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Nitrogen Transformation Inhibitors and Controlled Release Urea

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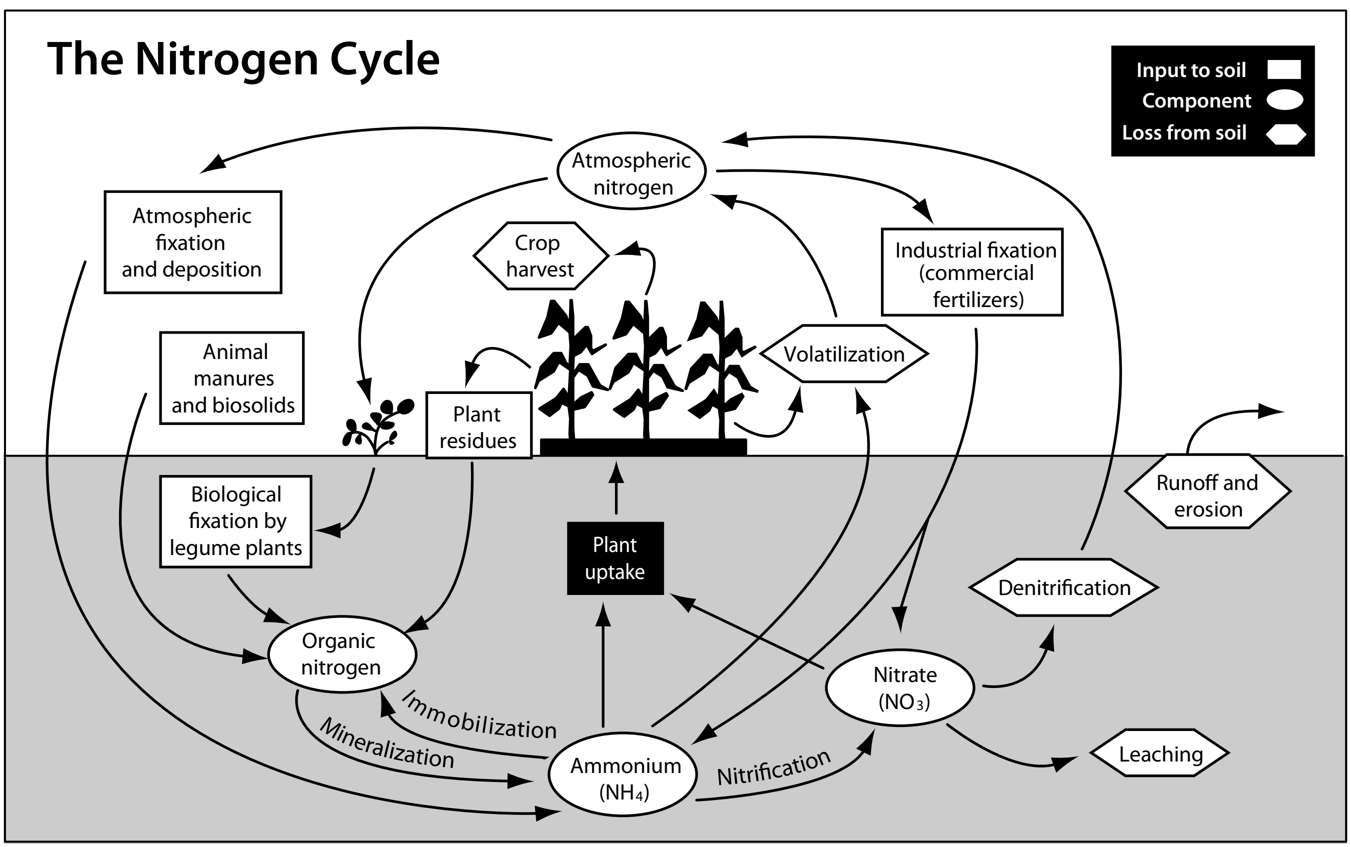
The soaring cost of fossil fuels is an indicator that nitrogen (N) fertilizer prices are going to remain high for the foreseeable future. With higher N prices, many producers are trying to evaluate the usefulness of several N additive products in their production systems. High N prices make these products more attractive because it takes fewer pounds of saved N to offset the price of the additive. Currently, there are three types of products being marketed that claim to improve nitrogen use efficiency: nitrification inhibitors, urease inhibitors, and controlled release fertilizer products. These products work by slowing one of the processes within the nitrogen cycle, thereby reducing N loss. Prior to purchase, producers should have a good understanding of how these products work in order to make informed decisions regarding their use.

Nitrification Inhibitors

Nitrification is the conversion of ammonium nitrogen (NH_4-N) to nitrate nitrogen (NO_3-N) in the soil (Figure 1). Depending on soil conditions, some inhibitors can slow this process by a few weeks. The most common, Nitrapyrin (N-Serve®), has been commercially available for 30 years. It can be used with any N fertilizer that contains or produces (when applied to the soil) NH_4-N. Examples are anhydrous ammonia, urea, and urea-ammonium nitrate (UAN) solutions.

Inhibiting nitrification is important because nitrogen in the NH_4-N form is held tightly by the soil particles and is not subject to leaching or denitrification loss. **Leaching** is when NO_3-N is moved deeper into the soil profile by moving water. It is possible that soil NO_3-N can be leached below the rooting zone and then become an environmental concern.

Figure 1. The nitrogen cycle showing components, inputs, losses, and transformations to soil nitrogen pools (from The International Plant Nutrition Institute).



Denitrification occurs when NO_3-N is converted into a gas and escapes into the atmosphere. This reaction only happens when soil lacks oxygen or is largely water saturated. Depending on the amount of oxygen in the soil, the gas emitted is in either the nitrous oxide or nitrogen gas form. Nitrous oxide is considered a greenhouse gas, and emissions may be regulated in the future. Denitrification losses are most common on poorly drained soils saturated for many days during the spring.

Urease Inhibitors

When urea fertilizers are applied to the soil, an enzyme called urease begins their conversion to ammonia gas. If this conversion takes place below the soil surface, the ammonia is almost instantaneously converted to NH_4-N, which is bound to soil particles. If the conversion takes place on the soil surface or on surface residues, there is a potential for the ammonia gas to escape back into the atmosphere in a process called **ammonia volatilization.**

Volatilization losses depend on the environmental conditions at the time of application. Soil temperature, soil moisture, amount of surface residue, soil pH, and length of time between application and the first rain event or irrigation are all factors that determine the total amount of N that could be lost via volatilization. Nitrogen losses from fertilizer applied prior to May 1 are generally very low. After May 1, N loss is greatest, especially when urea is surface-applied to soils with high residue or vegetation (i.e. no-till corn or pastures), during warm, wet weather followed by a warm, breezy drying period.

Volatilization losses can be substantially reduced if a urease inhibitor is used with the fertilizer. The most common urease inhibitor is NBPT (N-(n-butyl) thiophosphoric triamide), sold under the trade name Agrotain® (Agrotain International). Urease inhibitors reduce the activity of the urease enzyme for up to 14 days. As long as it rains during this 14 day period, the urea will be moved into the soil where it can be converted to NH_4-N without the risk of volatilization.

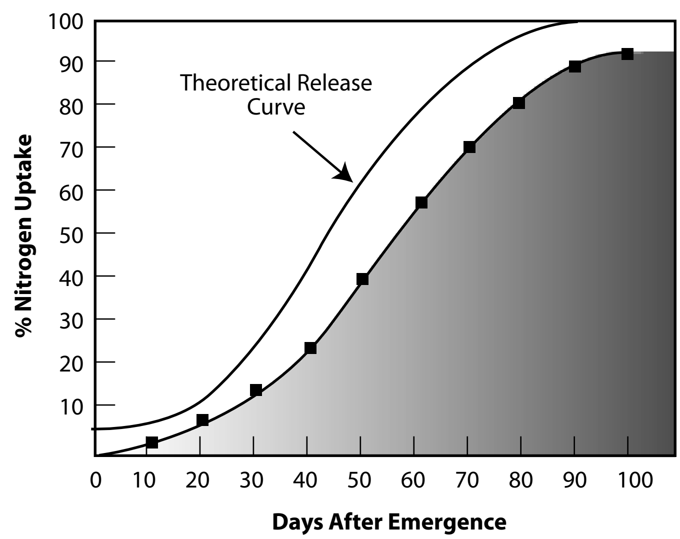
Controlled Release Urea

Controlled release fertilizer products have also been available for more than 30 years. Probably the best known of these products is sulfur-coated urea. A sulfur coating is applied to urea granules and urea dissolves/diffuses through imperfections in the coating. By altering the thickness and number of imperfections in the coating, release characteristics can be controlled. Sulfur-coated urea was not a useful agronomic product in part because the cost of coating was high relative to the cost of the N fertilizer.

Recent advancements in polymer (plastic) technology have created a whole new type of controlled release fertilizer, the most common of which is **polymer-coated urea** (PCU). Polymer-coated urea has been used in the turf and horticultural industries for several years, but the cost of the materials prohibited their greater use in the agricultural market. Now, Agrium Inc. has introduced a PCU called ESN® that is priced competitively in the agricultural market.

Modern polymers allow chemists to create release curves that closely match the uptake characteristics of target crops (Figure 2). The amount and rate of release is controlled by the thickness and other characteristics of the polymer.

Figure 2. Typical nitrogen uptake curve for corn and a theoretical polymer-coated urea release curve.

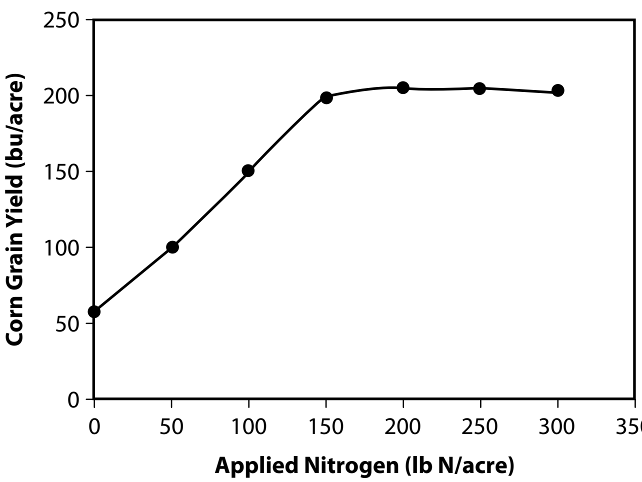


Agronomics of N Products

As alluded to earlier, there are several factors that should be considered before deciding if these products are appropriate and economical in your specific production system.

Ideally, corn producers strive to apply just enough N to reach maximum yield (example: 150 lb N/a in Figure 3). If a farmer applied the optimal amount of fertilizer and used an inhibitor or PCU, N would be saved, but yield would not be increased. This is because maximum yield has already been obtained. In order for these new products to be agronomically useful, the producer must reduce the rate of applied nitrogen by the amount expected to be saved as a result of using the additive. To be economical, the cost of the saved N must exceed the price of the additive.

Figure 3. Typical nitrogen response curve for corn grown on well-drained soils in Kentucky.



The second consideration is the time of year fertilizer is being applied. Denitrification occurs primarily when the soil is water-saturated. Therefore, losses are usually highest for N applied early in the spring. Later, side-dress applications usually result in very little denitrification loss, since soil saturation is less likely. The total amount of nitrogen lost as a result of denitrification is a function of the number of days the soil remains saturated and the amount of nitrogen in the NO_3-N form (Table 1). Approximately 3-4% of the NO_3-N can be lost per day of soil saturation beyond two days.

Table 1. The percentage of fertilizer N in the NO_3-N form 0, 3, and 6 weeks after application.

	Weeks After Application		
	0	3	6
N Source	% of Fertilizer as NO_3-N		
Anhydrous Ammonia (AA)	0	20	65
AA with N-Serve	0	10	50
Urea	0	50	75
Urea with N-Serve	0	30	70
UAN solutions	25	60	80
Ammonium Nitrate	50	80	90

Volatilization losses are highest when the soil is warm (above 60°F), experiencing high evaporation rates, and/or when soil pH is greater than seven. In most years, temperatures become high enough to cause concern in early May. After this time, urea N contained in surface applications is more volatile. If the fertilizer is surface-applied and incorporated or ¼ inch or more of rain is received within two days, volatilization losses will be minimal. If, on the other had, it is not incorporated and no rain is received, loss can exceed 25%, with an average of about 10% of the total. High surface residue levels also increase volatilization; therefore, maximum losses will be observed when urea is broadcast on no-till or pasture fields after May 1.

Polymer-coated urea, because of its slow-release characteristics, offers farmers the option of early fertilizer application with a reduced risk of denitrification or leaching loss. There is still the potential for volatilization losses from this product because it is urea.

Inhibitor Research Results

Several research studies have been conducted across Kentucky to assess the performance of these products under our growing conditions. Wheat research in western Kentucky demonstrates that soils stay too warm for nitrification inhibitors to be effective if all of the N fertilizer is applied in the fall (Table 2).

Table 2. Effect of time of urea and anhydrous ammonia N application and the use of nitrification inhibitors on the yield of wheat in KY (from Murdock 1985).

Nitrogen Treatment	Urea 5-Yr Average Wheat Yield (bu/a)
Check (no N)	31
Fall	46
Fall + Inhibitor	47
Spring	55

Nitrification inhibitors have been shown to be effective for corn where N fertilizers were applied at planting at yield-limiting rates. In a study conducted in Bath, Lewis, and Lee counties, corn yield was increased by an average of 32 bu/acre when N-Serve was applied with 75 lb N/acre as ammonium nitrate at planting (Frye et al., 1981). However, this study showed no significant yield increase with N-Serve at the 150 lb N/acre rate. These results demonstrate the need to reduce N application rates in order to get the benefit of the inhibitor. In general, Kentucky research has found economic benefits to nitrification inhibitors are more likely on poorly drained soils that tend to remain wet during the spring.

The urease inhibitor Agrotain has also been effective in some Kentucky cropping systems. A study was conducted in Fayette County to assess the response of Agrotain with surface applications of urea and urea ammonium nitrate (UAN) solution for fescue and corn production. Both crops were grown at yield-limiting N rates (140 and 75-100 lb N/acre/yr for fescue and corn, respectively). Fescue yield was 13% lower when urea was used without Agrotain, but only 3% lower when UAN was used without Agrotain. For corn, Agrotain increased average grain yield by 14 bu/acre with urea and 6 bu/acre with UAN (Frye et al., 1990).

A product called SuperU® (marketed by Agrotain International) is urea containing both a urease inhibitor (NBPT) and a nitrification inhibitor (dicyandiamide DCD). It is designed to prevent losses associated with surface applications of urea as well as leaching and denitrification losses. A two-year study in Meade County compared urea, ammonium nitrate, and SuperU on no-till corn. In both years of the study (1997-8), N was applied shortly after planting and early season rainfall was excessive. In both years, at yield-limiting rates of N, grain yield from SuperU was significantly higher than yield from urea. In 1998, at the low fertilization rate, grain yield using SuperU was significantly higher than the yield from ammonium nitrate (Table 3). Results indicate that volatilization was a factor in both years, but leaching/denitrification losses were only a factor in 1998.

In 2004, a Hardin County study compared the performance of several N products in no-till corn production. All plots received a pre-plant application of 50 lb N/acre. Side-dress applications of different N fertilizer products were made at the 6-leaf stage. Excessive rainfall was received between planting and the side-dress application, but the soil was not saturated after the side-dress treatments were applied, suggesting little potential for denitrification or leaching. Therefore, plots with SuperU (the combination of NBPT and DCD) were not statistically different (p=0.10) than plots with only Agrotain (Table 4). Weather and soil conditions were very conducive to ammonia volatilization losses. Yield was substantial lower for the urea and UAN treatments when compared to the ammonium nitrate application. When Agrotain was added to urea and UAN, yield was increased by 43 and 29 bu/acre, respectively (Table 4). At this point, it is not clear why Agrotain was less effective when used with UAN. The results may be an anomaly, since similar studies have shown NBPT to be equally effective with urea and UAN. The yield response was extremely high because less-than-optimal rates of N were used, but this study illustrates the loss potential in a no-till environment.

A relatively new product called Nutrisphere-N® (maleic-itaconic copolymer) is being marketed by Specialty Fertilizer Products through some Kentucky fertilizer retailers as both a urease and nitrification inhibitor. While the research results look promising in some locations across the United States, Kentucky data show that it is less effective than Agrotain when tested under high volatilization loss conditions. In a study conducted in 2007 at the University of Kentucky Research and Education Center near Princeton, Kentucky, corn yields were significantly lower for the Nutrisphere-N treatment compared to other products under high volatilization loss conditions. In this study, 75 lb N/acre was applied as a side-dress application to no-till corn. The yield difference between the plots receiving

Table 3. Effect of N-source and rate on corn yield in 1997 and 1998 (Wells et al., 1999).

N lbs/a	1997			1998		
	AN	Urea	SuperU®	AN	Urea	SuperU®
	Corn Yield (bu/a)					
0	*105*			*82*		
60				128	118	151
80	136	116	139			
120				161	138	159
160		143	136			
180				153	141	158

Table 4. Yield for side-dressed no-till corn in Hardin County, 2004.

Treatment[1]	Yield (bu/a)
Check[2]	117 d[3]
Urea	158 c
Urea + Agrotain®	201 b
SuperU®	201 b
UAN	150 c
UAN + Agrotain®	179 bc
UAN + Agrotain Plus®[4]	175 bc
AN	192 b
Poly-Coated Urea (at planting)	177 bc
AN (130 lbs N/a)	239 a

1 N side-dress rate was 50 lbs N/a.
2 Check received 50 lbs N/a at planting and 0 lbs N/a side-dress.
3 Numbers followed by the same letter are not significantly different.
4 A combination of NBPT and DCD formulated for use with UAN.

ammonium nitrate, which has no volatilization loss potential, and the plots receiving urea (Figure 4) can be attributed to N volatilization. Comparing the other products in the study, Agrotain, SuperU, and ESN® produced statistically equal yields to ammonium nitrate, while Nutrisphere-N was not statistically different from the unprotected urea. Similar comparisons, made in other years and locations across Kentucky, also show Nutrisphere-N is not as effective as other currently available products for reducing nitrogen losses. To date, Nutrisphere-N has not been evaluated under conditions conducive for denitrification loss in Kentucky. However, laboratory experiments conducted at North Dakota State University show that Nutrisphere-N had no effect on nitrification rate (Figure 5).

Polymer-Coated Urea (PCU) Research

The agriculturally priced PCU, ESN, has only been available to farmers since 2007. One potential use for this product is fall application on wheat, especially for wetter soils that might not support spreader trucks in the spring.

A wheat study begun in the fall of 2002 near Lexington evaluated ESN application timing on wheat. Treatments consisted of an unfertilized check, and 60 lbs of urea or ESN broadcast at four application times (planting, January, Feekes Stage 3, and Feekes Stage 6). Also included were a split urea application of ⅓ at Feekes 3 and ⅔ at Feekes 6, and another receiving 20 lbs urea-N/acre and 40 lbs PCU-N/acre all at Feekes 3. An additional treatment was included to determine the yield potential for the study site consisting of 30 lb urea-N/acre at Feekes 3 and 60 lb urea-N/acre at Feekes 6. Like earlier studies that compared N with and without a nitrification inhibitor, yields in this study were equivalent for ESN and urea applied in the fall (Figure 6). However, ESN applied in January produced significantly higher yields than January-applied urea. In fact, January ESN yield was not significantly different than that for the split application of urea. Therefore, part of the higher cost of ESN could be offset by one less fertilizer application. Applications of ESN later in the spring are not recommended because the slow release appears to reduce yield.

Studies have also been conducted in Lexington and Princeton to determine the effect of ESN on corn growth and yield. Study sites included both well and somewhat poorly drained soils. For the well-drained soils, there was no yield benefit to using ESN. On the more poorly drained soils, ESN applied at or before planting increased yield significantly compared to urea applied at the same time. ESNwas not, however, superior to a split application of urea (⅓ at planting and ⅔ at the 6-to-8 leaf stage).

Figure 4. The effect of nitrogen fertilizer material on corn grain yield at Princeton in 2007 (bars with the same letters are not significantly different: p<0.10).

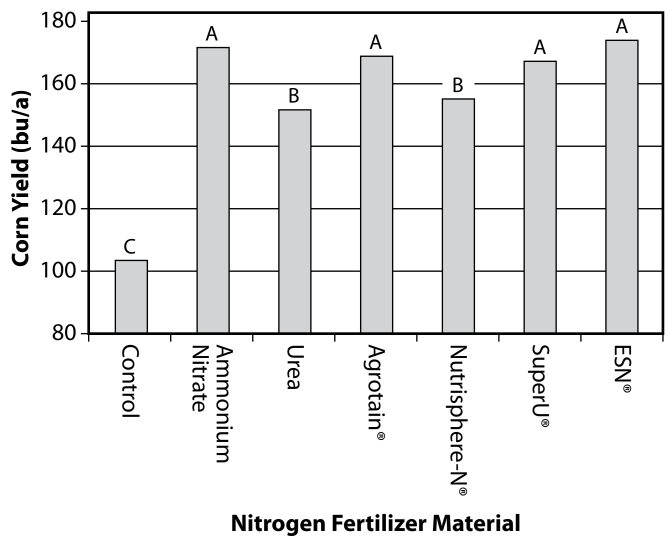


Figure 5. The effect of Nutrisphere-N (NSGR) on nitrate and ammonium concentration in the soil (Goos, 2008).

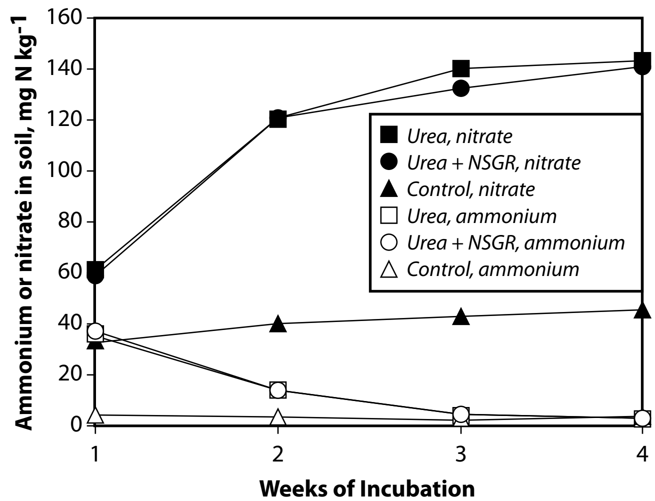
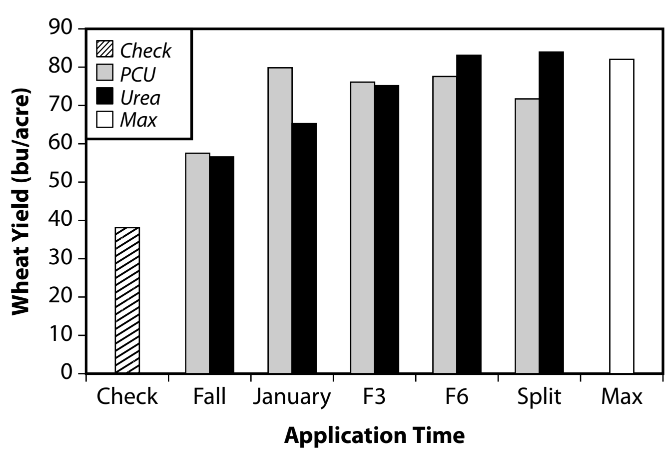


Figure 6. The effect of N applied as ESN® (polymer-coated urea, PCU) and urea on 2003-04 wheat grain yield in Lexington (LSD p<0.10 = 8 bu/a).



Conclusions

There are several products that Kentucky farmers could use to help improve fertilizer nitrogen efficiency. These products are only useful in specific situations, so it is important to understand how they work and when they are most useful. It is also important to realize these products are designed to conserve nitrogen. Benefits will only be realized if the total N application rate is reduced by the amount of N estimated to be saved by using inhibitors or PCU.

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Trade Names

- Agrotain® and SuperU® are registered trade names of Agrotain International, LLC, St. Louis, MO.
- ESN® is a registered trade name of Agrium U.S. Inc, Calgary, Alberta.
- N-Serve® is a registered trade name of Dow AgroSciences, LLC, Indianapolis, IN.
- Nutrisphere-N® is a registered trade name of Specialty Fertilizer Products, Leawood, KS.

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