SLOW-RELEASE NITROGEN FERTILIZERS AND NITROGEN ADDITIVES FOR FIELD CROPS

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Nitrogen management continues to be difficult due to transformations of nitrogen fertilizers that are possible when applied to soil and the uncertainties of weather (Cabrera et al., 2008). Nitrogen fertilizer in the form of urea is subject to ammonia volatilization through the activity of the urease enzyme found ubiquitously in soil (Kissel et al., 2008). Nitrate fertilizer is subject to leaching (Randall et al., 2008) or denitrification (Coyne, 2008) depending on the water content of the soil and water movement through the soil. Ammonium forms of N can be fixed (Kissel et al., 2008), or can be transformed to nitrate through the activities of specific soil bacteria (Norton, 2008). Because of these and other processes, nitrogen use efficiency is low.

Nitrogen is often applied to crops in the North Central region of the US before planting. The first 4-6 weeks after planting, corn will only require about 5% of the N applied. The following 2-4 weeks of growth require a large proportion of the total season requirement. In winter wheat, very low levels of N are required for over-wintering. However, once wheat breaks dormancy, a large proportion of N is required during the next few weeks. In spring wheat, a small of amount of N is required to establish the crop during the first 2-4 weeks after seeding, however, most of the remaining N is required during the next 30 days. To address some of the delayed N requirement issues of winter wheat, much of the crop is top-dressed in the spring. In corn, some growers use side-dress applications; however spring preplant application is most common, with fall application preferred by growers in some Northern states. In spring wheat in the Northern Plains, some post-N applications are made. Because of the lack of rain during the growing season in many years, post-N applications as a source of most of the N requirement are discouraged except under irrigation. To increase nitrogen use efficiency and thereby increase yields or decrease N rates, a number of products have been developed to delay an N transformation process so that the period of time in which the N source is available for uptake is closer to the time the crop needs the available N. These products can be classified into the following groups-

Nitrification inhibitors

Urease inhibitor additives

Nitrification and urease inhibitor

Urease inhibition through chemical binding with urea as applied with slow-release properties

Urease inhibition through physical separation of urea from soil

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Nitrification inhibitors

N-Serve®, or nitrapyrin (2-chloro-6-[trichloromethyl] pyridine) has been studied and commercially used since the late-1960's. Work by Janssen (1969), summarized by Hergert and Wiese (1980) showed that nitrapyrin was active as a nitrification inhibitor and that the degree of nitrification was influenced by nitrapyrin rate as a ratio of nitrapyrin to anhydrous ammonia. Greater N recovery with nitrapyrin than anhydrous ammonia alone was measured in April (190 days after application), June (230 days) and July (280 days) when anhydrous ammonia was applied from late October to early November.

Illinois studies in the mid-1970's showed that when injected into anhydrous ammonia or applied with urea the rate of nitrification decreased (Figures 1 and 2) (Touchton et al.,1978a, 1978b ; Touchton et al., 1979a); however rainfall during the years of the experiments did not result in consistent increase in corn N uptake or corn yield in Illinois (Touchton et al., 1979b). Lack of yield response from the use of nitrapyrin was also reported in Iowa by Blackmer and Sanchez (1988); however Stehouwer and Johnson, 1990 reported higher corn yield from fall-applied N with nitrapyrin related to higher N availability later in the season.

Higher corn yield with nitrapyrin in fall-applied N was also reported by Randall et al. (2003) and Randall and Vetsch. (2005) in Minnesota; however, spring-applied N was highest yielding with greatest N-use efficiency. N-Serve® is labeled for immediate incorporation or injection and not as a surface-applied product. Yield increases over the seven Minnesota study years were 15 bushels per acre more for fall anhydrous ammonia + N-Serve over fall anhydrous ammonia alone, and 27 bushels per acre more for spring anhydrous ammonia compared to fall anhydrous ammonia (Randall et al., 2008).

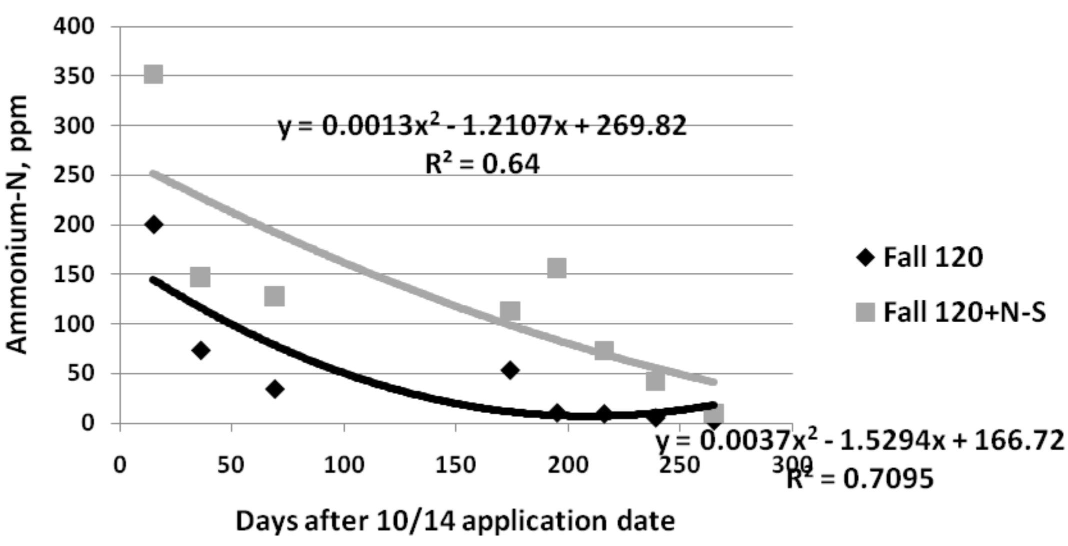

Figure 1. Ammonium-N concentration in soil after 120 lb/acre N as anhydrous ammonia was applied October 14, 1975 with and without 1 lb/acre ai (2X labeled rate) N-Serve® (nitrapyrin). Differences between treatments were significant at all sampling dates through day 239 (Touchton et al., 1978).

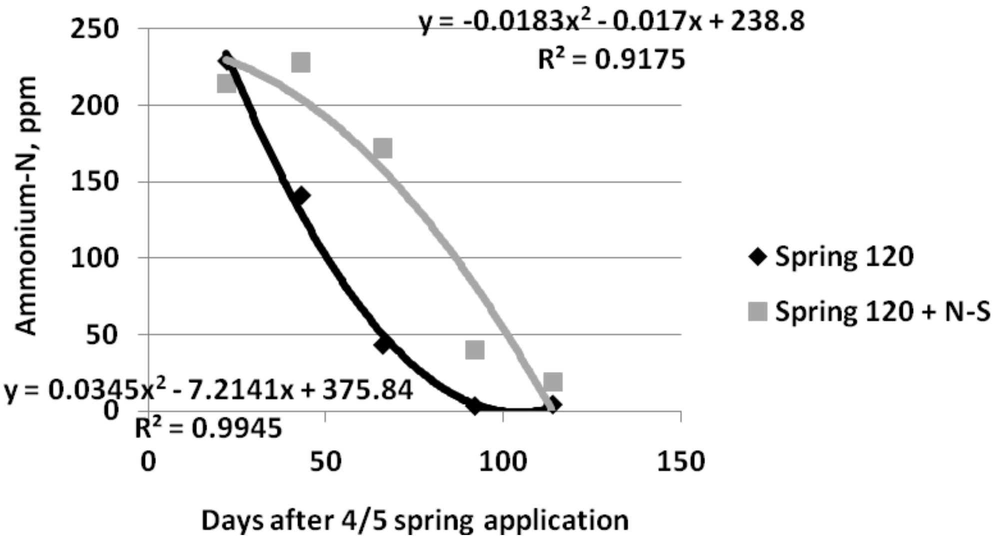

Figure 2. Ammonium-N concentration in soil after 120 lb/acre N as anhydrous ammonia was applied April 5, 1976 with and without 1 lb/acre ai (2X labeled rate) N-Serve® (nitrapyrin). Differences between treatments were significant at days after application all days after application through day 114. Touchton et al., 1978).

A Wisconsin study (Hendrickson et al.,1978) found that on May 6, 1976 following an October 6, 1975 application of anhydrous ammonia, 53% of the recoverable N was ammonium-N with nitrapyrin (0.5 lb/acre ai) compared with 11% ammonium-N without. Nitrapyrin also increased the ammonium-N in Minnesota (Malzer, 1977) through June 8 of the following spring. In North Dakota (Moraghan and Albus, 1979) , greater ammonium-N following fall anhydrous ammonia application was present through July 5 of the following spring.

Grain yield increases with the use of a nitrification inhibitor have been inconsistent due to the variability of rainfall necessary to lead to nitrate leaching in sandier soils or denitrification in high clay soils. Malzer et al. (1979) recorded a corn yield increase with the optimum N rate with fall anhydrous ammonia application with nitrapyrin, but a split application of N resulted in similar yield with nitrapyrin as without. Hergert et al. (1978) showed that the benefit of nitrapyrin use under irrigated sands increased as the irrigation water as a percent of evapotranspiration increased. Differences between use of nitrapyrin and without were most pronounced at irrigation water as a percent of evapotranspiration of 86% and higher.

Instinct® is an encapsulated nitrapyrin formulation that can be applied to fertilizer left on the soil surface for up to 10 days for delay of ammonium fertilizer nitrification. It received its label in 2009. Research is ongoing at a number of Universities. University of Nebraska studies in 2008 and 2009 (Ferguson et al., 2008, 2009) showed no yield benefits to the use of nitrapyrin (GF-2017, Instinct); however, the plots were hampered by heavy rainfall in June (2008) and spatial variability (2009). In Wisconsin, 2 years of work with Instinct® resulted in corn yield increases in 2008, but not in 2009 (Laboski, unpublished data). In Illinois, there were no yield increases due to the use of Instinct with UAN over six site-years (Fernandez, 2010). Iowa (Killorn, unpublished data) and Minnesota (Randall, unpublished data) research also showed no yield increase with Instinct compared to N fertilizer alone.

Research on DCD, dicyandiamide, or cyanoguanidine, has shown that it can be used as a nitrification inhibitor, although research has generally shown that its activity is shorter than nitrapyrin (Bronson et al., 1989).Products that contain DCD in the US include Super-U® (IMC Phosphate Company licensed exclusively to Agrotain International LLC) and Guardian® fertilizer additive (Conklin Company, Inc.). DCD contains about 67% N and was examined as an N source early in the last century (Reeves and Touchton, 1986). It was found to decrease crop yield when rates exceeded about 36 lb/acre (Cowie, 1918). The Guardian label recommends a 2% addition to fertilizer. The content of DCD in Super-U is not stated. It is unlikely that growers would over apply either product to the point of crop phytotoxicity. A review of North Central states research on DCD was published by Malzer et al. (1989). The review concluded that DCD was similar to nitrapyrin in its nitrification inhibition. Yield differences between fertilizer treated with DCD and fertilizer alone were inconsistent and limited to those soils and conditions where nitrate was lost through leaching or denitrification. The greatest value of either nitrification inhibitor would be in soils where nitrate loss through leaching or denitrification is more likely. A summary by Malzer et al. (1989) is reproduced in Table 1.

Table 1. Summary of corn grain yield responses to DCD and nitrapyrin at N rates equal to or less than optimum for fine-textured Midwest soils (from Malzer et al., 1989).

	DCD			Nitrapyrin		
	No. of comparisons			No. of comparisons		
	Total	With significant advantage	Average response	Total	With significant advantage	Average response
			%			%
Timing						
Fall	4	1	+1.6	2	0	-0.2
Spring	15	3	+3.4	7	1	-0.4
Sidedress	3	1	+1.4	3	2	+8.1
N Source						
Ammonium sulfate	2	0	-1.0	0	0	-
Anhydrous ammonia	6	1	+3.6	6	1	-1.8
Urea	4	4	+2.2	6	2	+1.1

In contrast to the relatively low frequency of corn responses in the Midwest, potato responses were more consistently positive (Table 2).

Urease Inhibitors

The compound that has most consistently decreased urea volatilization when mixed with urea or urea-ammonium nitrate solutions is NBPT (N-(n-butyl) thiophosphoric acid triamide). NBPT is marketed as Agrotain® (Agrotain International LLC). The mechanism for NBPT is to lock onto the urease enzyme binding sites, preventing the enzyme from reacting to the urease (Manunza et al., 1999). There are at least two possible uses for Agrotain in crop production; one is to serve as a seed injury safener for growers especially in the Northern Plains that apply urea with small grain seed at planting. Use of Agrotain has increased the rate of urea that can safely be applied with small grain seed in some studies (Table 3).

Table 2. Relative effect of dicyandiamide (DCD) used with three nitrogen sources on potato yield, % Grade A US1A tubers, and apparent N recovery in tubers at Hancock, WI, 1984-1986. (From Malzer et al., 1989).

N Source	Number of comparisons	Number of positive Significant responses			Average relative Response to DCD (%)		
		Yield	% Grade A	Tuber N recovery	Yield	% Grade A	Tuber N recovery
Ammonium nitrate	9	3	1	4	+2.0	-3.6	+6.5
Urea-ammonium sulfate	6	3	0	4	+5.1	-10.8	+23.7
Urea-ammonium Nitrate solution	9	2	2	6	+4.0	-5.1	+27.6

Table 3. Effect of seed-placed urea with and without Agrotain, on stand density and grain yield of barley on a fine sandy loam soil, 1994-96. (From Grant, 2004).

Nrate, lb/acre	Stand, plants/foot		Yield, bu/acre	
	No Agrotain	Agrotain	No Agrotain	Agrotain
0	7.6	7.6	50	50
18	7.9	8.2	55	52
36	7.3	7.7	53	62
54	6.0	7.1	59	57
72	5.7	7.1	63	61
89	4.7	7.1	57	65

Agrotain also decreases the rate of ammonia volatilization from urea applied to the surface as dry urea or urea-ammonium nitrate solutions (Brouder, 1996, Table 4). Ammonia volatilization losses from urea at Brandon, MB decreased from 40 mg to 2 mg and from 88 mg to 12 mg with Agrotain in two separate studies for a seven-day period after application (Grant, 2004).

Table 4. Mean corn yield from Purdue Agronomy Farm, SEPAC, Pinney Purdue and Kosciusko locations with urea and UAN alone and treated with NBPT, Brouder, 1996, citing work by Phillips, Mengel and Walker, 1989, unpublished work, Purdue, University.

Fertilizer treatment	Yield, bu/acre
Control- (20 lb N/acre in starter only	99
Urea broadcast, surface	130
Urea + NBPT broadcast, surface	143
UAN broadcast, surface	135
UAN + NBPT broadcast, surface	140
UAN dribbled, surface	139
UAN spoke injected	142
UAN coulter injected	147
UAN knife injected	145

Table 5. No-till corn yield as affected by N fertilizer sources, Agrotain and placement in Illinois. From Varsa et al., 1999.

Treatment	Belleville	Dixon Springs		
	Yield, bu/acre			
Control (0N)	34	53	62	73
Urea	106	120	98	100
Urea + Agrotain	134	143	112	112
UAN, surface	123	137	103	107
UAN + Agrotain, surface	128	145	107	114
UAN, dribble	139	137	108	112
UAN + Agrotain, dribble	143	152	110	120
UAN injected	172	176	123	121
Anhydrous ammonia	158	166	122	130

In a recent Kansas study (Weber and Mengel, 2009) urea was applied in three site years to the soil surface after corn emergence using a number of nitrogen extending additives including Agrotain. The Agrotain treatment was superior to urea alone by 25 bushels per acre in one of the three site years. The two locations that received significant rainfall immediately following applications did not receive a yield benefit from the Agrotain treatment. In sorghum, urea + Agrotain and urea + SuperU were 11 and 12 bushels per acre respectively greater in yield than urea broadcast alone (Weber et al., 2009a). At two drier locations there were no yield differences between urea + Agrotain and urea alone.

A 14-year study in southern Illinois (Ebelhar et al., 2010) showed a 3 bushel corn yield advantage of urea + Agrotain compared to urea broadcast in conventional till surface and incorporated over 12 years of treatments. In no-till, urea+ Agrotain held an 11 bushel/acre advantage over urea surface applied over 4 years of treatments.

In Kentucky, 50 lb N/acre was applied preplant to all corn plots (Schwab and Murdock, 2009). Side-dress applications of urea and UAN with several additives or formulations were applied to the soil surface at 6-leaf stage. Higher yields than urea alone were achieved with urea + Agrotain and SuperU. Higher yields than UAN alone were achieved with UAN + Agrotain and UAN + Agrotain Plus (combination of NBPT and DCD formulated for use with UAN) (Table 6).

Table 6. Yield for side-dressed no-till corn in Hardin County, KY. (From Schwab and Murdock, 2009)

Treatment	**Yield, bushels per acre**
Check (50 lb N/acre preplant N only)	117d*
Urea	158c
Urea + Agrotain	201b
SuperU	201b
UAN	150c
UAN + Agrotain	179bc
UAN + Agrotain Plus	175bc
Ammonium nitrate	239a

* Numbers followed by the same letter are not significantly different (5%)

Nitrification and urease inhibitors

Ammonium thiosulfate (ATS) and several additional commercial thiosulfates have nitrification (Goos, 1985; Janzen and Bettany, 1986) and soil urease inhibiting properties (Goos, 1985). In the process of identification of thiosulfates as nitrification and soil urease inhibitors, it was noted that the compounds would not be expected to perform as well as some other alternative nitrification and urease inhibitors due to the shorter decomposition period for ATS compared to nitrapyrin (Goos, 1985). One study was unable to duplicate urease inhibition results, but used different methods than originally presented at rates of ATS from 3.3 to 33 times the rates of Goos, 1985 (McCarty et al., 1990). Thiosulfate activity is regulated by its concentration (effective at S rates of 25 mg kg^{-1} (Goos and Johnson, 2001).

Thiosulfate readily breaks down rapidly in temperatures of 15^{o}C. In a laboratory study at 15^{o}C, ATS was essentially mineralized in about a week. Under cooler temperatures, however, significant thiosulfate remained after 2 weeks in 2 of 3 soils, with mineralization complete in all soils by week 3. When thiosulfate was placed in a band with aqua ammonia in the fall in North Dakota (October 3, 1996), thiosulfate resulted in similar spring (May 12, 1997) ammonium and nitrate levels as aqua ammonia treated with nitrapyrin (Goos and Johnson, 1999). Spring wheat yields of aqua ammonia treated with thiosulfate and nitrapyrin were similar, and both were greater than aqua ammonia alone.

Cautions were expressed by Janzen and Bettany (1986) on high rates of banded ATS (over 100 ppm) due to nitrite accumulation from ATS inhibition of not only the ammonium to nitrite process, but the nitrite to nitrate process. The rate used by Goos (1985) was about 43 ppm if expressed as a band with radius 2 inches, which did not accumulate nitrite in the Janzen Bettany (1986) study. Recently, the use of thiosulfate has been reexamined. In Kansas, the application in the spring of a 5% and 10% calcium thiosulfate by volume solution with UAN had similar yield as urea broadcast in no-till (Tucker and Mengel, 2007).

Nutrisphere-N is a product marketed by SFP (Specialty Fertilizer Products) LLC, Leaweed, Kansas. The formulation for dry fertilizer is a 30-60% maleic itaconic co-polymer calcium salt. The pH of the dry formulation is between 2.5 and 5 according to the label. The rate of use is 0.5 gallon per ton of urea/ammonium sulfate. The formulation for liquid fertilizer is a 40% minimum maleic-itaconic co-polymer. The pH of the liquid product is between 1 and 2 according to the label. The rate of mixing with liquid N products is 0.5 gallon Nutrisphere-N per 99.5 gallons of fertilizer solution. A gallon of Nutrisphere-N liquid or dry formulation weighs 9.6 pounds per gallon. Nutrisphere-N is marketed as both a urease inhibitor and a nitrification inhibitor. Marketing literature explains that the activity of Nutrisphere on nitrification is related to its binding to copper ions necessary for the nitrification process in soil bacteria. The activity of the product on urease is based on its binding to nickel ions necessary for the formation and function of the enzyme. Also, the product Avail®, which is marketed as a phosphate enhancing product by SFP, contains the same active ingredient as Nutrisphere. The Avail activity is attributed to binding of calcium or iron ions in the soil that might normally bind phosphate. Based on the mode of action of the ai of Nutrisphere/Avail, the compound is highly negatively charged and would tend to bind with any compound with a positive charge, not distinguishing one ion over another.

The most consistent yield increases and crop uptake of N from the use of Nutrisphere-N has been through work by Gordon (2008). In two years of corn at Scandia, KS and two years of grain sorghum at Belleville, KS, yield increases to the use of Nutrisphere-N were similar to those achieved with urea-Agrotain and ESN (Tables 7 and 8).

Table 7. Effects of N additive, averaged over source (UAN and urea) and N rate on corn grain yield, earleaf-N and grain-N, Scandia, KS (2-year average). From Gordon, 2008.

Treatment	Yield, bu/acre	Earleaf N, %	Grain N, %
Check	152	1.72	1.13
Urea/UAN	168	2.57	1.26
ESN	185	2.96	1.33
Nutrisphere-N	183	2.96	1.35
Agrotain	183	2.98	1.36
LSD 5%	6	0.09	0.04

Table 8. Effects of N source and rate on grain sorghum yield, Belleville (2 year average). Gordon, 2008.

Treatment	N-Rate, lb/acre	Yield, bu/acre
Check	0	71
Urea	40	108
	80	122
	120	128
ESN	40	120
	80	130
	120	132
Urea + Agrotain	40	116
	80	129
	120	133
Urea+ Nutrisphere	40	120
	80	133
	120	132
LSD 5%		5

The consistent results from Gordon (2008) are very curious considering that careful laboratory experiments by Goos (2008) and Norman (Franzen et al., 2010?) have shown that Nutrisphere-N has no nitrification or urease inhibitor ability (Figures 3 and 4, Table 9).

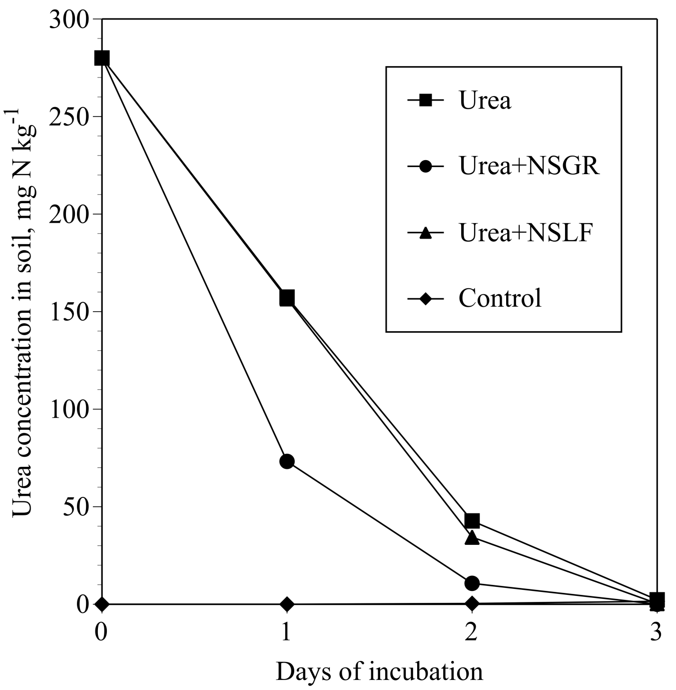

Figure 3. Urea remaining in an Overly soil, as influenced by time of incubation, and application of urea, urea plus Nutrisphere-N for granular fertilizers (NSGR), and urea plus Nutrisphere-N for liquid fertilizers (NSLF). (Experiment by R.J. Goos in Franzen et al., 2010?)

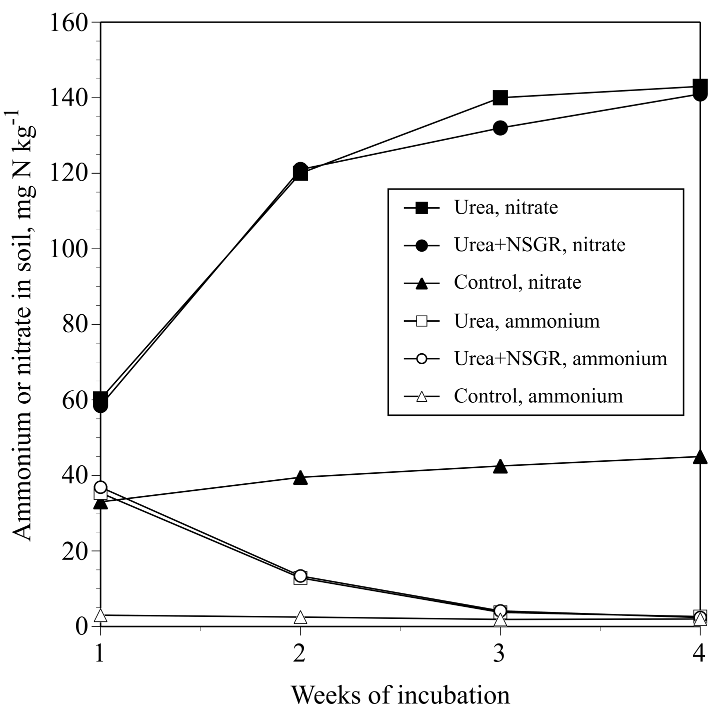

Figure 4. Ammonium and nitrate in a Renshaw soil as influenced by length of incubation and application of urea granules, and urea granules treated with Nutrisphere-N for granular fertilizers (NSGR). (Experiment by R.J. Goos, in Franzen et al., 2010?)

Table 9. Cumulative ammonia volatilization losses for urea, ammonium sulfate, urea + NBPT, and urea + 0.25% Nutrisphere (NSN) from a Dewitt silt loam soil during a 15-day laboratory incubation at 25°C. (Norman data, University Arkansas, Fayetteville, from Franzen et al., 2010?)

	Days after N source application			
	3	7	11	15
N sources	Cumulative NH_3 loss, % of N applied			
Urea	14.5	35.9	51.8	56.9
Ammonium sulfate	0.1	0.2	0.5	0.6
Urea + NBPT[†]	0.006	2.7	12.9	18.3
Urea + 0.25% NSN	17.6	42.2	57.8	62.7
LSD(0.05)[‡]	12.2			
LSD(0.05)[§]	9.6			

[†]NBPT= N-(n-butyl) thiophosphoric triamide
[‡]LSD to compare means between N sources within the same sampling time.
[§]LSD to compare means between sampling time within the same N source.

It is clear from the laboratory experiments that there is no nitrification inhibition or urease inhibition by Nutrisphere when used at label rates. Goos has observed some small nitrification inhibition when the Nutrisphere for liquid fertilizer is applied in a concentrated band. He attributes this to the strong acidity of the liquid formulation, and not to the Nutrisphere itself (Goos, personal communication, 2010). Acid conditions are known to inhibit nitrification bacteria (Schmidt, 1982).

In the field, it is uncommon to consistently find yield or quality responses to the use of Nutrisphere at labeled rate. In North Dakota studies on spring wheat at 8 locations, there were no yield increases or grain N uptake increases with Nutrisphere compared to urea (Franzen et al., 2010?). In Kansas (Tucker and Mengel, 2008), there were no increases due to Nutrisphere with UAN over UAN surface banded or injected in grain sorghum in 2007. In two years of corn in Kansas, there were no yield increases from the use of Nutrisphere-N UAN compared to surface applied UAN at three total sites (Weber and Mengel, 2009). In 2009, there was no response to Nutrisphere + UAN broadcast on grain sorghum compared to broadcast UAN alone in Kansas at three locations (Weber and Mengel, 2010). There was one sorghum yield increase with surface banded Nutrisphere + UAN compared to UAN surface banded alone and two non-responsive sites. The yield increase with surface band but not broadcast suggests that perhaps the acidity of the Nutrisphere may have delayed nitrification at this site (Schmidt, 1982).

At Waseca, MN in 2009, there were no corn yield differences between urea and urea with Nutrisphere applied in the fall (Randall and Vetsch, 2009). Grain and stover N between urea and urea with Nutrisphere were similar. In Illinois, at two locations in 2008 Nutrisphere-urea was lower in yield than urea, and similar in yield at the two locations with UAN and Nutrisphere-UAN (Ebelhar and Hart, 2009). At Dixon Springs in 2009, Nutrisphere urea, UAN, and ammonium sulfate treatments did not result in higher corn yield than the N sources with Nutrisphere-N (Ebelhar and Hart, 2010), although main effects for Nutrisphere-N on corn yield were significant. In Arkansas and Mississippi, Nutrisphere-N had no effect on rice yields in three field studies compared with urea (Franzen et al., 2010?). In South Dakota, Nutrisphere-N did not result in higher corn yield in 2007 (Bly and Woodard, 2007), 2008 (Bly et al., 2008), or 2009 at 2 sites (Bly et al., 2009).

In Montana, there were no spring wheat yield increases with Nutrisphere over 2 years (Jeffrey Stark, personal communication, 8/23/2010). In barley, however, there were yield increases in 2008 and 2009 with Nutrisphere, but no increase in grain protein over similar rates of urea. Plant N uptake with Nutrisphere was similar to urea without Nutrisphere, suggesting that the yield increase in barley came from some other response other than enhanced N nutrition (Stark, 2008. 2009).

Laboratory studies with Nutrisphere-N show no effect on nitrification or urease activity. Therefore, it is not surprising that the great majority of studies with Nutrisphere show no yield effects. What is surprising is that there are studies that show yield effects, but not from increased N nutrition. The results from Gordon (2008) suggest that under some conditions, Nutrisphere may have some effect on plant growth and development and even N nutrition not related directly to urease inhibition or nitrification. However, the company may need to reexamine its label as a nitrification inhibitor and urease inhibitor.

Urease inhibitors through chemical binding with urea and slow-release properties

These products function as slow release N fertilizers by binding the urea to another organic compound. As the compound degrades in the soil, urea is released. Similar products have been successfully used under irrigated turf for many years, and have only recently entered the agricultural sales arena. Some of these products have been tested as soil-applied preplant products and as foliar post-emergence fertilizers in certain field crops.

In North Dakota, 8 field studies were conducted with Georgia-Pacific Nitramin products (Triazone and methylurea), either a slow-release agent impregnated onto urea (43-0-0), or the slow-release agent mixed with UAN (30-0-0) (Franzen, unpublished data). In most of the studies, there were no spring wheat yield or protein differences with the use of the product over the fertilizer without the additive. However, in sandier soils with higher spring rainfall, some differences were observed (Table 10). The cost of these additives is economically prohibited for their general use as a substitute for traditional fertilizers and other additives.

Table 10. Effect of Georgia-Pacific 43-0-0 Nitramin amended urea compared to urea surface applied in no-till spring wheat, 2008 near Valley City, ND. Franzen, unpublished data.

Treatment	Lb N/acre	Yield, bu/acre	Protein, %
Check	0	37.8	12.1
Urea	30	45.8	12.4
	60	51.2	13.3
	90	57.2	14.1
	120	63.0	15.1
Urea +Nitramin 43-0-0	30	45.2	12.7
	60	57.4	13.3
	90	60.2	14.4
	120	57.6	15.0
LSD 5%		6.1	0.7

In South Dakota, application of Nitramin and UAN surface applied resulted in similar corn yields at Aurora in 2007 (Bly and Gelderman, 2007). In 2008, spring wheat yield was not increased with application of Nitramin, however, grain protein at the 27 lb/acre N rate (9 gallon/acre UAN compared to 7.2 gallon/acre UAN + 2.3 gallon/acre Nfusion) was increased with the Nfusion blend (Bly and Gelderman, 2008). Late foliar application of 30 lb N as either UAN or Nitramin 30-0-0 resulted in about 1% increase in grain protein. Both late foliar treatments were similar in yield with no advantage to Nitramin.

In North Dakota, foliar experiments with several application timings were conducted with Nitrarmin 30-0-0 in 2008 on barley, spring wheat and soybean. In barley, application in a high-yield environment at 2-leaf stage resulted in an 8 bu/acre yield increase (Table 11). This increase was probably the result of early tiller stimulation. No yield increase or increase in grain protein was recorded at early jointing, boot or anthesis (Franzen, 2009).

There were no improvements in spring wheat yield or protein at 3.5 leaf, first joint, early boot or anthesis with either 1 or 3 gal/acre 30-0-0 Nitramin. There were no improvements in soybean yield or protein when 2 gal/acre 30-0-0 Nitramin was applied at V3, V5, R1 or R3.

Table 11. Application of 2 gallon per acre 30-0-0 Nitramin at several barley growth stages near Valley City, ND, 2008. Franzen, 2009.

Treatment	Yield, bu/acre	Protein, %
Check	117	13.4
2-leaf	125	12.8
Early jointing	116	13.3
Boot	109	13.3
Anthesis	119	13.2
LSD %	6	NS

CoRon is a 28-0-0, with 8.4% urea N and 19.6% as methylene-ureas and methyl diurea, weight 10.6 lb/gallon. CoRon was tested near Minot, ND in 2006 on spring wheat. Preplant N was applied to achieve yields of 50 bu/acre. There were no additional increases in yield or protein, when 1, 2 or 3 gal/acre CoRon was applied at the 5-leaf stage in spring wheat. A study the following year near Roseglen, ND similarly showed no protein increase when CoRon was applied at flag-leaf at a rate of 1 gal/acre. In winter wheat at Roseglen, 1 gal/acre did not increase grain yield or protein compared to the similar preplant N treatment without it. Both treatments received 90 lb N/acre as a preplant urea treatment. Anthesis applications of CoRon at 1 gal/acre did not increase grain protein of spring wheat in 2005, but 10 gal/acre UAN increased protein significantly (McKay, unpublished data).

At Carrington, ND in 2009, CoRon was applied at 1 gal/acre and at a rate equivalent to 30 lb N/acre. There was also a treatment of 10 gal UAN/acre (30 lb N/acre) in the experiment. Treatments were applied immediately post-anthesis. The 1 gal/acre CoRon rate did not increase grain protein. The 30 lb N rate of CoRon and UAN both increased protein significantly (Endres, unpublished data). If these fertilizers were applied at rates comparable to rates necessary to achieve grain protein increases, they would have similar effects, but they have no efficiency advantage over traditional products in a foliar application.

N-Pact is a 26-0-0 liquid fertilizer with 17.4% urea-N and 9.6% N as urea triazone, with a weight of 10.1 lb/gallon. N-Pact is distributed by Loveland Products, Inc., Greeley, CO. N-Pact at 2 and 3 gal/acre was applied to spring wheat at the 5-6 leaf stage in 2008 near Valley City, ND. There were no increases in yield, flag-leaf N or protein from these applications. N-Pact was also applied in another experiment near Valley City, ND at a 3 gal/acre rate immediately following anthesis. There were no yield or protein increases in spring wheat due to these treatments.

Urease inhibition through physical separation of urea from soil

Fertilizers in this category have a coating around the urea pellet that physically separates the fertilizer from the soil. The fertilizer most tested in this category is ESN (Agrium). The strategy of this fertilizer is to have some of the fertilizer available early in the season and the N in the other pellets is released through polymer breakdown later in the season. Incubation experiments using poly-coated urea have shown that release of ammonium and nitrate-N is slowed when these products are used compared to urea (Doyle and Hernandez, 2008).

In an Illinois study conducted at four locations, ESN broadcast was similar to urea+Agrotain in corn yield and 3 bushels per acre higher in yield over 12 years compared to urea broadcast incorporated (Eberhar et al., 2010). Comparing urea broadcast to ESN in no-till corn production, ESN was 21 bushels per acre higher over 4 years. In another Illinois study at Dekalb over three years, there was no difference in corn yield between ESN and urea averaged over years and fall/spring applications (Below et al., 2009).

In Minnesota in dryland corn, ESN 4" deep-banded fall, broadcast-incorporated fall, and broadcast-incorporated in the spring resulted in similar yield as urea subjected to the same application over a 4-year period (Randall and Vetsch, 2009). ESN and 50% urea/50% ESN fertilized grain sorghum (Weber et al., 2009a) yield was similar to urea broadcast in a trial in which urea + Agrotain gave a positive response. At two drier Kansas locations grain sorghum yields were not increased with a 50% urea/50% ESN blend compared to urea alone. In corn, the 50% urea/50% ESN blend yielded more than broadcast urea, but ESN was similar in yield to broadcast urea in 2008 (Weber et al., 2009b). In 2009, ESN was had greater yield in grain sorghum than urea at 2 of 4 locations in Kansas, while the 50% urea/50% ESN blend had greater yield in 1 of 4 locations.

In Michigan winter wheat, fall ESN yields were greater at a 60 lb N rate compared to urea in two of three years, but not at a 90 lb N rate. Yields of winter wheat were higher with a spring 60 lb/acre and 90 lb/acre topdress N rate as ESN in one of three years compared to urea (Warncke and Nagelkirk, 2008).

A review of enhanced efficiency fertilizers (Nelson et al., 2008) compared several slow-release N fertilizers including ESN and Polyon (formerly Purcell Technologies, Inc., Sylacauga, AL, now Agrium Advanced Technologies) with urea, UAN and anhydrous ammonia. Average corn yield was similar for the poly-coated materials as with anhydrous ammonia and urea + NBPT. Poly coated fertilizers were 2 and 10 bu/acre greater urea and UAN respectively. There was variability in response to poly coated fertilizers attributed to variations in rainfall timing and amount.

Summary

Certain slow-release nitrogen fertilizers and nitrogen additives provide growers with options for extended activity of nitrogen nutrition for their crops. Their economics depends on rainfall following application, application methods, timing and soil characteristics, especially soil texture. Nitrapyrin has been effective in delaying nitrification. Dicyandiamide has also been shown to be effective in delaying nitrification. Thiosulfates have been shown to delay nitrification, but the body of literature to support their use is much smaller than that of nitrapyrin. NBPT (Agrotain) is an effective urease inhibitor. Thiosulfates have shown some urease inhibition characteristics, but again, the body of literature that supports their use is small.

Nutrisphere has been shown to be ineffective as both a nitrification and urease inhibitor. The data that support the use of Nutrisphere is small in comparison to the data that does not support its use. If one accepts that the laboratory studies, conducted in a similar manner to those used to evaluate products like Agrotain, show that Nutrisphere is not a nitrification or a urease inhibitor, than there must be other explanations for small number the field studies that show a yield benefit to the use of the product and in some circumstances even show an accumulation of N. The very acidic nature of the liquid formulation of Nutrisphere suggests that in banded applications, the nitrification delay may be associated with the acidity of the solution more than the Nutrisphere itself.

Slow-release fertilizers based on organic compound binding with urea may have some application in sandier soils in some years, but the expense of their use as a replacement for conventional alternatives probably makes their use impractical for field crops. Slow-release fertilizer use as a low-rate foliar application has not been supported by research.

Use of poly-coated urea has been supported by several studies, although there are several studies that have not shown an advantage to their use. The product label stresses that the product needs to be handled carefully to avoid cracking the polymer coating. If the coating is cracked, the urea inside would be expected to behave like urea and be at risk for loss.

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