DOES IT PAY TO USE NITRIFICATION AND UREASE INHIBITORS?

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Introduction

As nitrogen (N) prices have risen, corn growers are beginning to think about reducing N application rates. Growers are weighing decisions to reduce N rates along with the potential for N losses that may occur because of the form of N used, method of application, and weather conditions. In the past, growers may have increased N application rates to offset the potential for N loss and subsequent yield loss. This practice was considered to be cheap insurance largely because the cost of the extra N fertilizer was cheap. With today's N and corn prices, this type of insurance may not be so cheap. Thus, revisiting the practices and economics of applying nitrification and urease inhibitors to protect against N loss is relevant.

Urease Inhibitors

When urea is applied to the soil, it must breakdown before any of the N is available to plants. The following are the three main reactions of urea in soil.

1. Urea hydrolysis: $\underset{\text{urea}}{(NH_2)_2CO} + \underset{\text{water}}{2H_2O} \xrightarrow{\text{urease}} \underset{\text{ammonium carbonate}}{(NH_4)_2CO_3}$
2. $(NH_4)_2CO_3 + 2H^+ \longrightarrow \underset{\text{ammonium}}{2NH_4^+} + \underset{\text{carbon dioxide}}{CO_2\uparrow} + H_2O$
3. $NH_4^+ + OH^- \leftrightarrow \underset{\text{ammonia}}{NH_3\uparrow} + H_2O$

During the hydrolysis of urea (equation 1), urea acts with water in the presence of an enzyme called urease to produce ammonium carbonate. Ammonium carbonate then reacts with hydrogen ions to produce ammonium (one of the forms of N used by plants), carbon dioxide, and water (equation 2). Depending on the soil pH, the ammonium produced may form ammonia (equation 3) which can be lost through volatilization. If soil conditions do not favor volatilization, ammonium can either be held on the soil's cation exchange or converted to nitrate (which is subject to losses through leaching or denitrification).

Urease is ubiquitous in soil and breakdown of urea will occur within 2 to 3 days. If urea is not incorporated (mechanically or with 0.5 to 0.75 inches of rain/irrigation), then up to 20% of the N applied will be lost through volatilization (Bundy and Oberle, 1988). If urea is surface applied, halting the breakdown of urea (inhibiting the urease enzyme) until adequate rain or irrigation can wash the urea into the soil will reduce N losses through volatilization.

The discussion of urease inhibitors will focus on N-(n-butyl) thiophosphoric triamide (NBPT), the active ingredient in Agrotain. Urease inhibitors act by temporarily stopping/inhibiting the breakdown of urea in urea containing fertilizers.

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Agrotain has been shown to be effective at reducing the conversion of surface applied urea or urea ammonium nitrate solutions (UAN) to ammonium. This can increase corn yields when conditions for ammonia volatilization exist. Hendrickson (1992) compiled data on NBPT use with surface applied urea and UAN from 78 experiments in 17 states over 5 years where 45% of the experiments were on no tilled fields, 45% on reduced tilled fields, and 10% on conventionally tilled fields. A summary of corn yield increases from application of NBPT with surface applied urea and UAN is provided in Table 1. In general yield increases were greater when NBPT was applied with urea compared to UAN. This is to be expected as only 50% of the N in UAN is urea. Yield decreases with application of NBPT also occurred; yield reductions of 10 bu/a or more were seen in 7% of the sites. Consistent crop yield increases are not expected every year or on all fields. Benefits will likely occur 30 to 40% of the time; with negative impacts on yield in 5 to 10% of the time. (Bundy, 1992).

Table 1. Summary of corn yield increases from application of NBPT with surface applied urea and UAN (Hendrickson, 1992). Yield increases were significant ($P < 0.01$).

Experimental sites	Number of sites	—— Yield increase ——	
		Urea	UAN
		———— bu/a ————	
All sites	78	4.3	1.6
N responsive sites†	64	5.0	2.8
Sites with significant ammonia loss	59	6.6	2.7

† Sites where yield increased when fertilizer N was applied.

Bundy (1992) reported on a study assessing the effectiveness of Agrotain at Hancock. Urea, urea plus Agrotain, and ammonium nitrate were applied at several N rates and yield was measured. Results and an economic analysis are provided in Table 2. The N in ammonium nitrate is not subject to volatilization. The yield of corn was the same when 70 or 140 lb N/a was applied as ammonium nitrate. This shows that in this year on this site there was no response to N applied at rates over 70 lb N/a if the N was not lost. 70 lb N/a urea + Agrotain increased yield by 8 bu/a over urea alone at this rate. The increased income from the greater yield more than offset the cost of the Agrotain. When 140 lb N/a was applied, there was no difference in yield when urea was applied with or without Agrotain, because even with some N losses from urea alone, the amount of N applied was enough to reach the yield plateau. Economics for ammonium nitrate were not calculated as this fertilizer material is becoming increasingly unavailable.

Table 2. Effect of N rate, source, and NBPT on corn yield on an irrigated Plainfield sand at Hancock, WI in 1988 (Bundy, 1992).

Material	N rate lb N/a	Yield bu/a	Income * $/a	N Cost * $/a	Agrotain cost $/a	Return $/a
Check	0	88				
Urea	70	127	279.40	26.60	0	252.80
Urea + I †	70	135	297.00	26.60	4.76	268.24
AN ‡	70	140				
Urea	140	134	294.80	53.20	0	241.60
Urea + I †	140	132	290.40	53.20	9.51	232.88
AN ‡	140	138				

† I = inhibitor; Agrotain was applied at a rate of 0.25% by weight of urea (2.27 qt/T of urea).
‡ AN = ammonium nitrate
* Calculations were made using $2.20/bu corn and $0.38/lb N from urea.

Bundy (1992) also reported on other studies with Agrotain in Arlington, Wisconsin. However, there was no benefit to addition of Agrotain because 30 to 40 lb N/a maximized yield both years because of high residual N concentrations in the soil. Overall, these data highlight that when conditions for N loss exist, Agrotain can help prevent N loss. However, yield gains will not necessarily be realized every year.

The decision to use nitrification inhibitors rests with knowing when significant losses of N are likely (surface application of urea containing fertilizers in dry conditions particularly on high pH soils) and the cost benefit. A simple cost-benefit analysis on the use of Agrotain with urea was done. Urea was chosen for this analysis because most of the Agrotain usage in Wisconsin is with urea. The analysis is based on actual corn yield response to applied N in a field experiment; Agrotain was not a treatment. Assumptions in this analysis:

1. The price of corn is $2.20/bu
2. Corn is grown following soybean
3. High yield potential soil
4. Maximum yield achieved is 214 bu/a
5. Yield was maximized at 120 lb N/a
6. Agrotain applied at a rate of 5 qt/T of urea which is supposed to provide 14 days of control.
7. Agrotain costs $50/gal
8. When Agrotain is applied, no N is lost and yield remains the same as when no Argotain is applied and no N is lost. Realistically, this may not occur in all fields.

The analysis was completed using two different prices for N: $0.22/lb N, a price more typical five to ten years ago, and $0.38/lb N, a good estimate of the cost of N from urea in spring 2006. These N prices produce N:corn price ratios of 0.10 and 0.17 for $0.22/lb N and $0.38/lb N, respectively. Four nitrogen application rates were used: 140, 115, 100, 90 lb N/a. These rates were selected as they represent rates a corn grower may choose to apply based on their economic situation (Laboski, 2006). The results of the analysis are provided in Table 3.

Table 3. Cost-benefit analysis of using Agrotain with surface applied urea.

	— No N Loss —		——— Assume 20 % N Loss ———				With Agotain †	
N rate	Yield	Return ‡	N Loss	Yield	Return	Lost return	Agrotain cost	Return
lb N/a	bu/a	$/a	lb N/a	bu/a	$/a	$/a	$/a	$/a
If N costs $0.22/ lb N								
140	214	440.00	28	212	435.60	4.40	9.51	430.49
115	213	443.30	23	209	434.50	8.80	7.81	435.49
100	211	442.20	20	205	429.00	13.20	6.79	435.41
90	208	437.80	18	201	422.40	15.40	6.11	431.69
If N costs $0.38/ lb N								
140	214	417.60	28	212	413.20	4.40	9.51	408.09
115	213	424.90	23	209	416.10	8.80	7.81	417.09
100	211	426.20	20	205	413.00	13.20	6.79	419.41
90	208	423.40	18	201	408.00	15.40	6.11	417.29

† Assume no N was lost when Agrotain was applied.
‡ Return = (yield x price of corn) – (N rate x price of N) – (Agrotain cost if applicable)

These results show that at a relatively inexpensive price of N ($0.22/lb N) the most profitable N rate to apply if no N loss occurred would be 115 lb N/a. If a 20% N loss were to occur, then the most profitable N rate would be 140 lb N/a, because less yield is lost. In this field, the N rate that maximized yield was 120 lb N/a, thus the 140 lb N/a is oversupplying N if no N is loss. So when some N is lost at the 140 lb N/a rate, yield will be impacted little. If Agrotain were applied and no N was lost, then the N rate that would produce the greater return is 115 lb N/a because the cost of Agrotain at this N rate is less than the lost yield. However, if an N loss situation were to occur, return would be maximized by applying 140 lb N/a without Agrotain compared to the return from 115 lb N/a with Agrotain. This difference in these two programs is $0.11/a. Thus, applying extra N is relatively cheap insurance against N loss and subsequent yield losses when N is relatively inexpensive. It should be noted that N losses will contribute to environmental degradation and the practice of applying extra N to offset potential losses is not recommended.

When N is expensive like it is today, $0.38/lb N, the most profitable N rate when no N losses occur is 100 lb N/a. If environmental and management conditions were such that 20% of the N applied as urea was lost, then the most profitable N rate is 115 lb N/a. If Agrotain were applied and no N loss occurred, then 100 lb N/a would be the most profitable. In this situation, N is so expensive that application of extra N to offset yield losses produces a return less than applying 100 lb N/a with Agrotain. For the current economic climate, it is appropriate to reduce N rates to improve profitability. However, if situations for N loss exist, it is also appropriate to maintain a lower N application rate and apply Agrotain to maintain yield.

Nitrification Inhibitors

Nitrification is the process by which ammonium in soils is converted to nitrate. Two bacteria *Nitrosomonas* and *Nitrobacter* mediate this process. Nitrification of ammonium can occur in two to three weeks in most soils when soil temperature is over 50ºF, soil pH is over 5.5, and the soil is aerated (not waterlogged).

The N in ammonium once converted to nitrate can be taken up by plants, leached with excess water (particularly in course-textured soils), or lost through denitrification when warm wet conditions exist in fine-textured soils. In sandy soils, for every one inch of rain/irrigation, nitrate can move two and a half inches down the soil profile; while in fine-textured soils movement is about one inch (Nelson and Huber, 2001). Denitirification is mediated by bacteria and is maximized in soils that are warm (60ºF), have pH near 7.0, have a large concentration of nitrate, and a carbon compound is available. Up to 100 lb N/a can be lost through denitrifcation in waterlogged soils over a five day period if conditions are favorable. If soils are cold (40 ºF) or have pH values near 5.0, denitrification rates are much slower (Nelson and Huber, 2001).

Nitrification inhibitors (NI) interfere with the nitrification process by killing or impeding the metabolism of *Nitrosomonas* bacteria. The advantage of NI is that they maintain N in the ammonium form that is held by the soil and less likely to be lost. NI are effective for three to six weeks depending upon environmental conditions. The purpose of NI to fall applied N is to maintain the N in ammonium form until soil temperatures have dropped below 40ºF and denitrification potential is greatly reduced. For spring preplant applications of N, NI are expected to hold N in the ammonium form during the period when crop demand for N is low and rainfall is high. Past research has shown that the highest probability of yield increases with use of NI are on sandy soils (excessive leaching) and poorly drained fine-textured soils. This is because these situations represent the greatest potential for N loss.

Two examples of the impact of a NI, nitrapyrin (NServe), on yield are provided in Tables 4 and 5. The data in Table 4 show the effect of NServe on a sandy soil. When all of the N was applied preplant, application of NServe increased yield and overall return. However, when all of the N was sidedessed, NServe did not impact yield. Yield when N was sidedressed was greater than preplant N and NServe. This data shows that NServe can be effective in reducing nitrification and subsequent loss of nitrate on sandy soils when the N is applied prior to planting. However, split applications of N on these soils is a better management practice.

Table 4. Four-year average effect of N timing and use of N Serve on corn yield at Hancock (Wolkowski, 1995).

N timing†	NServe	Yield	Income	N Cost	NServe cost	Return
		bu/a	$/a	$/a	$/a	$/a
PP	No	116	255.20	47.60		207.6
SD	No	134	294.80	47.60		247.2
PP	Yes	121	266.20	47.60	8	210.6
SD	Yes	134	294.80	47.60	8	239.2

† 140 lb N/a was applied spring preplant (PP) or sidedressed (SD). NServe was applied at a rate of 2 pt/a.
‡ Calculations were based on $2.20/bu corn, $0.34/lb N, and $32/gal of NServe.

A study in Minnesota shows that fall application of anhydrous ammonia with NServe increases yield and return compared to fall N alone when averaged over seven years. Fall N with NServe produced yields as large as spring applied N, but had a lower return (Table 5). Randall et al. (2003) also found that split applications of N without NServe produced the greatest yields on average. This is because in some years N loss occurred in springs with above normal precipitation. It should be noted that in six of the seven years there was no significant difference between treatments. These data show that on poorly drained fine-textured soils, application of NServe with fall applied anhydrous ammonia can be a profitable practice when averaged over a number of years.

Table 5. Impact on N application timing and use of NServe on corn yield, seven year average on a poorly drained Mollisol in Waseca, MN (Randall et al., 2003).

N timing†	NServe‡	Yield	Income*	N Cost	NServe cost	Return
		bu/a	$/a	$/a	$/a	$/a
Fall	No	131	288.2	45.9		242.3
Fall	Yes	139	305.8	45.9	8	251.9
Spring	No	139	305.8	45.9		259.9
Split	No	145	319	45.9		273.1
LSD (0.01)		4				

† 135 lb N/a was applied as anhydrous ammonia in all treatments. Split application had 40% of the N applied in the spring and 60% sidedressed at V8.
‡ NServe was applied at a rate of 2 pt/a.
* Calculations were based on $2.20/bu corn, $0.34/lb N, and $32/gal of NServe.

Hoeft (1984) summarized results of research with NI in many states. Several trends were found. Soils with a greater potential for N loss through leaching or denitrification have greater probabilities of obtaining economic return through the use of NI. Use of NI in no-till and reduced tillage systems has been shown to conserve N in some regions. Generally, significant yield increases with the use of NI are more often found in fall applied N compared to spring applications. However, NI do not eliminate all potential for N loss on all soils. Some of these principles are demonstrated in Table 6. With the current prices of N, using NServe with fall N applications is cheap insurance against N loss compared with applying more N. For example, return was greater for fall applied N when 150 lb N/a was applied with NServe compared to 200 lb N/a alone ($278.98/a vs. $243.63). Yield with spring applications of N did not vary much with application of NServe. Spring N applications without NServe yielded more than the same amount of N applied in the fall with NServe; showing that while NServe conserved N, some N losses still occurred.

Table 6. Effect of time and rate of N application and NServe on corn yield in Illinois (Hoeft, 1984).

N rate	Nserve	Yield		N cost	Nserve cost	Return[†]	
		Fall application	Spring application			Fall application	Spring application
lb N/a		bu/a	bu/a	$/a	$/a	$/a	$/a
0		66		0		144.86	
100	No	100	144	34		185.47	282.04
100	Yes	124	134	34	8	230.13	252.10
150	No	124	161	51		221.13	302.34
150	Yes	154	159	51	8	278.98	289.93
200	No	142	173	68		243.63	311.66
200	Yes	158	172	68	8	270.76	301.49

[†] Calculations were based on $2.20/bu corn, $0.34/lb N, and $32/gal of NServe.

Summary

In summary, both urease inhibitors and nitrification inhibitors can be tools to manage N loss profitably in today's economic climate. In order to insure the greatest probability of positive economic returns with these materials, it is important to know what environmental and management conditions increase the risk of N loss. As corn growers may reduce N rates because of high N prices, urease and nitrification inhibitors may play a larger role in providing insurance against yield reductions should N losses occur.

Disclaimer

Tradenames are used in this manuscript for the ease of understanding by the reader. These particular products are not necessarily endorsed by the University of Wisconsin-Madison.

References

Bundy, L.G. 1992. Urease inhibitors: NBPT use with surface-applied urea and 28% N solution. New Horizons in Soil Science. no. 2. Dept. of Soil Science, Univ. of Wisconsin-Madison.

Bundy, L.G., and S.L. Oberle, 1988. Evaluation of methods for control of ammonia volatilization from surface-applied urea-containing fertilizers. J. Fert. Issues 5:24-30.

Hendrickson, L.L. 1992. Corn yield response to urease inhibitor NBPT: Five-year summary. J. Prod. Agric. 5:131-137.

Hoeft, R.G. 1984. Current status of nitrification inhibitors use in U.S. agriculture. p. 561-570. In R.D. Hauck (ed.) Nitrogen in crop production. ASA, CSSA, and SSSA, Madison, WI.

Laboski, C.A.M. 2006. Implementation of regional nitrogen fertilization guidelines for corn in Wisconsin. In Proc. 2006 Fert., Aglime, and Pest Mgmt. Conf. Vol. 45.

Nelson, D.W., and D. Huber. 2001. Nitrification inhibitors for corn production. NCH-55. Iowa State University.

Randall, G.W., J.A. Vetsch, and J.R. Huffman. 2003. Corn production on a subsurface-drained mollisol as affected by time of nitrogen application and nitrapyrin. Agron. J. 95:1213-1219.

Wolkowski, R.P., K.A. Kelling, and L.G. Bundy. 1995. Nitrogen management on sandy soils. UWEX Bulletin A3634. Univ. of Wisconsin-Extension, Madison, WI.