N Loss Mechanisms and Nitrogen Use Efficiency

R.L. (Bob) Nielsen, Purdue Agronomy
rnielsen@purdue.edu

Introduction

Applied fertilizer nitrogen is partly taken up and used by the corn crop and partly "lost" to the environment. Nitrogen Use Efficiency (NUE) is a term used to indicate the relative balance between the amount of fertilizer N taken up and used by the crop versus the amount of fertilizer N "lost". Another way of thinking about NUE is in terms of the number of lbs of grain harvested versus lbs of N applied. In other words, a high NUE value is desirable (more lbs of N in the plant, less lbs of N to the environment).

Nitrogen use efficiency is primarily influenced by two factors. One is the health of the "photosynthetic factory" (the corn crop). A healthy vigorous crop represents a "factory" operating at maximum efficiency and one that uses all of its available resources efficiently.

An example of such efficiency was the nearly stress-free 2004 growing season throughout much of Indiana. Corn grain yields that year for many fields were phenomenally high even though most growers did not apply any more nitrogen fertilizer than they usually do. In other words, NUE was very high.

Consequently, the use of solid agronomic crop production practices that help ensure the development of a vigorous healthy crop will also increase the probability of high NUE. Important decisions under your control include variety selection, planting date, seeding rate, soil fertility in general, pest management, and tillage practices.

The second factor that influences NUE is the combination of the frequency and severity of nitrogen loss opportunities within the nitrogen cycle (Fig. 1). The two predominant N loss mechanisms that affect Indiana corn fields are leaching and denitrification of the nitrate-N form of nitrogen. Nitrogen loss due to volatilization of surface-applied urea-based products is a third source of N loss for some fields.

Leaching of Nitrate-N

All applied N fertilizer sources eventually convert completely to the nitrate-N form. This form of nitrogen is not held tightly by soil particles and can be leached from the soil profile with excessive rains, especially on lighter-textured soils. Nitrate-containing fertilizers, including UAN solutions and ammonium nitrate, are susceptible to leaching loss as soon as they are applied. Urea can convert to nitrate-N in less than two weeks in late spring; and thereafter is susceptible to leaching loss. Anhydrous ammonia converts more slowly to nitrate-N because of its initial toxic effects on the soil microbes responsible for the conversion of ammonium-N to nitrate-N.

Denitrification of Nitrate-N

Certain soil bacteria that thrive in saturated (anaerobic) soil conditions will convert nitrate-N to oxygen and nitrogen gases. Volatilization of the nitrogen gas can result in N losses of as much as 5% of the available nitrate-N per day[1]. Soils at greatest risk to denitrification N loss are those that are naturally heavy and poorly drained, plus fields with significant levels of soil compaction that restricts natural drainage. Because denitrification affects nitrate-N, the relative risk of N fertilizer products is identical to that for leaching N loss (see above).

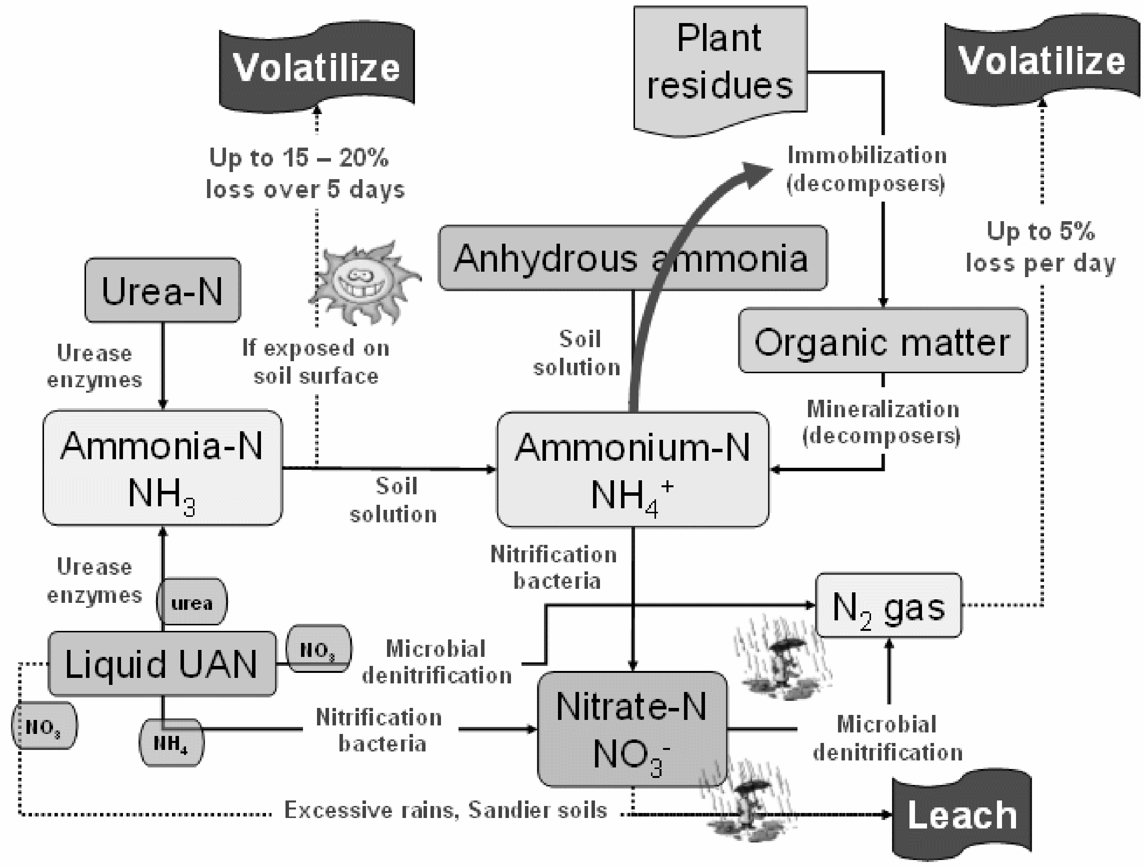

Fig. 1. The nitrogen cycle as it relates to several nitrogen fertilizer sources (anhydrous ammonia, liquid UAN, urea) and their susceptibility to N loss mechanisms (volatilization, immobilization, denitrification, leaching).

Volatilization of Urea-Based Products

Urea-based nitrogen fertilizer products are susceptible to volatilization losses of nitrogen if surface-applied and not incorporated. Urease enzymes in the soil and plant residues convert the urea component to free ammonia gas. If this conversion occurs at the soil surface and is accompanied by warm sunny days, as much as 15 ~ 20% of the urea-based

---

[1] Hoeft, Robert. 2004. Predicting and measuring nitrogen loss. Univ. of IL Pest Mgmt Newsletter. 28 May 2004. Online at http://www.ipm.uiuc.edu/bulletin/article.php?issueNumber=10&issueYear=2004&articleNumber=8 [URL verified 1/3/06].

nitrogen may volatilize within a week after application[2]. If a half-inch or more of rain occurs within the first 24 hours after surface application, the risk of subsequent volatilization also drops to essentially zero[2]. If the urea-based product is injected or mechanically incorporated after application, the risk of volatilization is essentially zero.

Forms of nitrogen fertilizer susceptible to volatilization losses include dry urea or liquid urea-ammonium-nitrate (UAN) solutions surface-applied without incorporation. The risk of volatilization loss is greatest with high-residue cropping systems, warm sunny days after application, and surface soil pH levels greater than 7.0. Volatilization risk is also high on lighter textured soils with low buffer capacity.

Nitrogen Immobilization

A fourth N loss mechanism is more temporary in nature. Soil microbes that decompose high carbon-content plant residues to organic matter use soil N during the decomposition process[3]. Consequently, the nitrogen from the surface-applied fertilizer is "tied up" in the resulting organic matter and is temporarily unavailable for plant uptake until mineralization of the organic matter occurs at a later date. Such immobilization of soil N can be especially prevalent in high-residue no-till cropping systems. Unfortunately, applying N fertilizer in the fall to corn residues has not been shown to reduce N immobilization or speed residue decomposition.

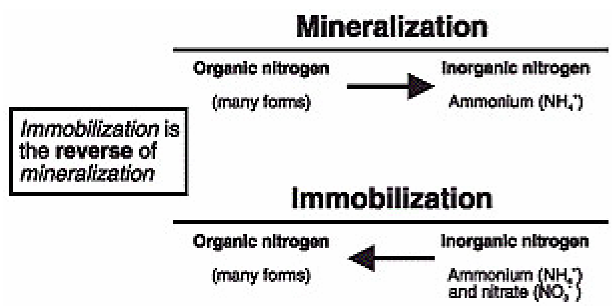

Fig. 2. Comparison of mineralization and immobilization. From: Killpack & Buchholz, 1993.

Challenge of Nitrogen Management

Nitrogen use efficiency varies from one situation to another due to variability for crop health (plant stresses) and the magnitude of nitrogen loss. Nitrogen loss potential is influenced primarily by weather conditions and soil type. Rainfall, sunshine, and temperature all influence the rate of volatilization of surface-applied urea-based products. The timing and amounts of rainfall influence the rates of leaching and denitrification losses of available nitrate-N.

---

[2] Bundy, L.G. 2001. Managing Urea Fertilizers. Univ. of Wisconsin. Presentation at 2001 Area Fertilizer Dealer Meetings, 27 Nov – 6 Dec. 2001. Online at http://www.soils.wisc.edu/extension/publications/horizons/2001/Urea_management.pdf [URL verified 1/3/06].

[3] Killpack, Scott C. and Daryl Buchholz. 1993. Nitrogen in the Environment: Mineralization Immobilization. Univ. of Missouri Extension Publ. WQ260. http://muextension.missouri.edu/explore/envqual/wq0260.htm [URL verified 1/3/06].

Nitrogen loss potential is also obviously influenced by the fertilizer source of N and how it is used. Managing nitrogen wisely therefore requires managing N fertilizer sources wisely to minimize the odds of N loss specific to the N source. The three most commonly used sources of fertilizer N in Indiana are anhydrous ammonia, liquid UAN, and dry urea.

Anhydrous Ammonia (82% N). This source of fertilizer N remains the cheapest source of nitrogen per pound of actual N even at current prices greater than $500 per ton. This gas form of N obviously must be injected, so the risk of surface volatilization is essentially zero if the knife slots are properly closed.

Once applied, anhydrous ammonia quickly converts in the soil solution to the ammonium-N form, which is held tightly to soil particles and is not susceptible to either leaching or denitrification. The ammonium-N form eventually undergoes a microbial conversion (nitrification) to the nitrate-N form.

Because of the toxic effects of the ammonia on the nitrifying soil microbes within the band of application, anhydrous ammonia acts as its own nitrification inhibitor for at least a week and delays the microbial conversion of ammonium-N to nitrate-N. Consequently, the risk of leaching or denitrification of nitrate-N is delayed.

Further delay of the nitrification process can be achieved by adding a nitrification inhibitor (e.g., N-Serve®) with the anhydrous ammonia to delay the microbial nitrification process for 4 to 10 weeks[4]. The use of such nitrification inhibitors is best suited to late fall or early spring applications, with less likelihood of yield responses with late spring or sidedress applications.

Urea and UAN Solutions. Both of these sources of N, while less costly per ton of product than anhydrous ammonia, are more expensive per lb of actual N because they contain smaller percentages of actual N (46 and 28%, respectively). The higher cost per lb of actual N for these products is partially offset by their typically lower application costs per acre.

Both products are subject to nitrate-N losses sooner after application than is anhydrous due to their quicker conversion to the nitrate-N form (2 ~ 3 weeks after application) and, for UAN, the fact that part of the product is already in the nitrate-N form. If surface applied, the urea component of these products is also subject to volatilization loss.

The risk of N loss by volatilization can be reduced by including a urease-inhibitor (e.g., Agrotain®) with the fertilizer products to delay the initial microbial conversion of the urea components to ammonia. Volatilization loss can be prevented entirely by injecting or incorporating urea-based products. A compromise to injection or full incorporation is to surface-apply these products in a concentrated surface band, thus reducing the percentage contact with surface residues and the urease enzymes that reside therein.

A nitrogen fertilizer technology common to the turf industry is slowly making inroads to field crop production; polymer coated urea (PCU). The premise of PCU is that the polymer coating allows moisture through to dissolve the urea but delays the movement of

[4] Nelson, D. and D. Huber. 1992 (rev.) Nitrification Inhibitors for Corn Production. NCH-55. Iowa State Univ. Online at http://www.extension.iastate.edu/Publications/NCH55.pdf [URL verified 1/3/06].

the dissolved urea solution back out to the soil solution and thus delays the contact of the urea component with urease enzymes. The risk of nitrate-N loss by denitrification or leaching can be delayed by including a nitrification inhibitor (e.g., N-Serve®) with the fertilizer product to delay the microbial conversion of ammonium-N to nitrate-N, though this practice is not common in Indiana.

Inhibitors vs. Sidedress

Urease inhibitors (used with urea or UAN solutions), nitrification inhibitors (used primarily with anhydrous ammonia), or polymer coated urea represent various forms of nitrogen loss "insurance" that add cost to your nitrogen management program (from ~ 5 to 10 cts per lb of actual N). Like any insurance policy, the policy will "pay off" only if conditions are suitable for N loss to occur prior to plant uptake.

Another strategy to manage the risk of N loss is sidedress apply your fertilizer N instead of applying it pre-plant. The main reason that sidedress N applications will be more efficient in the "long haul" is that there is a shorter calendar "window" between application and plant uptake for sidedress than for pre-plant applications. The shorter time period means there are fewer opportunities for heavy rainfall events and nitrate-N loss; and thus NUE will be greater on average. Sidedress applications often do not add dollar cost to your fertilizer program, but obviously alter the logistics of your farming operation and are more at risk from rainy weather prior to "too tall" corn.

In Summary…

One of the keys to managing costs of nitrogen fertilizer or maximizing nitrogen use efficiency is to manage N sources wisely to minimize the risk of nitrogen loss due to leaching, denitrification, or volatilization. The use of a sidedress application strategy remains one of the easiest and least expensive ways to maximize nitrogen use efficiency. Other application methods and timings need to be matched wisely to nitrogen fertilizer source to minimize the risk of nitrogen loss prior to plant uptake.