



Enhanced Efficiency Fertilizer Materials: Nitrogen Stabilizers

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What Are Nitrogen Stabilizers?

The recent increase in fertilizer costs, especially nitrogen fertilizers, has resulted in technologies that may improve nitrogen use efficiencies in agronomic cropping systems. Many of these technologies are designed as fertilizer additives to increase fertilizer use efficiencies by increasing plant fertilizer uptake and crop yields. The resulting fertilizer formulations include some type of extra additive within the formulation or applied as a coating and are often referred to as “enhanced efficiency fertilizers” (EEFs).

The Association of American Plant Food Control Officials defines EEFs as products with characteristics that allow increased plant uptake and therefore reduce potential nutrient losses to the environment (e.g., gaseous losses, leaching, or runoff) when compared to an appropriate reference fertilizer that does not contain additives (AAPFCO 2012). When comparing nitrogen EEFs, examples of reference products would be traditional fertilizer such as anhydrous ammonia, granular urea, ammonium sulfate, and urea-ammonium nitrate solutions.

The AAPFCO further breaks down EEFs into two distinct subcategories: (1) stabilized fertilizers and (2) controlled or slow-release fertilizers.

1. Stabilized fertilizers – Products claiming stabilization of nutrients must reduce the transformation rate of fertilizer compound(s), extending the time of nutrient availability to the plant by a variety of mechanisms relative to its unamended form.

2. Controlled or slow-release fertilizers – Products that convert and/or release nutrients that are in the plant-available form at a slower rate relative to a “reference-soluble” product (AAPFCO 2012).

When discussing stabilized nitrogen fertilizers, having a basic understanding of the nitrogen cycle is critical. The nitrogen cycle describes the chemical transformations, input processes, loss pathways, and uptake of nitrogen in ecosystems (fig. 1).

Why Are Nitrogen Stabilizers Needed?

The overall nitrogen fertilizer use efficiency in cereal production systems worldwide is estimated to be 33 percent (Raun and Johnson 1999). Nitrogen fertilizer use efficiency is low due to numerous loss pathways that include gaseous losses to the atmosphere via volatilization, as well as denitrification, leaching, and runoff (fig. 1).

In Virginia, all of these loss mechanisms are a distinct possibility in our cropping systems. For example, increased cover crop usage and no-tillage are positive for improving soil structure and increasing organic matter content in agronomic production systems, but they also increase the likelihood of nitrogen loss via ammonia volatilization.

In addition to gaseous losses, water percolating through soil will carry nitrate beyond the root zone and eventually to groundwater through a process called leaching.

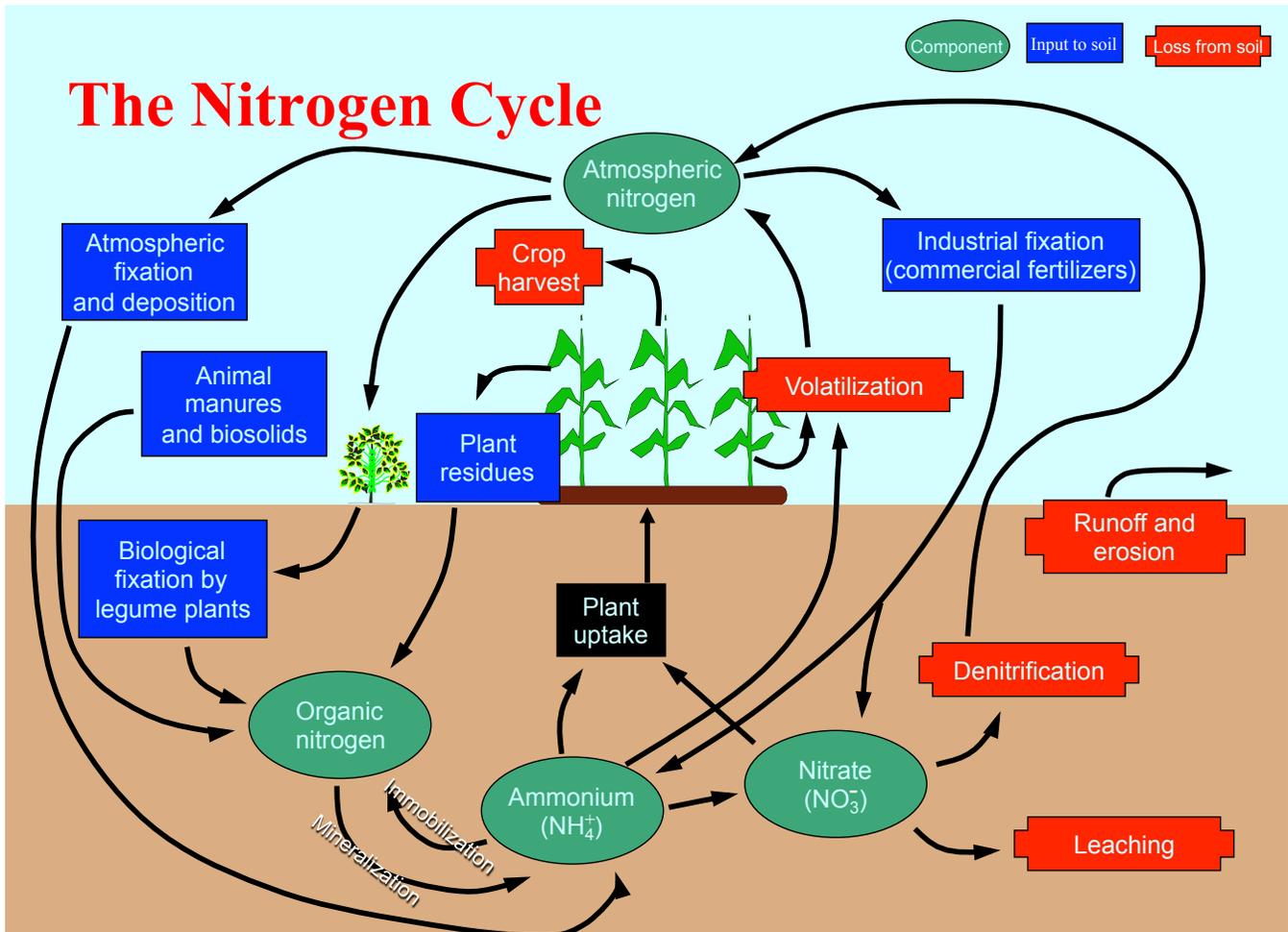


Figure 1. The nitrogen cycle (adapted from International Plant Nutrition Institute [2013]).

The largest row crop production areas of the commonwealth are located on sandy loam soil in the Coastal Plain that has a high propensity for leaching.

How Do They work?

Ammonia Volatilization Control With Nitrogen Stabilizers

Nitrogen stabilization products (fig. 2) potentially act on two nitrogen transformation processes: mineralization and nitrification.

Mineralization is the process by which nitrogen — in forms unavailable to plants — is converted by microbes into usable forms. These unavailable nitrogen forms include proteins and other chemical compounds from decomposing plant and microbial biomass (such

as organic matter). The degradation of these complex nitrogen “organic” molecules results in the formation of ammonium, which is one plant-available form of nitrogen.

Mineralization describes many chemical reactions taking place in the soil environment simultaneously, but of these chemical reactions, urea hydrolysis is the principal reaction targeted by nitrogen stabilizers.

Urea hydrolysis is the conversion of urea — the most common nitrogen fertilizer source worldwide — to ammonium (fig. 3). However, this chemical reaction does not occur without a penalty. The urea hydrolysis reaction produces bicarbonate, which raises soil pH around the reaction zone. The rise in pH results in the transformation of ammonium to ammonia gas, which can be lost to the atmosphere via ammonia volatilization.

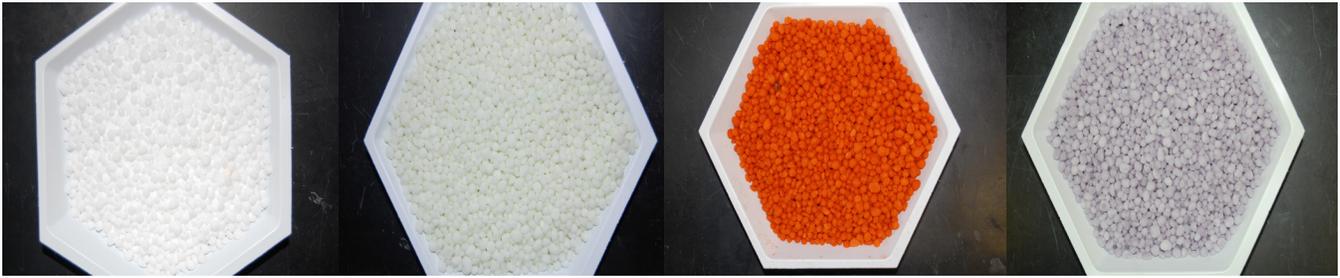


Figure 2. Untreated urea (1), urea stabilized with a urease inhibitor (2 and 4), and urea coated with potassium sulfate (3).

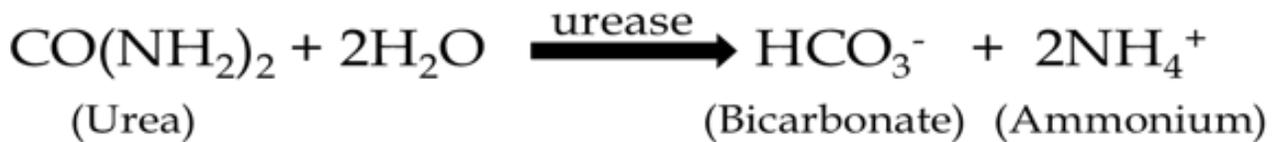


Figure 3. Urea hydrolysis reaction.

Nitrogen stabilizers focus on limiting urea hydrolysis and ammonia volatilization by inhibiting the enzyme urease. When urease is absent, urea hydrolysis proceeds much slower — 10^{14} times slower — than the catalyzed reaction (Krajewska 2009). Stabilized nitrogen products that claim a reduction in nitrogen loss via ammonia volatilization must slow the transformation of urea to ammonium and the resulting buildup of bicarbonate. This slower conversion allows soluble urea to spread into a larger volume of soil. This in turn, minimizes the pH increase and production of ammonia gas.

Reducing Nitrate Leaching With Nitrogen Stabilizers

Nitrate is a plant-available form of nitrogen, but nitrate is also very mobile in soils. The mobility of nitrate is due to its negative charge (fig. 4); which prevents it from forming bonds with clay minerals and organic matter, also predominantly negatively charged. Think of a magnet: The same poles (charge) will repel one another.

Nitrification is the process of ammonium transforming into nitrate. The nitrification process needs to be mediated by microorganisms. In soils, two microorganisms, specifically bacteria, are responsible for driving

nitrification. The two bacteria genera are *Nitrosomonas* spp. and *Nitrobacter* spp. Each plays a different role in nitrification, with *Nitrosomonas* spp. responsible for conversion of ammonium to nitrite and *Nitrobacter* spp. responsible for the conversion of nitrite to nitrate (fig. 4).

Inhibiting nitrification at the right place is critical, and nitrification inhibitors should target *Nitrosomonas* spp. Accumulation of nitrite in soils could result in nitrite toxicity to plants. Inhibiting *Nitrosomonas* spp. will maintain nitrogen as plant-available ammonium that is less mobile in soils than nitrate because ammonium has a positive charge that allows it to “stick” to the negatively charged soil particles. Think of a positive side of a magnet (the ammonium) sticking to the negative side of a magnet (the soil particle).

Maintaining nitrogen as ammonium minimizes leaching and groundwater contamination risk while maximizing available nitrogen in agroecosystems. The mode of action for different nitrification inhibitors typically falls into two primary categories: (1) bactericide and (2) bacteriostatic activity.

1. Bactericides kill *Nitrosomonas* spp. and are labeled as pesticides.

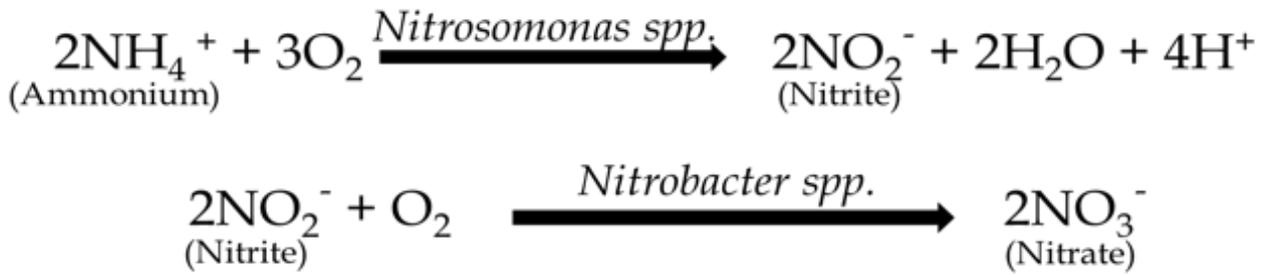


Figure 4. Nitrification reactions.

2. Nitrification inhibitors that have bacteriostatic activity slow the metabolism of targeted species or genera (*Nitrosomonas* spp.), thereby slowing the transformation of ammonium to nitrite.

One common nitrification inhibitor incorporated into fertilizers and used around the world today is dicyandiamide (DCD; [HN=C(NH₂)-NH-CN]). The DCD additive itself is a slow-release nitrogen fertilizer (approximately 67 percent nitrogen) and has bacterio-

static properties on *Nitrosomonas* spp. Research conducted on a silt loam soil by Reiter (2008) found that DCD applied at a rate of 10 percent w/w (by weight) of fertilizer halted *Nitrosomonas* spp. activity over the 110-day growing season, and nitrification was negligible (fig. 5). Keeping nitrogen in the ammonium form allows the cation to “stick” to the soil’s cation-exchange capacity and removes the chance of gaseous losses from denitrification.

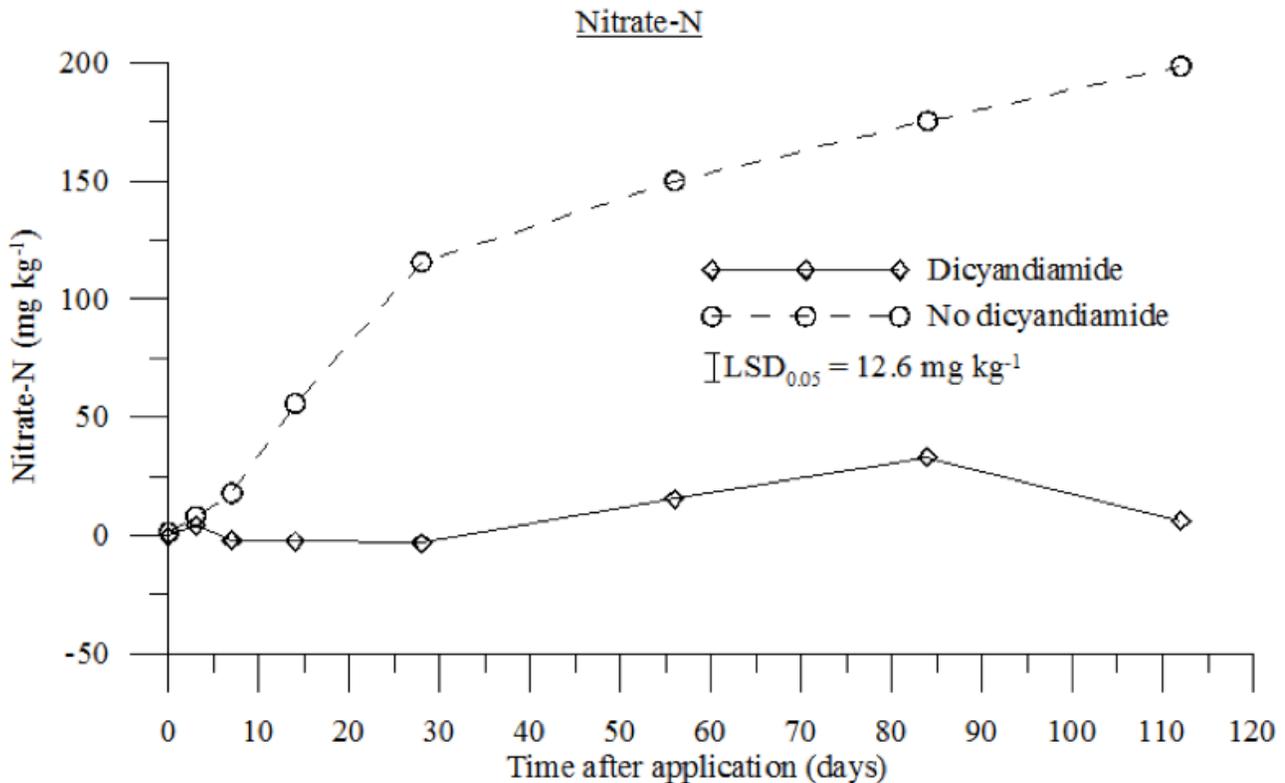


Figure 5. Soil nitrate concentrations as impacted by addition of dicyandiamide (DCD) to a silt loam soil (Reiter 2008).

Will They Pay Off?

Controversy often surrounds the use of nitrogen stabilizers. The answers to payback and application questions are complex because nitrogen loss depends largely on the environmental conditions at the time of nitrogen application as well as during the weeks following application. The cost of applying nitrogen stabilizers varies depending on the specific active ingredient and formulation of the product to be applied.

One common nitrogen stabilizer for controlling ammonia volatilization is the compound N-(n-butyl) thiophosphoric triamide (NBPT). Trials conducted by Frame and his collaborators (2012) showed the loss of nitrogen from untreated urea averaged 35 percent of the applied nitrogen on a silt loam soil (fig. 6). If ammonia volatilization was slowed by additions of a urease inhibitor or a rainfall event within 96 hours after

nitrogen application, a difference in nitrogen loss of 26 percent was observed. This means that if a producer applied 100 pounds of nitrogen as urea per acre, NBPT would have saved the farmer 26 pounds of nitrogen per acre. At \$0.65 per pound of nitrogen, this would equate to \$17 per acre in nitrogen savings. However, if a substantial rain event occurred within 12 hours of fertilizer application, no appreciable benefits would have occurred.

Holcomb and his collaborators (2011) found that ammonia volatilization losses could be reduced by 90 percent when 0.57 inch of precipitation or irrigation was applied immediately following granular urea application. **It is important to note that this is one example for one soil texture, and ammonia volatilization losses will depend on soil type, nitrogen source applied, and environmental conditions such as temperature, soil moisture, and organic matter.**

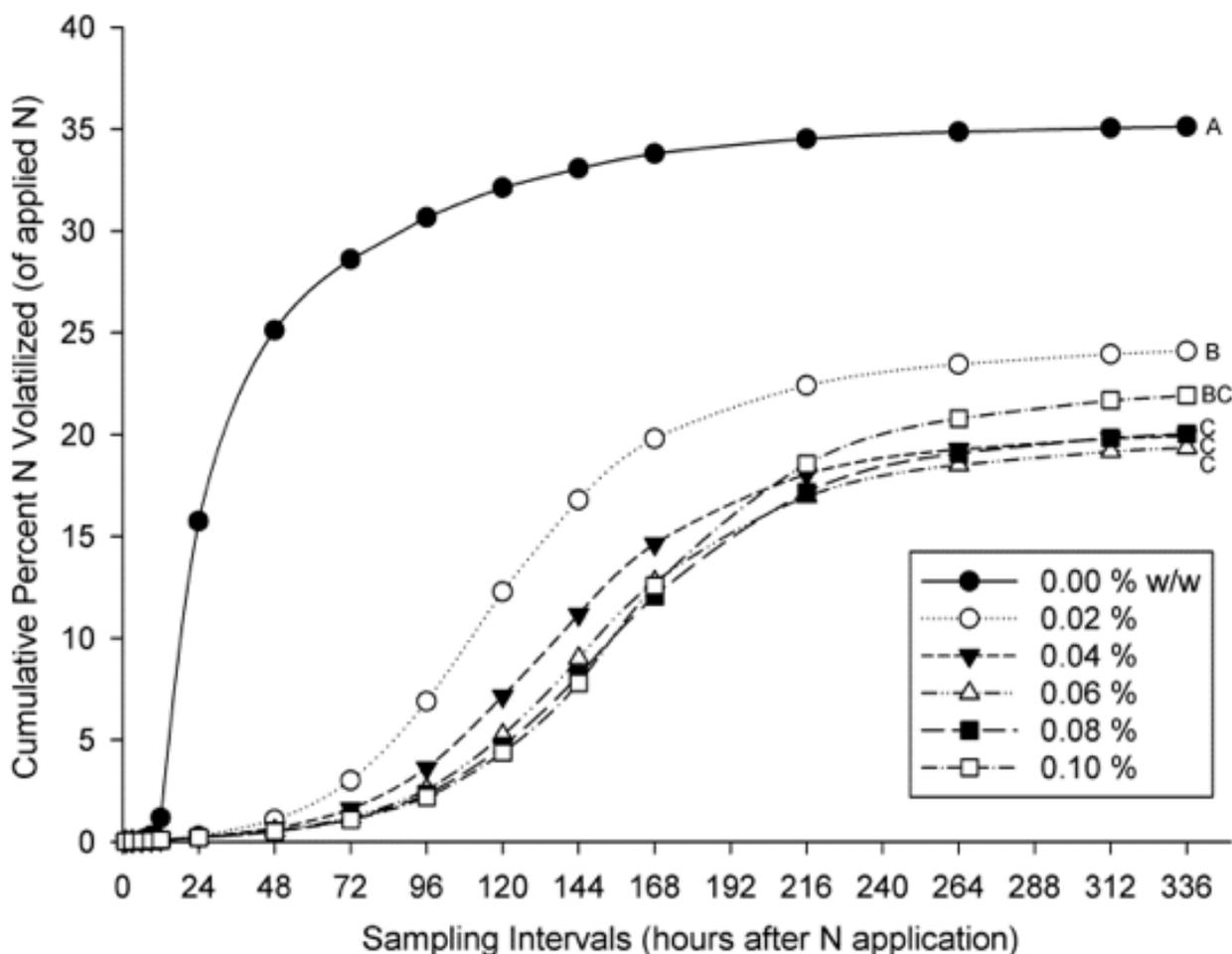


Figure 6. Cumulative nitrogen loss from varying rates of the urease inhibitor NBPT (Frame et al. 2012).

Alley, Thomason, and Woodward (2009) describe characteristics of common fertilizer sources used in Virginia. Urea-based fertilizer sources (granular urea and urea-ammonium nitrate solutions) will be more prone to ammonia volatilization losses than ammonium sulfate or ammonium nitrate. However, nitrogen sources containing nitrate, ammonium nitrate, or calcium nitrate may be prone to greater leaching losses if excess rainfall occurs following nitrogen application.

Measuring yield responses to nitrogen stabilizers in various crop species can be difficult because environmental conditions also dictate plant uptake of nutrients. Frame and his collaborators (2013) saw an increase in nitrogen content in corn ear leaves using NBPT on granular urea at tasseling at five out of 10 locations in Virginia; however, a yield response to NBPT was only detected at three out of the 10 locations during the same study. The use of nitrogen stabilizers should be aimed at ensuring minimal loss of nitrogen. Minimizing loss of nitrogen will allow more nitrogen to be available for uptake and may increase yields compared to the appropriate reference nitrogen fertilizer.

Conclusion

There are many articles and publications that detail the research on commercially available nitrogen stabilizers, and you are encouraged to conduct your own literature review on individual products. For any product, be sure to understand the overall mode of action and whether this is the correct mode of action needed to increase nitrogen fertilizer use efficiency in your production system. For example, if you are worried about losing nitrogen via volatilization gas losses, you need to make sure your product reduces urea hydrolysis. If you are more concerned that nitrogen losses are occurring from leaching, a product that inhibits nitrification is what you need. Do not hesitate to ask technical experts about these products and ask for localized data to show potential benefits for your crop in your climatic conditions on your soils.

Disclaimer

Reference to chemical names or product category is for informational purposes only. Virginia Tech and Virginia Cooperative Extension do not warrant any aforementioned product nor exclude any other product that may be suitable.

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