NITROGEN
A CRITICAL INPUT FOR CORN

Nitrogen (N) fertilizer is a critical input in corn production. One of the most challenging aspects of successfully managing nitrogen is the fact that nitrogen from fertilizer can be lost from the soil before the corn crop is able to take it up. Under prolonged wet field conditions and warm temperatures, nitrogen can be lost either by leaching—the downward movement of nitrates below the root zone, or denitrification—loss to the atmosphere caused by reactions in the soil under anaerobic conditions. Surface-applied nitrogen can also be lost through ammonia volatilization if it's not incorporated into the soil by tillage or rainfall.

NITROGEN FERTILIZER FORMS

The most commonly used forms of nitrogen fertilizer in corn production in North America are anhydrous ammonia, urea and urea-ammonium nitrate (UAN) solutions. Although there are several other forms of nitrogen fertilizers such as ammonium sulfate, calcium nitrate and diammonium phosphate, over 80% of the N needs of corn in North America are met by anhydrous ammonia, urea and UAN solutions (Table 1).

Fertilizer	Form	% N
Anhydrous ammonia	Gas, applied as liquid from pressurized tank	82
Urea	Solid	46
UAN solutions	Liquid	28-32

Table 1. Nitrogen fertilizers most commonly used for corn production in North America.

Anhydrous ammonia (NH_3) is the most basic form of N fertilizer. Ammonia, a gas at atmospheric pressure, must be compressed into a liquid for transport, storage and application. Consequently, it is applied from a pressurized tank and must be injected into the soil to prevent its escape into the air. Anhydrous ammonia is applied by injection 6 to 8 inches below the soil surface to minimize escape of gaseous NH_3 into the air. When applied, ammonia reacts with soil water and changes to the ammonium form, NH_4^+. As a positively charged ion, ammonium binds with negatively charged soil constituents including clay and organic matter. Nitrogen in the ammonium form is held in the soil exchange complex and is not subject to movement with water. Ammonium ions are converted to the nitrate (NO_3^-) form by the action of soil bacteria in a process known as **nitrification**.

Nitrification is a two-step process: 1) oxidation of ammonia (NH_3) into nitrite (NO_2^-), and 2) oxidation of nitrite into nitrate (NO_3^-). Most other common N fertilizers are derivatives of ammonia transformed by additional processing, which increases their cost.

Urea is a solid fertilizer with high nitrogen content (46%) that can be easily applied to many types of crops and turf. Its ease of handling, storage and transport; convenience of application by many types of equipment; and ability to blend with other solid fertilizers has made it the most widely used source of N fertilizer in the world. Urea readily dissolves in water, including soil water; consequently, it can be incorporated into the soil by sufficient rainfall or irrigation (½ inch is typically suggested). Otherwise, it should be incorporated by tillage to reduce losses.

Urea-ammonium nitrate (UAN) solutions are liquid fertilizers made by dissolving urea and ammonium nitrate (NH_4NO_3) in water. The composition of common N solutions is shown in Tables 2 and 3.

Total N	UAN-28 28%	UAN-30 30%	UAN-32 32%
	– approx. lbs in 100 lbs of solution –		
Urea	30	32	35
NH_4NO_3	40	43	45
Water	30	25	20

Table 2. Total N content and quantities of urea, ammonium nitrate and water in 100 lbs of common UAN solutions.

Total N	UAN-28	UAN-30	UAN-32
	28%	30%	32%
Amide (NH_2)	14%	15%	16%
Nitrate (NH_4^+)	7%	7.5%	8%
Nitrate (NO_3)	7%	7.5%	8%

TTable 3. Percent of nitrogen by type in UAN solutions. Half of the total N in UAN solutions is amide N (NH_2^-) derived from urea, ¼ is ammonium N (NH_4^+) derived from ammonium nitrate and ¼ is nitrate N (NO_3^-) derived from ammonium nitrate.

NITROGEN LOSSES

Nitrogen loss constitutes a major challenge to agricultural efficiency and sustainability. Globally, less than half of nitrogen applied to crop land is taken up by the crop.[1] Not only is this economically wasteful, the loss of reactive nitrogen from agricultural soils is associated with several adverse environmental consequences, including contamination of ground and surface water, algal blooms in lakes and rivers, hypoxic dead zones in coastal waters and nitrous oxide emissions into the atmosphere. The majority of nitrous oxide emissions from soils are produced during denitrification. **Denitrification** is a microbially facilitated process where nitrate (NO_3^-) is reduced and converted to N_2 gas through a series of intermediate steps. The greatest nitrogen losses through denitrification generally occur in the spring when rainfall events are most frequent and crop uptake of nitrogen from the soil is relatively low.

NITROGEN STABILIZERS

Nitrification inhibitors

Nitrification inhibitors are compounds that slow the conversion of ammonium to nitrate, prolonging the period of time that nitrogen is in the ammonium form and reducing nitrogen loss from the soil. Several compounds have proven effective for this purpose, including nitrapyrin, dicyandiamide (DCD) and ammonium thiosulfate.

Nitrapyrin, or 2-chloro-6-(trichloromethyl) pyridine, works by inhibiting and depressing the activity of *Nitrosomonas* bacteria. Specifically, it inhibits the activity of ammonia monooxygenase (AMO), the enzyme that oxidizes NH_4 into NH_2OH in the first step of nitrification. Inhibition of the AMO enzyme by nitrapyrin delays nitrification activity for several weeks to months following application. Nitrapyrin products for delaying nitrification of ammoniacal and urea fertilizers include N-Serve® nitrogen stablizer and Instinct NXTGEN® nitrogen stablizer. N-Serve nitrogen stabilizer is an oil-soluble formulation of nitrapyrin for use with anhydrous ammonia. Instinct NXTGEN nitrogen stabilizer is a water-based micro-encapsulated formulation of nitrapyrin that may be used with urea, UAN solutions, ammonium sulfate, liquid manure, aqua ammonia, liquid fertilizers containing N and ammonium-containing dry fertilizers (MAP or DAP).

Nitrification inhibitors have proven very effective in increasing soil nitrogen retention and reducing losses through leaching and denitrification. A 2004 meta-analysis of hundreds of comparisons across a diversity of environments found that the use of nitrification inhibitors increased soil nitrogen retention by an average of 28% and reduced leaching by 16%.[2] Corteva Agriscience field trials conducted over several years found that the use of nitrification inhibitors increased corn yield by an average of around 6 bu/acre.

Urease inhibitors

Urease inhibitors are compounds that reduce volatilization losses of urea applied to the soil surface by slowing down urea hydrolysis. For the nitrogen in urea to be available to plants, it must undergo hydrolysis, a chemical reaction that transforms the amide groups of the urea molecule to ammonia (NH_3). The urease enzyme, ubiquitous in soils, catalyzes this hydrolysis reaction. If this process occurs at the soil surface, ammonia can be lost to the air. However, if this reaction is delayed until surface-applied urea is incorporated into the soil by tillage, rainfall or irrigation, the risk of ammonia loss is greatly reduced. Certain compounds are known to inhibit the hydrolytic action of the urease enzyme, delaying urea hydrolysis. The most widely used urease inhibitor in agriculture is N-butyl-thiophosphoric triamide, (NBPT). NBPT is the active ingredient in PinnitMax® TG nitrogen stabilizer. PinnitMax TG is an additive for use with urea and urea-ammonium nitrate solutions.

PERFORMANCE OF NITROGEN STABILIZERS

Nitrogen stabilizers/additives have been widely tested over many years and have proven effective at increasing soil nitrogen retention. However, corn yield increases can vary from 0-20%. This is not surprising; when conditions favor nitrogen losses for a period, and a stabilizer is applied and effective during that period, a large benefit is predictable. On the other hand, under conditions not conducive to nitrogen losses, little advantage would be expected.

Because the risk of nitrogen loss is always present, growers should take appropriate precautions to reduce loss of this important crop nutrient. Nitrogen management decisions should take into account all factors that influence the risk of loss for a particular field, including local climatic conditions, topography, soil type, residue level, form of nitrogen fertilizer applied and timing of application relative to crop growth.

[1] Zhang, Xin, Eric Davidson, Denise Mauzerall, Timothy Searchinger, Patrice Dumas, and Ye Shen. "Managing nitrogen for sustainable development." *Nature*, 528 (September 23, 2015):51-59. doi:10.1038/nature15743.

[2] Wolt, Jeffrey. A meta-evaluation of nitrapyrin agronomic and environmental effectiveness with emphasis on corn production in the Midwestern USA. *Nutrient Cycling in Agroecosystems*, 69 (2004):23-41. https://doi.org/10.1023/B:FRES.0000025287.52565.99.