Nitrogen additives: What is what, and do they work?

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Introduction

Increases in nitrogen prices and environmental pressures have caused many corn producers to reevaluate nitrogen (N) management to determine if they can improve use efficiency. One potential avenue of improving N use efficiency is to allow applied N the ability to avoid volatilization losses when utilizing urea-based fertilizers and to lengthen the amount of time ammonium is present since it is much less susceptible to loss than nitrate. This obviously means considering either a urease inhibitor or a nitrification inhibitor. The goal of this proceedings article is to discuss various urease and nitrification inhibitors, examine modes of action, and evaluate agronomic utility.

Urease inhibitors

Urea based nitrogen fertilizers are an organic commercial form that requires a biological enzyme to promote degradation to ammonia (Eq. 1). Ammonia exists as a gas at normal temperature and pressure, thus it may be lost by volatilization if not exposed to water. Ammonia loss potential by volatilization for incorporated urea products is negligible because soil holds enough water to capture ammonia as ammonium (Eq. 2) that can be held on the soil's cation complex. Surface applications of urea are at risk of loss because there is no opportunity to capture the ammonia as it is produced. Additionally, urea hydrolysis causes an increase in soil pH, and increasing soil pH can cause more ammonia to be produced resulting in more ammonia volatilization.

$$CO(NH_2)_2 + 3\ H_2O \text{ ----urease---» } 2\ NH_3 + 2\ H_2O + CO_2 \qquad \text{Eq. 1}$$

$$NH_3 + H_2O \text{ «----» } NH_4^+ + OH^- \qquad \text{Eq. 2}$$

Urease inhibitors can have different modes of action, and the first question we should ask is do they work? The active ingredient in the inhibitor can act as a substrate for the urease enzyme, therefore protecting free urea by allowing it to stay in solution longer, or the inhibitor can inactivate the enzyme. Agrotain is the most common commercially available urease inhibitor. The active ingredient in Agrotain is N-(n-butyl) thiophosphoric triamide. The mode of action is not clearly defined, but it is thought to act as a substrate for the urease enzyme. Regardless of the mode of action, laboratory evidence has shown that it does allow urea to be retained in the soil longer (Kariuki and McGrath, 2009).

Another commonly promoted urease inhibitor is Nutrisphere. It does not have a well-defined mode of action, and laboratory data collected to date to provide empirical support for its activity is not positive (Kariuki and McGrath, 2009). Other inhibitors are marketed, but consultants/producers should inquire whether laboratory data exists to substantiate claims of activity.

Even if a urease inhibitor has been demonstrated in a laboratory to have some inhibition properties on the enzyme urease, the agronomic question still remains as to its usefulness in a field setting. This is a merging of the basic science that demonstrates its activity, and the applied science that demonstrates is applicability.

Several data sets exist to demonstrate the applicability of Agrotain under different agronomic practices (including application timing and method and tillage). One such study conducted in Illinois between 1995 and 1998 reveals that broadcast applications of urea in no-till corn can respond positively to Agrotain inclusion (Table 1; Varsa et al., 1998). Out of 9 site-years of experimentation, seven years showed positive yield increases as the result of including Agrotain with broadcast urea, and the average yield increase was 23%. Yield increases as a result of inclusion of Agrotain with broadcast liquid UAN occurred less than 50% of the time. Out of 9 site-years, four site-years showed positive yield responses, and the average yield increase was 10%. Dribble applications of liquid UAN showed positive yield increases in 5 out of 9 site-years, and the average yield increase was 9%.

Research conducted at Ohio State University reveals that urease inhibitor performance is closely tied to fertilizer source and method of application as well as environmental conditions experienced after the application (Tables 2 & 3). As demonstrated by the research conducted in Illinois (Varsa et al., 1998), surface applications of dry urea in no-till systems are more likely to show yield benefits from urease inhibitors than liquid UAN applications.

Should urease inhibitors be utilized? It really depends upon how nitrogen is to be applied (and the form) and the rate of nitrogen being applied. Higher rates of nitrogen (under most conditions) likely do not require urease inhibitors. Surface application of dry urea in high residue situations is a good place for the use of urease inhibitors. Dribble applications of liquid UAN may benefit from a urease inhibitor in high residue situations, but clean till fields are less likely to benefit. Injected liquid UAN (whether it is knifed or coultered) does not require stabilizers based upon current research.

Nitrification inhibitors

Any nitrogen supplied as a commercial fertilizer is ultimately transformed to a nitrate form of nitrogen (or at least a significant fraction of that supplied). In the presence of adequate oxygen, warm temperatures (> 50 F), and some moisture, ammonium-N is converted to nitrate-N through a biochemical process that requires two forms of soil bacteria known as nitrification. The first bacterium Nitrosomonas converts ammonium-N to nitrite-N (Eq. 3). The second bacterium Nitrobacter converts nitrite-N to nitrate-N (Eq. 4). The entire process of conversion can occur quite rapidly primarily determined by oxygen availability and temperature (Chandra, 1962).

$$2\ NH_4 + 3\ O_2 \text{ ---» } 2\ NO_2^- + 2\ H_2O + 4\ H^+ + \text{Energy} \qquad \text{Eq. 3}$$

$$2\ NO_2^- + O_2 \text{ ---» } 2\ NO_3^- + \text{Energy} \qquad \text{Eq. 4}$$

Nitrification inhibitors have one primary way of delaying the nitrification process, and that is eliminating the bacteria Nitrosomonas in the area where ammonium is to be present. There are two common nitrification inhibitors that are commercially available: 2-chloro-6-(trichloromethyl)-pyridine (nitrapyrin) and dicyandiamide (DCD).

Nitrapyrin is the active ingredient found in the DOW product N-Serve and Instinct. The biochemical activity of nitrapyrin and its ability to suppress growth of Nitrosomonas has been known since the 70s and it was initially registered in 1974. It is quite effective even at relatively low rates. Rates as low as 0.1 ppm have been shown to effectively inhibit certain strains of Nitrosmonas, but rates of 10 ppm has been shown to be effective against most strains (Belser and Schmidt, 1981).

Dicyandiamide (DCD) is the active ingredient in nitrification inhibitors such as Agrotain Plus and SuperU. Dicyandiamide is required at a significantly larger concentration to be effective. Zacherl and Amberger (1990) found that DCD had to be applied at concentrations of 300 ppm to inhibit the activity of Nitrosomonas.

Since each of the products discussed above is highly sensitive to concentration, it is imperative that if they are used they are applied at labeled rates. Cutting rates is not in your best interest as an end user because a lower concentration may not allow the product to perform its job in the soil.

Again, the activity of the nitrapyrin and DCD is well known, but the question is do they provide some agronomic benefit?

Several research studies have shown that nitrification inhibitors can provide agronomic benefit. A summary report published in 1992 showed that nitrification inhibitors could provide benefit, but there were considerations that should be made to determine where there was a greater probability of a yield improvement (Tables 4 & 5; Nelson and Huber, 1992). Another consideration to be made beyond those illustrated is nitrogen rate. The use of higher rates of N (especially in the spring) makes it more difficult to show yield improvements from the use of a nitrification inhibitor.

Summary

Economic and environmental pressure to improve N utilization for corn production may be causing some producers to reevaluate their N management programs. One consideration is decreasing N application rates. This will improve the likelihood of positive yield responses to utilization of both urease and nitrification inhibitors. Additional considerations should be made to determine where producers should be using these materials. Application timing, N source, application method, soil texture, and tillage are all factors that should be evaluated to determine where urease and nitrification inhibitors should be used. If considering the use of a urease or nitrification inhibitor, first ensure that the activity of the inhibitor is based upon scientific evidence. Lack of good scientific data, demonstrating that the inhibitor does what it claims, should be a cause for concern for producers and consultants considering its use.

References

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Table 1. Influence of Agrotain on corn grain yield in a no-till system based upon cropping system, application methodology, and N source (Varsa et al., 1998).

	Belleville		Dixon Spring	
Treatment	**Corn-corn[a]**	**Soy-corn[b]**	**Corn-corn**	**Soy-corn**
	------------------------------bu/acre------------------------------			
Urea[c]	106	120	98	100
Urea + Agrotain	134	143	112	112
Ammonium nitrate	151	156	118	119
UAN (B)[d]	123	137	103	107
UAN + Agrotain (B)	128	145	107	114
UAN (D)[e]	139	137	108	112
UAN + Agrotain (D)	143	152	110	120
UAN (I)[f]	172	176	123	121
$LSD_{0.05}$	12	8	13	17

a – Corn after corn received 180 pounds N/acre;
b – Corn after soybean received 140 pounds N/acre
c – broadcast applied urea
d –broadcast applied UAN
e – dribble applied UAN; f – injected UAN.

Table 2. Impact of Agrotain and Nutrisphere on dry urea surface applications in no-till systems at five locations in

Ohio, 2006-2009.

Treatment[a]	Western 06	NW[b] 07	Western 07	NW 08	NW 09[c]
	-------------------------------bu/acre------------------------------				
Urea	165	122	224	99	115
Urea + Nutrisphere	178	137	218	103	119
Urea + Agrotain	178	129	243	---[d]	106
$LSD_{0.1}$	23	10	16	10	10

a – all sources of N were applied at a 100 lb N/acre rate
b – Northwest
c – Northwest 2009 urea was incorporated with tillage
d – Agrotain® was absent at Northwest 2008.

Table 3. Impact of Agrotain and Nutrisphere on liquid UAN applications in no-till systems at five locations in Ohio, 2006-2009.

Treatment[a]	Western 06	NW[b] 07	Western 07	NW 08
	-------------------------------bu/acre------------------------------			
UAN (B)	159	---	---	96
UAN + Nutrisphere (B)	169	125	195	100
UAN + Agrotain (B)	157	135	195	---
UAN (D)	---	134	231	---
UAN + Nutrisphere (D)	---	126	210	---
UAN + Agrotain (D)	---	133	235	----
$LSD_{0.1}$	23	10	16	10

a – all sources of N were applied at equivalent rates within each site-year
b – Northwest

Table 4. Summary of corn responses from nitrification inhibitors added to ammonia/ammonium forms of fertilizers (adapted from Nelson and Huber, 1992).

Region	Time of application	% of studies with yield increase	% yield increase
Eastern Cornbelt (IL, IN, OH, KY)	Fall	69	9
	Spring	51	3
	Spring (no-till)	82	13
Northern Cornbelt (MI, MN, WI)	Fall	25	5
	Spring	17	12
Western Cornbelt (KS, MN, NE) irrigated coarse-textures soils	Spring	52	30
Western Cornbelt (KS, NE) irrigated medium- and fine-textured soil	Spring	10	5

Table 5. Probability of corn yield increase due to the use of a nitrification inhibitor with ammonia/ammonium containing fertilizers applied in fall or spring (adapted from Nelson and Huber, 1992).

Soil texture	Time of application	Eastern Cornbelt	Western Cornbelt
		-------probability of corn yield response[1]-------	
Sands	Fall	Poor	Poor
	Spring	Fair	Fair[2]
Loamy sands, sandy loams, and loams	Fall	Fair	Poor
	Spring	Fair[3]	Fair[2]
Silt loams	Fall	Good	Fair
	Spring	Fair[3]	Poor
Clay loams and clays	Fall	Good	Fair
	Spring	Good	Poor

1-Poor = <20% chance of yield increase; fair = 20-60% chance of yield increase; good = greater than 60% chance of yield increase.
2-Fair for irrigated soils, poor for dryland corn.
3-Good for no-till production systems.