microorganisms, primarily bacteria, have the ability to use nitrate instead of oxygen to carry out their metabolic functions. In this process, nitrate (NO_3^-) is reduced to NO_2^- and then to gaseous forms including N_2O and N_2.

Temperatures between 75 and 95 degrees F, low soil oxygen levels for several days (waterlogged conditions), soil pH > 6 and the presence of a carbon source (organic matter) are ideal conditions for denitrification to proceed at a high rate. Denitrification varies widely among locations and time of year, but it normally represents only a small percentage of total N loss. The process of denitrification is detrimental, since plant-available nitrogen is lost to the atmosphere. However, denitrification also can be used as a means to prevent the buildup of nitrates in groundwater wells, manure storage lagoons and wastewater treatment plants.

Nitrogen Cycle in Flooded Soils

In upland soils, the process of mineralization gradually converts organic nitrogen to ammonium and then to nitrate. Under flooded conditions, due to the low oxygen concentration, the end product of the mineralization process is ammonium (Figure 3).

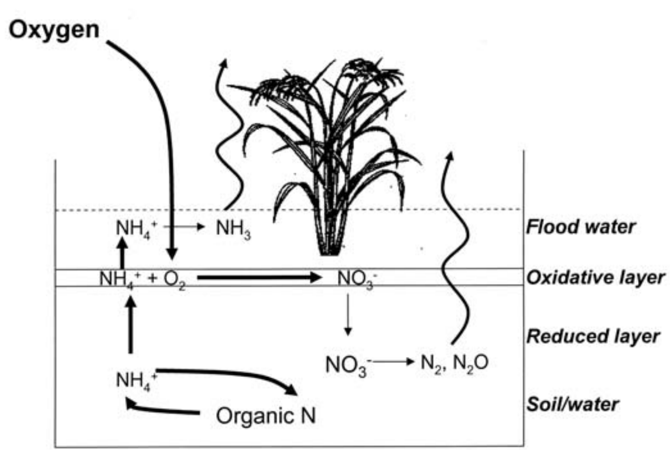

Figure 3. Simplified nitrogen cycle in flooded soils

In flooded soils, such as rice paddies, two layers are formed – an **oxidative layer** at the soil/water interface, which is less than one inch thick, and a **reductive layer** beginning immediately beneath. If nitrate fertilizer is added to flooded soil, bacteria can convert it to nitrogen gas (denitrification), which may be lost to the atmosphere. Ammonium fertilizer placed in the oxidative layer also may be converted to nitrates, just as in an upland soil.

The Phosphorus Cycle in Soils

Phosphorus (P) occurs in soils as both organic and inorganic forms (Figure 4). Phosphorus can be found dissolved in the soil solution in very low amounts or associated with soil minerals or organic materials. The relative amounts of each form of phosphorus vary greatly among soils, with the total amount of P in a clayey-textured soil being up to ten times greater than in a sandy soil.

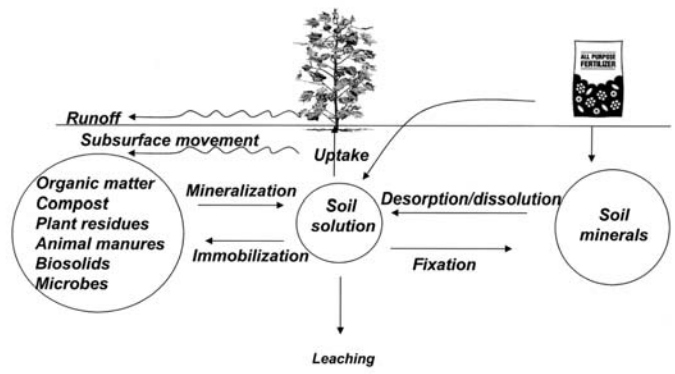

Figure 4. Simplified phosphorus cycle in soils

Organic P in soils. A large number of compounds make up the organic P in soils, with the majority being of microbial origin. Organic P is held very tightly and is generally not available for plant uptake until the organic materials are decomposed and the phosphorus released via the **mineralization process**. Mineralization is carried out by microbes, and as with nitrogen, the rate of P release is affected by factors such as soil moisture, composition of the organic material, oxygen concentration and pH.

The reverse process, **immobilization**, refers to the tie-up of plant-available P by soil minerals and microbes that use phosphorus for their own nutritional needs. Microbes may compete with plants for P, if the decomposing organic materials are high in carbon and low in nitrogen and phosphorus (i.e., wheat straw). *Mineralization and immobilization* occur simultaneously in soil. If the P content of the organic material is high enough to fulfill the requirements of the microbial population, then mineralization will be the dominant process.

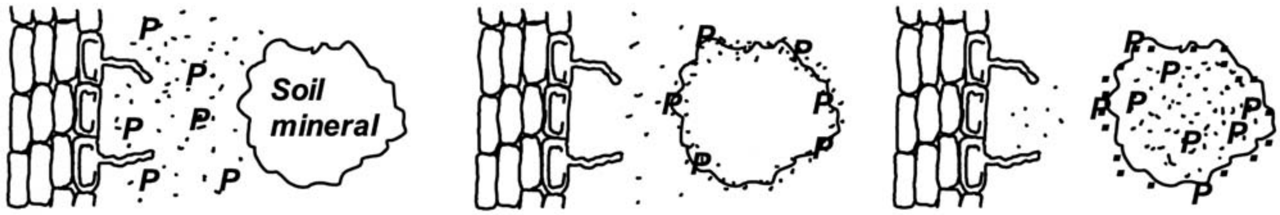

Figure 5. How phosphorus (phosphates) are tied up by soil minerals. A) A large percentage of the P is available for root uptake immediately after fertilization application. B) P in solution binds rapidly to the surface of soil minerals. Roots may still use this P. C) Eventually, most of the bound P becomes part of the structure of the mineral, with its plant availability being significantly reduced.

Inorganic P in soils. The concentration of inorganic P (orthophosphates) in the soil solution at any given time is very small, amounting to less than 1 lb/A. Phosphorus in the inorganic form occurs mostly as aluminum, iron or calcium compounds.

The chemistry of soil P is very complex, with more than 200 possible forms of P minerals being affected by a variety of physical, chemical and biological factors. Soluble P resulting from commercial fertilizer applications or from mineralization reacts with soil constituents to form P compounds of very low solubility (low plant availability). This series of reactions is commonly referred to as **sorption** or **fixation**. Iron and aluminum compounds will fix (tie-up) P under acidic conditions (soil pH < 6), while under alkaline conditions (soil pH > 7), phosphorus is preferentially fixed by calcium and magnesium compounds. Figure 5 shows the sequential process by which plant-available phosphorus is fixed by soil minerals.

Phosphorus availability to plants in most soils is greatest when soil pH is in the range of 6 to 7. Application of liming materials is a common production practice to raise the pH in acidic soils to make P more available. However, lowering the pH of calcareous soils to increase the solubility of P is not an economically viable option, since large amounts of acidifying material are typically needed. Thus, soils with high pH generally have P fertilizer applied every year immediately before planting the crop.

Soils that have not received P fertilization for a few years can render much of the P fertilizer applied unavailable. Thus, it is best to maintain proper P fertilization of soils and not to mine them of their P. Otherwise the soil may fix P until the P mineral fractions in the soil have been replenished through proper P fertilization practices.

Printed by University of Arkansas Cooperative Extension Service Printing Services.

DR. LEO ESPINOZA is Extension agronomist - soils and **DR. MICHAEL DANIELS** is Extension environmental management specialist - agriculture, University of Arkansas Division of Agriculture, Cooperative Extension Service, Little Rock. **DR. RICHARD NORMAN** is professor, soil fertility, and **DR. NATHAN SLATON** is associate professor, soil testing, University of Arkansas, Fayetteville.

FSA2148-2M-10-05N