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What Happens to Nitrogen in Soils?

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Efficient crop production requires an adequate supply of all essential plant nutrients. However, the use of commercial nitrogen (N) fertilizers to increase production, maintain profits and provide low-cost food and fiber is a necessity of modern agriculture. In general, crops need nitrogen in the greatest quantity of all plant nutrients.

The environmental effect of nitrogen fertilizers has been a long-term issue. Concern over nitrogen pollution of rivers, lakes and groundwater has caused agricultural producers to become increasingly aware of their potential contribution to the total pollution problem.

To effectively use nitrogen and to limit its adverse impact on the environment, producers need to develop an awareness of the chemistry of nitrogen and how it is added to and removed from the soil.

Commercial fertilizers used by agricultural producers are a significant source of nitrogen addition to soils. Nitrogen is continuously recycled through plant and animal waste residues and soil organic matter. Nitrogen is removed from the soil by crops, gaseous loss, runoff, erosion and leaching. The magnitude and mechanism responsible for nitrogen losses depend upon the chemical and physical properties of a given soil. Figure 1 is a schematic representation of the possible gains and losses of soil nitrogen.

Chemistry of Nitrogen

Nitrogen accounts for 79 percent of the air we breathe. The surface 6 inches of a fertile prairie soil may contain 2 to 3 tons of nitrogen per acre. The air above this same acre will contain about 35,000 tons of inert nitrogen gas (N_2). Most of the nitrogen found in soil originated as N_2 gas and nearly all the nitrogen in the atmosphere is N_2 gas. This inert nitrogen cannot be used by the plant until it is changed to ammonium (NH_4^+) or nitrate (NO_3^-) forms.

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Three important methods for changing nitrogen gas (N_2) to ammonium (NH_4^+) are:

- Free-living N_2-fixing bacteria
- N_2-fixing bacteria in nodules on the roots of leguminous plants, and
- Nitrogen fertilizer production factories.

Another important method of N_2 conversion is through lightning. When lightning flashes, the nitrogen gas in super-heated air is converted to nitrate (NO_3^-) and nitrite (NO_2^-). Lightning may account for 1 to 50 pounds of plant-available nitrogen per acre per year.

Although nitrogen enters the soil in several chemical forms, it eventually converts to the inorganic nitrate (NO_3^-) ion. Figure 1 shows that NO_3^- can be used by plants, be converted back to nitrogen gas or be leached downward with soil water.

Commercial fertilizers, plant residues, animal manures and sewage are the most common sources of nitrogen addition to soils. Rates of application vary widely. Single application rates may be as high as 150

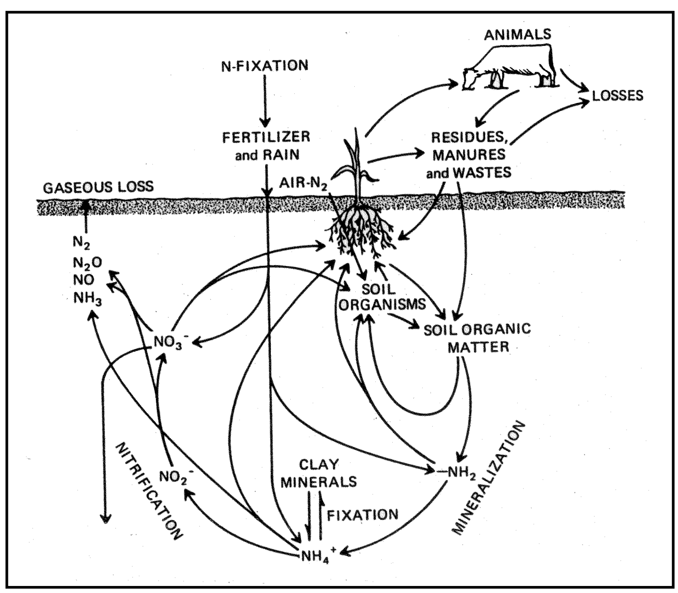

Figure 1. The nitrogen cycle is a complex system involving the air, soil and plant.

pounds of nitrogen equivalent per acre for crops such as coastal bermudagrass. However, such high application rates should be limited to soils with a low potential for erosion and runoff.

Nitrogen in organic materials (plant residues, animal manures, sewage, soil organic matter) is present as part of proteins, amino acids and other plant and microbial materials. It becomes available to plants only after the compound is decomposed by soil microorganisms. This is called "mineralization" (Fig. 2). The first step of mineralization is "ammonification." The ammonium (NH_4^+) derived from ammonification is then converted to nitrate-nitrogen (NO_3^--N) by "nitrifying" bacteria in the soil through the process called "nitrification."

Figure 2. The mineralization process.

Mineralization = Ammonification + Nitrification

R* – NH – R*

$R^* - NH_2 \longrightarrow NH_4^+ \longrightarrow NO^-_2 \longrightarrow NO_3^-$

R* = N – R   ammonium   nitrite   nitrate

Ammonium   Nitrification

Organic N ⟶ to ⟶ Inorganic N

Mineralization

R = Complex organic molecule, organic radical

The locations of the ammonification and nitrification reactions in the nitrogen cycle are shown in Figure 1. The positively charged ammonium (NH_4^+) ion produced by ammonification or added to the soil in fertilizers is attracted to negatively charged clay particles in the soil. However, in most non-arid soils the NH_4^+ ion is rapidly transformed to nitrate nitrogen (NO_3^- N) Growing plants absorb most of their nitrogen in the form of nitrate (NO_3^-).

Common sources of inorganic nitrogen include ammonia (NH_3), ammonium (NH_4^+), amine (NH_2^+) and nitrate (NO_3^-). Most fertilizer materials contain or will form NH_4^+ which is converted rapidly to NO_3^- once in the soil.

Removal of Nitrogen from Soil

Nitrogen is removed from soils by four major processes:

- Plant uptake
- Gaseous loss
- Runoff and erosion
- Leaching

Plant uptake refers to nitrogen absorption by roots. Cotton, corn, tomatoes and turf grasses require 60 to 300 pounds of nitrogen per acre to produce good growth and profitable yields or desired aesthetics. The actual requirements for a given crop varies according to the production potential and are influenced greatly by climatic factors.

Because most soils are low in plant-available nitrogen, the nitrogen requirements are often supplied as commercial nitrogen fertilizer. Nitrogen requirements above 150 pounds per acre generally are divided into two or more applications. However, only plant nitrogen in the harvested crop actually leaves the field. The remainder of plant nitrogen is returned to the soil as plant residue and reenters the cycle as organic nitrogen as illustrated in Figure 1.

Gaseous loss of nitrogen takes place by denitrification or ammonia volatilization. Denitrification is a process through which nitrate nitrogen (NO_3^--N) is converted to gaseous nitrogen oxide (N_2O) or elemental nitrogen (N_2). This involved the action of anaerobic bacteria (those which do not require free oxygen) and commonly occurs in wet or water-logged soils.

$NO_3^- \longrightarrow NO_2^- \longrightarrow N_2O$ or N_2

Nitrate   Nitrite   Nitrous oxides or Gas

Nitrate to nitrite to nitrogen gases

Since this is an anaerobic process, gaseous losses from a normal (aerobic) soil are small. However, when soils stay very wet or saturated for long periods, a large portion of the nitrate can be lost.

Ammonia gas can evolve from nitrogen compounds such as urea on the surface of a soil. Urea is present in animal manure and may be purchased in pure form as a fertilizer (45-0-0).

$$\underbrace{\begin{matrix} NH_2 \\ NH_2 \end{matrix} \Big> CO}_{\text{urea}} + \underbrace{2H_2O}_{\text{water}} \longrightarrow \underbrace{H_2CO_3}_{\text{carbonic acid}} + \underbrace{2NH_3}_{\text{ammonia (volatilization)}}$$

Other ammonium-containing fertilizer compounds, including ammonium sulfate (21-0-0) and, to a lesser extent, ammonium nitrate (33-0-0) and ammonium phosphate, have been shown to produce free ammonia in the presence of calcium carbonate. This condition exists in some high pH soils (pH > 7.3).

Runoff and erosion losses may include nitrate (NO_3^-), ammonium (NH_4^+), and organic nitrogen. The negatively charged NO_3^- ion remains in the soil water and is not held by soil particles. If water containing dissolved NO_3^- or NH_4^+ runs off the surface, these ions move with it. However, when nitrogen fertilizers are applied to dry soils, and rain or irrigation water is applied, the first water dissolves the fertilizer and carries it into the soil. Rainfall does not generally cause surface losses of fertilizer nitrogen, unless very intensive rainfall occurs shortly after application.

Ammonium held by clay particles can be carried into surface water supplies by soil erosion. In fact, soil erosion moves more nitrogen than does rainfall in moving dissolved nitrogen compounds. When erosional soils are deposited in rivers and lakes, microbial activity will slowly convert nitrogen compounds into soluble forms.

Leaching losses involve the movement of water downward through a soil below the root zone. This loss most frequently occurs with nitrate (NO_3^-) in areas of high rainfall, under excessive irrigation and with coarse-textured (sandy) soils. Losses of nitrogen through leaching reduce the amount of nitrogen available to crops and may potentially contaminate shallow water wells and aquifers.

The rates of nitrogen used and the time of application should be related to soil conditions and crop requirements to minimize leaching losses. Numerous research studies show that because of plant uptake, little nitrate nitrogen (NO_3^--N) leaches from soils on which a crop is actively growing. Since the sandy soils most subject to leaching are located in East Texas, where grass is the predominant crop, minimum leaching losses of nitrogen generally are expected from nitrogen fertilization statewide.

While studies have shown limited problems with nitrate (NO_3^-) movements, improper applications of commercial and organic nitrogen fertilizers can result in NO_3^- runoff into surface waters and leaching into groundwater.

Preventing Nitrogen Loss

The best way to prevent losses of nitrogen from agricultural lands is through good soil and water management practices. The first step in reducing potential nitrogen losses is to have the soil tested. A properly obtained soil sample will provide an estimate of nitrate-nitrogen (NO_3^-–N) present in the soil, and can be used as a guide for applying the appropriate amount of nitrogen fertilizer for the crop being grown.

Proper fertilization and control of surface runoff and erosion offer the best methods for preventing nitrogen from getting into streams and lakes. Leaching losses can be prevented by dividing the nitrogen requirement into several applications where coarse-textured soils and high rainfall are common.

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