



**Nutrient Management Technical Note No. 6**

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## **Nitrogen Efficiency and Management**

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# Nitrogen Efficiency and Management

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## Overview

Nitrogen (N) is an essential element for plant growth and animal nutrition and is the nutrient taken up in the largest amount by plants. N is a component of essential plant compounds required in numerous biological processes, including genetic transmission (DNA, RNA), plant growth (proteins, enzymes) and photosynthesis (chlorophyll). Most non-leguminous crops require added N to achieve the yields expected in modern agriculture. Nitrogen is also the nutrient that is most likely to be lost to the environment.

Excess N in the environment can adversely affect humans, animals, and the biology of the environment. The movement of N into surface waters often leads to its contamination and eutrophication, a general enrichment in fertility, which later produces a decline in oxygen content of the water. The reduced oxygen concentration results in subsequent death of fish and decline in aquatic life. Nitrogen as a gas (nitrous oxide) can degrade the ozone level and contribute to global warming. Ammonia losses from soil and plants contribute to off-site contamination and even acid rainfall.

## Nitrogen Use Efficiency and Management

The objective of N management is to maximize the efficiency of plant use of the applied N. An increase in efficiency will increase the agronomic value of the fertilizer by increasing crop production, conserve energy by saving on the raw material used to make the N, and minimize the potential for adverse effect on the environment.

Nitrogen use efficiency is defined as the ratio of the crop nitrogen uptake, to the total input of nitrogen fertilizer. It can also be defined more broadly as the ratio, of crop nitrogen uptake, to available soil N which would include applied fertilizer N plus residual mineral N in the soil. The greater the ratio the better the nitrogen use efficiency. Producers and agronomists strive to optimize crop yields with minimum nitrogen inputs. High nutrient use efficiencies reduce the

amount of nitrogen remaining following crop production. Excess nutrients are subject to various fate and transport processes that deliver the residual nitrogen to locations where it is not needed and resource degradation can occur.

## Fate and Transport Processes

### Leaching

Nitrate ( $\text{NO}_3^-$ ), a negatively charged ion, is repelled by negatively charged clay and organic surfaces in soil. Nitrate nitrogen, the primary form of N leached into groundwater, moves freely with water through most soils. The undesirable addition of  $\text{NO}_3^-$  to ground water is a consequence of its high solubility, mobility, and easy displacement by water. Leaching losses in agricultural systems can be large, often in a range of 10 to 20% of the nitrogen applied.

### Erosion

Nitrogen attached to soil is moved to surface water by the processes of detachment, transport, and deposition of soil particles. Soil particles can be detached by raindrops or by surface flow. Eroded sediments may travel only a few inches or long distances before they are redeposited to the landscape or reach a surface water resource (e.g., lakes, reservoirs, estuaries, or streams).

Wind may also erode and transport soil particles to surface water resources.

Ammonium ( $\text{NH}_4^+$ ), a positively charged ion is attracted and bound to negatively charged clay and organic surfaces in soil. Ammonium typically moves with detached fine sediments (clay, silt, organic matter).

When  $\text{NH}_4^+$  laden sediments are combined with  $\text{NO}_3^-$  in surface runoff, the resulting total N value can be greater than that measured in the contributing soil(s).

### Surface Runoff

Surface runoff is the loss of water from an area by flow over the land surface. Runoff water can induce desorption and movement in solution of

nitrogen compounds as it passes across the soil surface. The highest potential for nitrogen runoff comes from surface applied fertilizers and manures, even if erosion is minimal. Under these conditions, N losses in runoff can be high, but they can vary depending on the amount of nitrogen applied and the soil surface conditions.

### **Ammonia volatilization**

Ammonium ions ( $\text{NH}_4^+$ ) in the soil solution exist in equilibrium with ammonia ( $\text{NH}_3$ ) in the soil solution. There is a tendency for the equilibrium to favor conversion to ammonia because solution  $\text{NH}_3$  is subject to gaseous losses to the atmosphere.

Soil pH and the concentration of ammonium ( $\text{NH}_4^+$ ) in the soil solution are important factors affecting amount of ammonia ( $\text{NH}_3$ ) volatilized. As soil pH increases, the fraction of soil-solution ammonium and  $\text{NH}_3$  increases by an order of magnitude for every unit of pH above 6.0.

The following summarizes favorable conditions for  $\text{NH}_3$  volatilization:

- Prominent on calcareous soils, especially as soil pH exceeds 7;
- Can be appreciable for neutral or alkaline soils as they dry out;
- Increases with temperature and wind speed;
- Greater in soils of low CEC, such as sands where  $\text{NH}_4^+$  adsorption is low;
- High when high-N organic wastes, such as manure, are applied to the soil surface and permitted to decompose;
- High from urea when it is applied to grass or pasture, as a result of hydrolysis of the urea to  $\text{NH}_3$  by urease enzyme;
- Losses are decreased by growing plants.

Volatilization losses can be as high as 100% of the ammonium on or near the soil surface if one or more of the above conditions exist.

### **Mineralization, Nitrification and Denitrification**

As plants and other organic residues decompose, nitrogen is converted from organic-N into ammonium ( $\text{NH}_4^+$ ), a process referred to as *mineralization*.

### **Nitrification**

Is generally viewed as a two-step process involving several types of specialized bacteria.

Step 1. Ammonium ( $\text{NH}_4^+$ )  $\rightarrow$  Nitrite ( $\text{NO}_2^-$ )  
In the presence of genus *Nitrosomonas* bacteria.

Step 2. Nitrite ( $\text{NO}_2^-$ )  $\rightarrow$  Nitrate ( $\text{NO}_3^-$ ) occurs  
In presence of genus *Nitrobacter* bacteria.

The over-all process results in the biological oxidation of ammonia with oxygen into nitrite followed with the oxidation of these nitrites into nitrates. Nitrification is an important step in the nitrogen cycle.

### **Denitrification**

Nitrate can also be lost to the atmosphere through the *denitrification* processes. Nitrite ( $\text{NO}_2^-$ ) usually does not accumulate in soils because it is rapidly transformed to  $\text{NO}_3^-$  or is denitrified to  $\text{N}_2$  gas, nitrous oxide ( $\text{N}_2\text{O}$ ), nitric oxide ( $\text{NO}$ ), or one of the other gaseous nitrogen oxide ( $\text{NO}_x$ ) compounds. Nitrous oxide, a product of incomplete denitrification, is a greenhouse gas and may contribute to global climate change and to thinning of the ozone layer.

Denitrification is the route for most losses of gaseous N compounds to the atmosphere. The potential for denitrification is increased as oxygen levels in the soil decrease. Nitrate, a desirable nutrient for plants, is reduced first to  $\text{NO}_2^-$ , then to  $\text{NO}$ , next to  $\text{N}_2\text{O}$ , and finally to  $\text{N}_2$ . In addition to limited oxygen, denitrification needs a carbon source of energy, effective microbes, and oxides of N. Denitrification losses can be as high as 10 pounds of nitrogen per acre per day when conditions are optimum.

### **N Management Practices that Improve Nitrogen Efficiency**

The objective of N management is to maximize the efficiency of plants to use the applied N. Improvements in nitrogen use efficiency are associated with decreases in N loss through processes of fate and transport mentioned above. While losses cannot be avoided completely, significant improvements can be realized by applying management and conservation practices to the cropping system. The following

list of techniques and practices provide some general guidance.

### **Conservation Tillage**

- Conservation tillage reduces total N losses due to reduced sediment and runoff.
- Conservation tillage optimizes soil moisture conditions that improve water use efficiency.
- Runoff and leaching losses of nitrate are not consistently affected by conservation tillage.

### **Other Conservation Practices**

- Crop rotations favorably impact the fertility of the soil. Deep-rooted crops capture nitrates lower in the soil profile.
- Cover crops capture residual nitrogen after crop harvest and recycle it as plant biomass.
- Soil erosion and runoff control lessens the nutrient transport processes.
- Incorporation and/or injection lessen the volatilization of ammonium nutrients.

### **Nitrogen Rates**

- Maintain accurate yield records or use an alternate realistic method to determine reasonable yield expectations.
- Follow your Land Grant University's recommendation for nitrogen application.
- Take credit for N applied as manure, irrigation water, atmospheric deposition, and fixed by legumes in rotation.
- Use appropriate soil tests to determine residual soil, water and plant N.

### **Soil Testing for N**

- Preplant soil tests provide information on the soil's supply power.
- Late spring or pre-side-dress N tests can determine if and how much additional N is needed.
- New soil test and sampling procedures, such as amino sugar tests, grid mapping, and real-time sensors will define N requirements.
- Post-harvest soil tests determine if N management the previous season was appropriate.

### **Application Precision of N**

- New designs of manifolds on application equipment increases the uniformity of anhydrous ammonia distribution.
- Row applicators, such as injectors, which form a compacted soil layer and surface ridge, can reduce N losses.
- Variable rate applicators, combined with intensive soil or crop sampling, allow more precise and responsive application rates.

### **Irrigation Management of N**

- Schedule irrigation based on soil moisture estimates and daily crop needs to improve irrigation efficiency and soil moisture use.
- Sprinkler irrigation systems apply water more uniformly and in lower amounts than furrow or basin irrigation systems.
- Furrow irrigation efficiency can be improved by adjusting set time, stream size, furrow length, watering every other row, or the use of surge valves.
- Alternate row irrigation and fertilization minimizes water contact with nutrients.
- Application of N fertilizer through irrigation systems facilitates supplying N when crop demands are greatest.
- Polyacrylamide (PAM) treatment during furrow irrigation reduces sediment and N losses.

### **Crop Testing for N**

- Plant tissue tests can identify N deficiencies.
- Sensing variations in plant chlorophyll content facilitates variable rate N applications in-season.
- Post-black-layer corn stalk nitrate tests help to determine if N rates were low, optimal, or excessive in the previous crop, so that management changes can be made in following crops.

### **Timing of N Applications**

- Apply N close to the time when crops can utilize it.
- Make side-dress N applications close to the time of most rapid N uptake.

- Split applications, involving more than one application, allow efficient use of applied N and reduce the risk of N loss to the environment.
- Fall N applications may be discouraged in some areas, but can be successful if ammonium fertilizers and manures are applied when soil temperatures are below 50° F.

### **N Fertilizer Application Method and Placement**

- Injection or incorporation of urea or N solutions reduces volatility losses.
- In ridged crops, placing N fertilizers in a band in ridges makes N less susceptible to leaching.

### **N Forms, including Slow or Controlled Release Fertilizers and Inhibitors**

- Slow or controlled release fertilizer delays the availability of nitrogen to the plant until a time that is more appropriate for plant uptake and can avoid periods of potentially risky fate and transport.
- Nitrification inhibitors maintain applied ammoniacal fertilizers in the ammonium form longer, reducing leaching and denitrification losses.
- Where fall N applications are appropriate, nitrification inhibitors reduce risk of leaching loss.
- Urease inhibitors temporarily block the function of the urease enzyme, maintaining urea-based fertilizers in the non-volatile urea form, reducing volatilization losses when these fertilizers are surface applied in high residue, conservation tillage systems.

### **Drainage Tile Systems**

- Subirrigation systems recycle nitrate leached from the soil profile and reduce nitrate lost to subsurface tile drainage.
- Controlled drainage favors denitrification.

### **Conservation Buffers**

- Buffers trap sediment containing ammonia and organic N.
- Nitrate in subsurface flow is reduced through denitrification enhanced by carbon energy sources contained in the soil associated with buffer vegetation.
- Buffer vegetation takes up nitrogen, other nutrients, and reduces loss to water.

### **Constructed Wetlands**

- Constructed wetlands located strategically on the landscape to process drainage effluent reduces sediment and nitrate loads to surface water.

### **Pest Management**

- Appropriate pest management allows crops to attain their potential yields, optimizing applied N thus reducing the excess N available for loss.
- Bt corn prevents European corn borer feeding and associated stalk rots, which can cause corn to die early and leave excess N in the soil.

### **Breeding Crops for Efficient N Uptake**

- Particular crop varieties are able to more efficiently extract N from the soil and improve N use efficiency.

### **References**

- 1) Follett, R.F. 2001. Nitrogen Transformation and Transport Processes. pp. 17-44, In R.F. Follett and J. Hatfield. (eds.). 2001. Nitrogen in the Environment; Sources, Problems, and Solutions. Elsevier Science Publishers. The Netherlands. 520 pp.
- 2) van Es, H.M., S.D. Klausner, and W.S. Reid. 1991. Nitrogen and the Environment. Cornell Coop. Ser. Bull. 218. Cornell University, Ithaca, NY.