Importance of Nitrogen in Soils

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Nitrogen (N) cycling in soils is a complex mix of chemical and biological processes. Add interactions from weather, fertilization, cropping systems and soil properties and it is no wonder that management effects on soil N and N availability for crop production are poorly predictable and not fully understood.

The majority (> 90%) of N in soils is contained in organic matter, with smaller inorganic proportions as ammonium fixed in clay mineral layers, exchangeable ammonium, and nitrate. Soil organic N includes a wide range of complex compounds: humified (stable) soil organic matter (the largest part), fresh crop residue, manure, partially degraded crop residue and manure, and microbial biomass. There is a constant microbial processing of soil organic matter and freshly added organic materials, and over time a stabilization of N into organic compounds that are difficult to degrade. The N content of soils varies greatly as the organic matter varies, but is within a range of approximately 0.06 to 0.30% (1,200 to 6,000 lb N/acre in the top 6 2/3 inches) for cultivated soils.

Plants take up simple inorganic N compounds from the soil, ammonium and nitrate. Utilization of organic N by crops requires prior transformation by soil microbes to these inorganic forms. Microbial processing of organic N with release of inorganic ammonium is called mineralization. If this processing results in a gain of inorganic N in soil, then mineralization is considered a net positive, with an increase in plant-available N. If the microbial processing of organic N results in a reduction of inorganic N in the soil, then mineralization is considered a net negative, and plant-available N decreases and is “tied-up” or immobilized by microbes. This “tie-up” occurs when organic materials are added to soils with high carbon (C) and low N content. Microbial activity is not instantaneous, and occurs at various rates depending on many conditions. The continual microbial processing of organic materials with concurrent gain or loss of C, N, and other elements results in a trend toward a relatively constant 10:1 C:N ratio found for soil organic matter. Soil organic matter is more difficult for microbes to degrade than crop residues. Approximately 2 to 4% of soil organic matter may be broken down each year, compared to 50% or more for recently returned crop residue.

Soil Nitrogen Supply to Crops

If not fertilized with N, yield of crops that do not acquire N through symbiotic atmospheric N fixation (such as alfalfa and soybean) can be very limited. For example, corn yield in Iowa is on average approximately 95% (for corn following alfalfa), 70% (for corn following soybean), and 55% (for corn following corn) of optimally fertilized corn. This is the expectation for normal production fields – more N in the plant derived from the soil system than from applied N fertilizer (Figure 1).

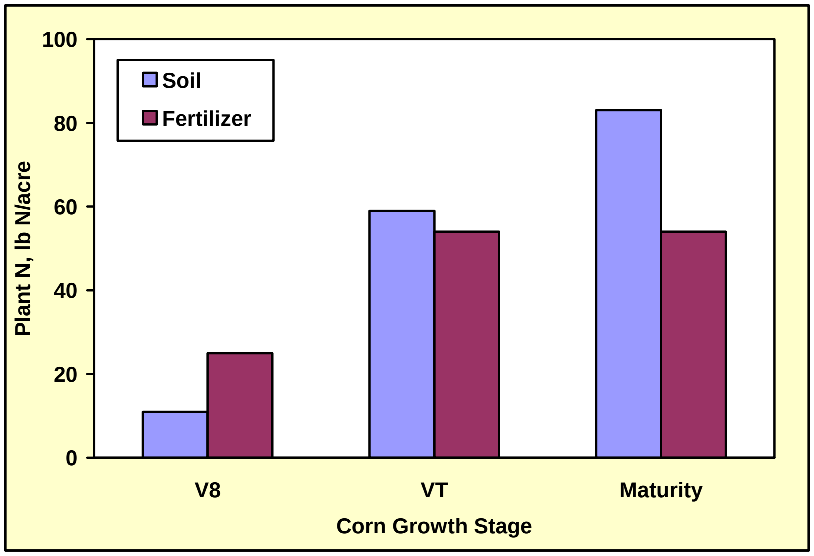

Figure 1. Aboveground plant N uptake derived from soil or applied fertilizer N (applied at 100 lb N/acre) at three corn growth stages, corn following soybean. (Source: J. E. Sawyer)

If no N is applied for many years (fertilizer or manure), the soils ability to supply plant-available N becomes depleted, and long-term research in Iowa shows corn yields will average only about 50 bu/acre for continuous corn and 100 bu/acre for corn following soybean. Where does the N come from if there is no N fertilization? Precipitation supplies about 10 to 20 lb N/acre, and some fixed ammonium can be released from clay minerals. However, the majority comes from microbial processing (net mineralization) of crop residues and soil organic matter. The amount of N release from organic matter breakdown varies significantly between soils and years.

An example:

- Assume:
    - A soil has 3.5% organic matter in the top 6 2/3-inch layer (3,500 lb N/acre).
    - About 100 lb N/acre is left after harvest in crop residue and 50% of crop residue N is released as plant-available.
    - About 3% of soil organic matter N is released as plant-available inorganic N.
    - About 10 lb N/acre is deposited in precipitation.
- The above assumptions result in a total of 165 lb N/acre from sources other than fertilization. The remainder of the crop N need would be supplied by applied fertilizer or manure N.
- If conditions are adverse or better for microbial activity and organic matter processing than assumed above, then net mineralization would change. For example, a ±25% change in N mineralization would be about a ±30 lb N/acre change in N derived from the soil for plant use. Using a fertilizer N use efficiency of 60% (a realistic average figure), then the change in N fertilization need would be ±50 lb N/acre – a wide range.

Nitrogen Fertilization of Corn

Some applied fertilizer N is always processed by soil microbes and incorporated into soil organic matter (perhaps 20 to 25% on average, which helps maintain soil organic matter), and some is lost to denitrification, leaching, and ammonia volatilization (perhaps 20%). Therefore, N use efficiency is always less than 100%. In the above example and using a 60% fertilizer N use efficiency, if the total corn plant N uptake is 275 lb N/acre (what might be found with a 200+ bu/acre corn crop), then the plant N needed from resources other than the soil is 110 lb N/acre, which could be met with a 180 lb N/acre fertilization rate. Since the supply of plant available N from the soil varies and plant N use efficiency varies, both the corn plant growth and response to applied N and the point of economic optimum N rate vary between years and fields. Figure 2 illustrates this for corn grain yield response to fertilizer N rate for six consecutive years at the same site with corn following corn. This uncontrolled variation in net N mineralization and N use efficiency is the major reason why it is difficult to predict optimal fertilization rates.

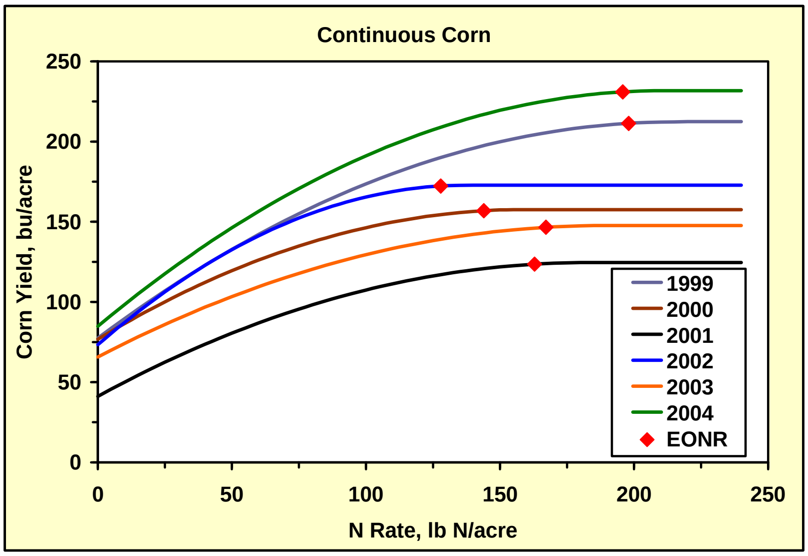

Figure 2. Variation in corn grain yield response to fertilizer N and economic optimum N rate (EONR) in six consecutive years at the same site near Ames, Iowa. (Source: J. E. Sawyer)

Maintaining Total Soil N

There is currently a debate in the scientific community about N fertilization rates needed to maintain soil N (and also C) and long-term sustainability of crop production for cropping systems that do not include forage legumes or mixtures of grasses and forage legumes. For corn, several principles are clear.

- Maintaining soil N means maintaining soil organic matter.
- Without N fertilization soil N will be depleted, and small changes in total soil N can drastically affect plant-available N supply.

- Without N fertilization soil organic matter will decline and supply of plant-available N will decrease, and stabilize at a low net plant-available N level with resultant low corn yield.
- High corn yields require N fertilization to supplement the soil N supply.
- Applied N furnishes required plant N and maintains soil N.
- The hope is that economic optimum N rates will approximately balance the input and output of N from the soil (maintain soil N) in corn production systems. This is very difficult to measure and is at the center of scientific debate.
- Nitrogen mineralization from soil organic matter and crop residues supplies inorganic plant-available N, and also nitrate that can leach from soils (Figures 1 and 3).
- Nitrogen fertilization supplies needed plant-available and nitrate that can leach from soils (Figure 3).
- The hope is that nitrate leaching at economic optimum N rates applied to corn is at an acceptable level.
- Reducing N fertilization to below economic optimum rates can reduce nitrate loss, but will not eliminate it.
- Growing forage legumes in rotation with grain crops can reduce but not stop nitrate loss because of N mineralization in soils.
- Because the soil is an open system (top and bottom), losses of N will occur. This makes maintenance of soil N (and organic matter) and optimal crop yields with fertilization difficult while attempting to minimize environmental impacts.

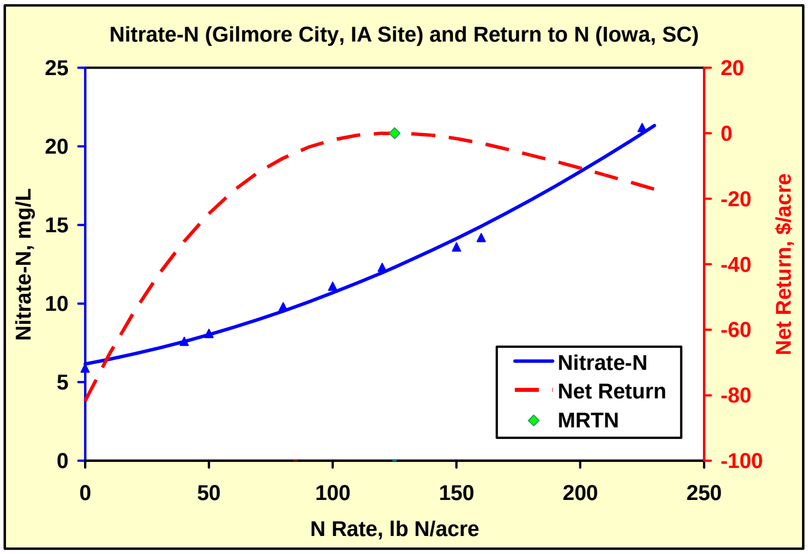

Figure 3. Tile-flow annual average nitrate-N concentration and economic return relative to the maximum net return across N rates for corn following soybean (SC) in Iowa. The maximum return to N (MRTN) is indicated by the diamond symbol. (Source: Adapted from Sawyer and Randall, 2008)

The Difficult Task
Many soil chemical and physical properties benefit from having organic matter in soils, with resultant benefits for soil sustainability and crop productivity. To maintain (or increase) soil organic matter requires a concurrent maintenance (or increase) of soil N. Because of the complex and open soil system, it difficult if not impossible to produce high-yielding row crops in Iowa agricultural systems without impacting soil N and nitrate loss to the environment. Proven soil management and N fertilization practices should be used to help optimize crop yields, N use efficiency, and water quality. At the same time, improved N management practices and alternative cropping systems could greatly aid in this challenging task.