NITROGEN SOURCES AND THEIR MANAGEMENT ON WHEAT YIELD AND PROTEIN

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Nitrogen Sources and Their Management on Wheat Yield and Protein

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ABSTRACT

Nitrogen (N) fertilizer management in wheat (*Triticum aestivum* L.) can impact grain yield and protein. Develping strategies that improve N efficiency are needed to optimize wheat production in North Dakota. Field experiments were conducted to evaluate N stabilizers, N rate, N placement and application timing on grain yield and protein of winter and spring wheat. The timing of N release from a polymer coated urea (ESN) was also studied. Nitrogen stabilizers improved N efficency in some environments but not all. Deeper placement of urea helped reduce N losses. The closer that N fertilizer was applied to the date it was utilized by wheat usually increased protein. Nitrogen release from ESN was gradual over several months offering potential protection against N losses from a fall or spring applicaton.

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LIST OF ABBREVIATIONS

ANOVA ....Analysis of variance.

DCD ....Dicyandiamide

ESN ....Environmentally Smart Nitrogen.

LSD ....Least Significant Difference.

N..Nitrogen.

NBPT ....N-butyl-thiophosphorictriamide.

NDSU...North Dakota State University.

PCU..Polymer coated urea.

RCB..Randomize complete block.

SAS ....Statistical Analysis System.

UAN..Urea ammonium nitrate.

USDA...United States Department of Agriculture.

INTRODUCTION

Nitrogen (N) fertilizer is one of the most important inputs to wheat (*Triticum aestivum* L.) production as it impacts both yield and grain protein content. Efficient management of N fertilization is therefore a critical component of profitable wheat production. Following the four "R"s of fertilizer management can improve fertilizer efficiency, a concept first introduced by Thorup and Stewart (1988) and later promoted globally by the International Plant Nutrition Institute (IPNI). The 4 R's are: the right rate, the right type, the right placement and the right timing of the fertilizer used. One area of recent research has been the development of N fertilizer sources and N fertilizer additives that may reduce the loss of N after application in crop production. Some of these additives have been available for many years. The urease inhibitor, N-butyl-thiophosphorictriamide (NBPT), and the nitrification inhibitor, nitrapyrin (2-Chloro-6-(trichloromethyl)pyridine), are two chemistries that are used to reduce N loss, by reducing enzymatic and bacterial reactions in the soil that affect N transformation. More recently polymer-coated urea (PCU) was developed. These products act to slow the release of urea N fertilizer through a thin polymer on the urea fertilizer prill. The polymer coating is initially impermeable to water. With time, however, cracks and thinning of the coating by abrasion with soil particles and chemical degradation allows water to slowly diffuse into the prill. After the urea is solubilized it slowly exits the prill capsulation and enters the soil water environment. The slow release of N helps to extend its effectiveness, particularly if environmental conditions that promote N loss through ammonia volatilization, leaching or denitrification are present after application. By reducing N loss, the hope is that more of the applied N is available at the time when the plant needs it. In spring wheat, this is usually from 30 to 60 days after seeding. Polymer coated urea is a relatively new slow release source of fertilizer N and research is needed in order to understand how it can most effectively be utilized. The objective of this study was to determine how PCU can be used to improve N-use efficiency and improve the productivity of spring and winter wheat compared to traditional fertilizers, fertilizers with nitrapyrin or NBPT and other fertilizer management practices.

LITERATURE REVIEW

Nitrogen (N) fertilizers are typically the most important fertilizer applied to wheat for optimum production. Nitrogen fertilizers are also often the most expensive input used in wheat production; therefore, farmers need to utilize the N they apply as efficiently and cost effectively as possible. Multiple applications of N throughout the growing season, multiple forms of N, timing of N applications and application placement have been used to address these concerns (Mahler et al., 1994). These methods are three of the 4 "R"s of N fertilizer management, with the 4th R being the right rate (Johnston and Bruulsema, 2014). Although these management practices may help improve N use efficiency, they may not always be completely effective due to adverse environmental conditions. Nitrogen losses can be affected by many environmental factors whose consequences are difficult to predict (Grant, 2004).

Along with losses in crop productivity when N is lost from the root zone, there are growing concerns with the effect of off-farm movement of N, N product safety, high fuel costs of some application methods, and the high price of certain fertilizer products. These concerns have produced a need for new or improved N fertilizer products and recommendations (O'Leary et al., 1994). Off-farm fertilizer has been an increasing problem for many areas of the United States due to its role in eutrophication of surface water bodies, and in contamination of aquifers used for livestock and human drinking water. There has been an increase in aquifer nitrate levels in certain regions that are attributed to improper fertilizer management (Mahler and Keith, 2002). Issues of safety, transportation insurance costs and application costs have impacted anhydrous ammonia use/sales. Anhydrous ammonia is a liquid/gas product that is injected into the soil under pressure. While anhydrous ammonia is the cheapest N source, its transportation, storage and application have significant safety risks. Its use is also prone to application mistakes, most notable too shallow an application, or application when the soil is too wet, or when the soil is too cloddy, leaving the application trench open and susceptible to ammonia volatility (Shutske, 2005). Since 1991, sales of anhydrous ammonia have declined in the USA from more than 4.6 million metric tons per year to only 907,184 metric tons per year in 2013 (USDA 2013).

The most popular synthetic N products in North Dakota are urea followed by anhydrous ammonia, followed by N in phosphate products, and N solutions containing urea and ammonium nitrate (UAN). While the use of anhydrous ammonia is declining, the use of N solutions and urea are on a steady increase (USDA, 2013). However, both of these products may be more prone to loss from the soil rooting zone than anhydrous ammonia (Butzen, 2013).

There are three main types of losses that can occur to N after being applied to the soil: ammonia volatilization, leaching, and denitrification. Ammonia volatilization when urea is the source of fertilizer occurs when the urea ($(NH_2)_2CO$) dissolves and is enzymatically converted into ammonia (NH_3) gas. In this gaseous state, it can easily move into the atmosphere. Volatilization is most likely to happen when urea is broadcast on a wet soil surface compared to a dry surface, when soil surface residue is high and when soil pH is >7 (Jones et al., 2007). Most volatilization occurs during the first three weeks after application. However, NH_3 volatilization rates are hard to predict. Rates are influenced by weather conditions following application and several soil properties.

The best way to minimize volatilization from urea is to soil incorporate the product within a couple of days of the broadcast application to a depth that places most of the urea at least 5 cm deep (Rochette et al., 2013). Urea incorporation or deeper placement is crucial to the effectiveness of its application (Grant, 2004). Incorporation can be done by one of three ways. The first is to band apply the fertilizer directly into the soil at least 5 cm deep, the second being broadcast on the soil surface and then tilled into the soil, and third is to apply it to the surface of the soil and have it incorporated by rain or irrigation. In this latter case, at least a 13 mm of rain (or irrigation) is necessary to dissolve the urea and move it deep enough into the soil so that gaseous NH_3 will not be lost to the atmosphere (Jones et al., 2007). Within the soil profile when urea converts to ammonia (NH_3) it rapidly goes through a hydrolysis reaction and converts to ammonium (NH_4^+). Ammonium is the preferred state for N in the soil because it is available to the plant but is also relatively immobile in the soil profile as its positive charge is attracted to soil particles and organic matter.

Ammonium can, however, be converted rapidly to nitrite (NO_2^-) and then to nitrate (NO_3^-) in a bacterial-mediated process called nitrification. Temperature significantly impacts the amount of time it takes for nitrification to occur (Butzen, 2013). Temperatures under 10°C slows the bacteria mediated process down to the point that there is almost no conversion (Engel et al., 2011). This can be especially important when applying N in the fall for a crop the next growing season. Delaying the application until soil temperatures drop below 10°C can greatly improve the retention of the N in the root zone for the next season.

Nitrogen in the nitrate form is very mobile with soil water as it does not adhere to the soil like ammonium ions. Nitrate is readily available to the plant, but because it is mobile it can be leached out of the root zone making it inaccessible to the crop (Jones et al., 2007). Leaching is the downward movement of N in the soil profile and is influenced by the amount of rain, snowmelt or irrigation water received onto the soil and the water infiltration rate of the soil which is related to soil texture.

When rainfall, snowmelt or irrigation rates exceed the rate of infiltration, waterlogging and lateral runoff can occur. Waterlogging leads to oxygen (O_2) depletion in the soil called anoxia and can lead to another loss of N from the soil profile through a bacteria mediated process called denitrification (Butzen, 2013). Denitrification results when O_2 depletion is so great that the oxygen from the nitrate molecule is used by anaerobic bacteria resulting in nitrate N conversion to nitrous oxide, N_2 or other forms of gaseous N. Once in these gaseous forms the N cannot be converted to plant useable forms and moves from the soil profile into the atmosphere.

Urea is a granular fertilizer that contains 46% N. It is currently the most widely used granular source of N and is used on most crops across the United States (USDA, 2013). Urea has been available commercially since the 1920’s but it was not widely used as a fertilizer until 1950 (Howarth et al., 2002). Urea can be a very efficient source of N when proper application techniques and timing are utilized. With relatively easy adjustments, large differences in N efficiency from the applied urea can be achieved (Middleton et al. 2004). Yet, many of these practices come with added costs to the farmer, may be time consuming, and deplete management resources, particularly labor. Sometimes even when properly implemented these management practices may not perform well because of unusually wet conditions that result in N loss.

Technologies called N stabilizers (additives) are being used to combat the loss of N from the plant rooting zone of the soil profile (Butzen, 2013; Franzen, 2017). These additives are applied with urea before it is applied to the field. There are three types of N stabilizers which are most used.

The first to be discussed is polymer-coated urea (PCU). A polymer-coated urea is urea with a thin polymer coating over each individual urea prill that allows the slow release of urea through the membrane over a long period of time. Each prill coating releases urea at different timings because there is variation in coating thickness with a batch (Wilson, 2007). By doing so, the urea is protected from the soil environment for longer periods compared to urea alone. This reduces, at least for the early part of a growing season, the problems of ammonia volatilization, leaching, or denitrification. The PCU therefore may help to provide N to the crop through the entire growing season with a single preplant application. There are still, however, few good recommendations for using this technology in winter or spring wheat.

Making good recommendations for PCU is difficult because of the mechanisms needed for release are not controllable. Water must first diffuse into the polymer coating before it can solubilize urea so that it can then move into the soil solution. The rate at which water can enter the prill differs for each prill is regulated by both soil temperature and moisture. The greater amount of each increases the release rate from each prill, while cooler and dryer conditions reduce the rate (Killorn and Moore, 2006). Previous studies conducted at Iowa State University showed that the polymer coated urea marketed as Environmentally Smart Nitrogen™ (ESN) (Nutrien, Saskatoon, Canada), applied in the spring, was able to increase corn (*Zea mays* L.) yield by 501 kg ha^{-1} compared to untreated urea at the same rate and timing (Killorn and Moore, 2006). In the same experiment, ESN applied in the fall compared to urea applied in the spring yielded about 491 kg ha^{-1} less. Similar trials like these are essential for discovering the most effective use of this product. One aspect of this technology that holds promise is that if it can be applied more safely than urea in the fall it could save time for farmers in the spring, when they are usually pressed for time. The ability to fall-apply ESN would result in more timely planting, depending on the season. A study in Iowa with corn showed that by using ESN in the fall, there was still a slight yield decrease compared to urea in the spring (Grant, 2004). However, by using ESN in the fall the yield decrease was reduced in two of the three years and out yielded the spring application of urea in one of the three years. More research is needed to optimize the efficiency of this product and to verify that it can be cost effective at current prices, particularly under the rainfed and often semi-arid conditions of North Dakota.

In North Dakota, ESN is being aggressively marketed as a N fertilizer source for wheat. Additional information is needed as to its effectiveness on yield and protein of spring and winter wheat when applied in the fall or spring. Furthermore, its performance relative to other N fertilizer additives is also needed so that farmers can make an informed decision on its usefulness, compared to other N regulating products.

The second type of additive available to improve the efficiency of urea is the urease inhibitor. Urease is the enzyme produced by bacteria and plants which catalyzes the breakdown of urea. This reaction can occur at or below the soil surface, depending on where the urea is located when it encounters this enzyme. If it occurs above the ground, it can lead to volatilization. To prevent this from happening, a urease inhibitor can be used. The most widely used agricultural urease inhibitor is N-butyl-thiophosphorictriamide (NBPT) which blocks the active site of the urease enzyme (Butzen, 2013). This chemistry simply delays the breakdown of urea to ammonium but does not protect it from further reactions or from other potential losses from the soil (Wolt, 2004).

The third type of additive currently available to reduce N losses are nitrification inhibitors, which slow the conversion of ammonium to nitrate (Mullen and Lentz, 2011). By using a nitrification inhibitor the loss of N through denitrification and leaching can be reduced. There are several types of nitrification inhibitors, but the most widely used in North America are dicyandiamide (DCD) and nitrapyrin.

The objective of this research was to identify and compare different N sources/additives for optimizing wheat grain yield and kernel protein.

MATERIALS AND METHODS

Experiments were conducted to determine the effectiveness of nitrification inhibitors, urease inhibitors, slow release urea, and split applications of N at different application rates and application timings on increasing the yield and protein content of winter wheat and spring wheat. These experiments were established in six locations, four in North Dakota (Fargo, Carrington, Prosper, and Forman) and two in Minnesota (Argyle, and Red Lake Falls) in 2013 and 2014.

Winter Wheat Experiments

Winter wheat experiments were established in three locations: Carrington, Prosper and Forman, ND in the fall of 2013. Experiments were identical at all locations. Prior to planting in the fall, each location was treated with glyphosate (isopropylamine salt of N-(phosphonomethyl) glycine) at a rate of 1.67 kg ha^{-1} of acid equivalent, in order to control spring wheat volunteers and eliminate any competition between the emerging wheat crop, weeds, and volunteers. At all three locations, the cultivar 'SY Wolf' was planted using a seeding rate of 3.7 million live seeds ha^{-1}. Each site was planted within a 10-day period between September 15-25, with all early fall applications of N fertilizer being applied on the same day as planting (Table 1).

Before fertilization, ten 1 cm diameter soil cores at 0-30 cm and 30-60 cm depths taken randomly from the experimental area were bulked together for each depth and were analyzed for residual nitrate. Results from these analyses were used in construction of optimum fertilization rates for each experiment. Experimental units at each location were demarcated using a tractor equipped with an RTK GPS system to help ensure that they were of similar size, thereby reducing variability between plots within and between locations. Each experimental unit was 1.5 m wide and 5.48 m long and consisted of 7 rows of wheat with an 18 cm spacing between rows. Border areas were established on the outside edges of the trials to reduce border effects from errant neighboring fertilizer applications on the first and last column of experimental units. The entire experimental area was laid out before planting using an implement that scores the ground with disk blades making each plot recognizable. Also prior to planting, N was applied to plots receiving the band application treatment.

After fertilizer treatments were applied, wheat was seeded without alleys between ranges using a plot seeder with double disk openers. This was done to eliminate the variability that alleys can cause and for ease of applying the treatments. Before harvest, 1.98 m alleyways between ranges of plots were mowed in order to allow for the harvest of each plot separately with a small plot combine.

The experiment was established as a randomized complete block design (RCBD) with four replications. There were 33 fertilizer treatments including an untreated control treatment in each replication. The factors that were included in the development of the treatments included N rate (two), timings of N applications (three), application placement (two), types of N fertilizers and blends (five) with a urease and nitrification inhibitor NBPT and DCD (SuperU) being only applied to broadcast treatments and exchanged for the nitrification inhibitor nitrapyrin (Instinct) when being band applied. The 100% rate of N that was used was 123 kg N ha^{-1}.

The two application methods used were banded and surface broadcast. The banded application was made directly before planting. This was done using a grain drill with openers placing the fertilizer about 6 cm deep with the rows offset from the seeding row by 6.4 cm, so as not to interfere with planting depth and possible seed/seedling injury caused by too much N near the seed at germination. This treatment was similar to a mid-row band that would have been put down at the time of planting with a planter set-up for such an application. All surface applications applied in the fall were applied immediately after planting and were broadcast by hand. The four different fertilizer types that were used were: urea, urea with a urease and nitrification inhibitors (SuperU), urea blended with nitrapyrin at a rate of 567 g ha^{-1} ai as the commercial formulation Instinct™ in band applications and SuperU in the top dress applications, a polymer coated urea (ESN™), and a 25% urea 75% ESN blend. These treatments were applied at the 50% and 100% calculated optimum rates (Table 1).

Eight treatments were applied in the late fall when soil temperatures started to drop below 7°C. These treatments were identical to the eight treatments that were broadcast in the fall at planting and were also replicated again in the spring, when environmental conditions were favorable, and the wheat plants started to green up. An untreated control was also included which did not receive any fertilizer.

In the spring, a visual vigor score was taken for each plot which varied from 1 to 9 with 1 being the most vigorous and 9 the least. Plots were harvested with a Wintersteiger Classic (Wintersteiger, Austria) research combine for yield once the grain matured and reached a harvestable moisture level of less than 18%. Yield was determined directly from the combine's weighing system. A subsample of the grain was used to determine grain moisture, test weight, protein and thousand kernel weight. Moisture and test weight were determined with a GAC 2100™ (Dickey John Corp, Minneapolis, MN). Yields were adjusted to 13.5% moisture. Grain protein was measured using a 0.5 kg sub-sample of seed from each plot using a Diode Array 7200 NIR Analyzer (Perten Instruments, Springfield, IL) and reported on a 12% moisture basis. Initially, the data were analyzed using an ANOVA with means separated using an LSD at α=0.10 which allowed determination of the treatment effects relative to the untreated control. The data were then analyzed as a three-factor factorial after excluding the untreated check which allowed quantification of the effect of each factor and their interactions.

Table 1. Treatments in the winter wheat trials.

Treatment	Rate (% of optimum†)	Timing	Type/method
1	100	Late Fall‡	Urea broadcast
2	100	Late Fall	ESN broadcast
3	100	Late Fall	SuperU broadcast
4	100	Planting	ESN:Urea 75:25 broadcast
5	100	Spring	Urea broadcast
6	100	Spring	ESN broadcast
7	100	Spring	SuperU broadcast
8	100	Spring	ESN:Urea 75:25 broadcast
9	100	Planting	Urea band
10	100	Planting	ESN band
11	100	Planting	Urea + Instinct band
12	100	Planting	ESN:Urea 75:25 band
13	100	Planting	Urea broadcast
14	100	Planting	ESN broadcast
15	100	Planting	SuperU broadcast
16	100	Planting	ESN:Urea 75:25 broadcast
17	50	Late Fall	Urea broadcast
18	50	Late Fall	ESN broadcast
19	50	Late Fall	SuperU broadcast
20	50	Planting	ESN:Urea 75:25 broadcast
21	50	Spring	Urea broadcast
22	50	Spring	ESN broadcast
23	50	Spring	SuperU broadcast
24	50	Spring	ESN:Urea 75:25 broadcast
25	50	Planting	Urea band
26	50	Planting	ESN band
27	50	Planting	Urea + Instinct band
28	50	Planting	ESN:Urea 75:25 band
29	50	Planting	Urea broadcast
30	50	Planting	ESN broadcast
31	50	Planting	SuperU broadcast
32	50	Planting	ESN:Urea 75:25 broadcast
33	0	NA	Untreated control

† The 100% rate was equal to 123 kg ha^{-1}.

‡ Late fall refers to an application after soil temperatures were below 10ºC.

Spring Wheat Experiments

Experiments were established to compare the effects of N fertilizer source, additives, and application timing on germination and their effects on yield and fertilizer efficiency on spring wheat. Experiments were planted in 2014 in three locations (Prosper ND, Arglyle, MN and Red Lake Falls MN). The general management of the plots were similar as described for the winter wheat experiments. However, the size of the experimental units in MN, was 1.7m by 7.62m (as compared to 1.5m by 5.48m in ND). Experiments were established in the spring as weather permitted; Prosper was planted on May 28th, Red Lake Falls on May 5th, and Argyle on May 18th. 'Prosper', a commonly grown variety of spring wheat for the region, was used in all spring wheat experiments. 'Prosper' is a high yielding variety with relatively lower than average protein and test weight.

Table 2. Treatments in spring wheat trials.

Treatment	Rate (% of optimum†)	Timing/method	Type/method
1	0	Check	0-Check
2	50	With seed	100% ESN
3	50	With seed	75:25 ESN:urea
4	50	With seed	50:50 ESN:urea applied
5	75	With seed	100% ESN
6	75	With seed	75:25 ESN:urea
7	75	With seed	50:50 ESN:urea applied
8	100	With seed	100% ESN
9	100	With seed	75:25 ESN:urea
10	100	With seed	50:50 ESN:urea applied
11	125	With seed	100% ESN
12	125	With seed	75:25 ESN:urea
13	125	With seed	50:50 ESN:urea applied
14	125	Fall	Broadcast-100% ESN
15	100	Fall	Broadcast-100% urea
16	100	Spring	50:50 ESN:urea broadcast
17	100	Spring	100% Urea broadcast
18	100	Spring	50% Urea at seeding 50% UAN at 4 leaf stage
19	100	Spring	Urea + Instinct
20	100	Fall	50:50 ESN:urea, broadcast
21	100	Fall	75:25 ESN:urea broadcast
22	100	Fall	100% urea + Instinct

† The 100% rate was equal to 101 kg ha^{-1} at all locations.
‡ Fall applications were done when the soil temperatures were below 10ºC.

The experiments were structured using a RCB design with four replications. Treatments were based on a factorial combination of fertilizer rates (four), blends of ESN and urea (two), split applications of urea and UAN (one), N applications dates (two), and fertilizer application placement (two). There were twenty-two treatments, including an untreated check (Table 2). The 100% rate that was used was 101 kg N ha^{-1} at all locations.

ESN and ESN/urea blends were applied with the seed in treatments 2-13. Applying the N with the seed allowed determination of evaluation of seed-safety from these products on germinating seed and young seedlings. Also, by being placed with the seed the effects of seed placement with regards to plant establishment, yield, and protein response was possible.

Treatments 14-22 were broadcast by hand. However, treatment 18 was a split application, with urea applied at planting followed by UAN at the 4-leaf stage. The UAN was applied with streamer bars with 18 cm spacing using a backpack CO_2 sprayer. In treatment 22, nitrapyrin as Instinct™, was blended with the urea before application at the rate of 567g ha^{-1} active ingredient within one hour of application. Treatments 14-15, and 20-22 were applied on October 28, 2013 and 16-19 were applied in the spring at planting and in treatment 18 the UAN was applied at the 4-leaf stage.

Stand counts were taken after emergence by counting the plants in a 1 m length of two adjacent rows in the center rows of the plot. Yield, protein, and test weight were measured at harvest in the same manner as described for the winter wheat trial. Initially, data were analyzed using an ANOVA with means separated using an LSD at α=0.10 in order to allow for the comparison of all treatments.

Because of the complexity of the treatments in the trial, two groups of treatments were analyzed separately. The first was the factorial combination of N rates and blends of ESN:urea (treatments 2-13). These treatments were analyzed as a two-factor factorial (N rates and blends as the two factors). The second group of treatments were the 100% N rate treatments with different additives and application timings. These groups were analyzed separately so that each treatment within the group could be compared to all other related treatments where there was only one factor in the analysis.

Nitrogen Release

An experiment was established to quantify the timing of release of N from urea and ESN. This experiment was in an Experiment Station field on the NDSU Fargo campus. Prior to the placement of the trial, the area was tilled using shovels to remove weeds and sod, leaving a soil surface similar in tilth to a soil that had be worked prior to planting. Flags were then placed to identify where each replication began and ended. In this experiment, fertilizer prills were placed in nylon meshed bags that allowed as much natural penetration of water and sunlight as possible. These bags were made by sewing together strips of nylon mesh about 3.8cm wide and 7.62cm long. These small bags were filled with 40 prills of either ESN or urea. Prills were counted using a seed counter. After they were counted each set of 40 prills were weighed and transferred to their individual bags. Each bag was coded with a plastic label so that its plot designation could be readable throughout the duration of the trial.

The experiment was arranged using a RCB design with a split plot restriction. The whole plot treatments were two dates of placement of the fertilizer bags in the soil. The subplots were a factorial combination of fertilizer type (urea and ESN), depth of placement (two), and retrieval dates (six). The treatments were replicated three times. The first placement date was 10/11/13 followed by the second placement date on 10/25/13, which was after soil temperatures had dropped below 7° C. Each bag of fertilizer prills was randomly assigned a plot and depth. A shovel was used to insert bags to the lowest depth of 5cm. This depth was to mimic the depth of a band fertilizer application. The other depth was on the surface mimicking a broadcast application without incorporation. In order to be able to locate each plot and to hold down the surface applications, flags were used to stake each bag to the ground. At the time of the second placement of date, the first removal of samples was taken from packets placed on the first date. It was discovered that by this date all the urea had dissolved, and only ESN was left so all subsequent measurements were taken only on the ESN treatments. The second sample retrieval date (11/8/13), was the last sample taken in the fall because by the next retrieval date the ground was frozen. The 3rd retrieval date was in the spring after the soil had thawed on 4/29/14. Subsequent retrieval dates were every two weeks thereafter until the last date of 6/10/14. There were a total of six retrieval dates for each group of placement date treatments.

After each retrieval process, the bags were opened, and the contents of the bags were screened to remove debris and soil so that only the ESN or urea prills remained. The cleaned prills were then weighed. This weight was then subtracted from the original weight to determine how much of the prills had dissolved. Data were converted to a percentage of the original prill remaining. Data were analyzed using an ANOVA with means separated using an LSD at α=0.10.

RESULTS AND DISCUSSION

Winter Wheat Trial

Weather Conditions

Precipitation was above average during the winter wheat establishment periods of September through November in 2013 (NDAWN, 2018). During this period, winter wheat was planted and fall treatments were applied. The Carrington, Prosper, and Forman locations had 67 mm, 48 cm, and 101 cm above average rainfall, respectively for this period, enabling very good establishment and movement of fertilizers into the soil. After winter wheat had broken dormancy in the spring, rainfall was above average in April with 18.4 mm, 42.9 mm and 45.6 mm of rainfall at Carrington, Prosper and Forman, respectively. During this period, the rainfall at Prosper and Forman was potentially more than required to cause leaching and/or denitrification of nitrate. For the remainder of the growing season, rainfall at Carrington was below average, while Prosper and Forman had above average precipitation in June when the wheat was in the flowering stage.

The first N applications were performed from September 18th to the 25th when soil temperatures were greater than 10°C. Soil temperatures remained above 10°C until the middle of October (NDAWN, 2018), at which point, nitrification would likely have slowed to a minimal rate until the following spring (Butzen, 2013). The late fall broadcast treatments were applied from October 28th to the 30th. Overall, temperatures were below normal to average from planting until harvest.

The cold winter weather coupled with the lack of snow cover during most of the winter resulted in significant winter injury to the winter wheat at Forman. Stands were reduced by about 20% at this location. Winter injury was relatively uniform across all treatments, however. The vigor of the wheat at Forman was much less in the spring than at the other locations (data not shown). Additionally, the persistent rainfall during flowering at Forman and Prosper coupled with disease-supporting temperatures led to the development of Fusarium Head Blight (FHB), which resulted in reduced yields at both Forman and Prosper. The FHB infected kernels were shriveled, discolored, and were light in weight, which affected yield and quality (Freije and Wise, 2015).

Soil Environment

Prior to application of the N treatments, soil nitrate-N was measured to a depth of 60 cm at all locations. The fall residual nitrate-N level at Carrington was 139 kg ha^{-1}. This value was greater than anticipated and probably masked the effects of some of the treatments at this location. This location had higher yields and protein than the other locations, probably due to the lack of severe disease and less winter injury than the other locations. There were fewer differences between treatments. Even though Carrington was the highest yielding of the three locations, yields were still modest relative to the amount of N applied. While this seemed to be a possible problem for Carrington, Forman also had a relatively high residual soil nitrate-N level (99 kg ha^{-1} of N) prior to planting. Prosper had a much lower residual N content of 47 kg ha^{-1}. The residual nitrate at Prosper was more typical of what would normally be expected in the fall after a cereal crop.

Winter Wheat Yields

The winter wheat check treatment was not used for analysis, and data from the remaining treatments were analyzed as a factorial. However, the check yield was significantly lower than that of the other treatments. Carrington was the highest yielding of the locations, and yield was quite high relative to the statewide average for winter wheat (NASS, 2018). Although the

Carrington soils had high residual N levels, additional mineralization would have been required to achieve the yields obtained. However, there were no statistical differences in yield between any of the treatments at this location (Table 3). The failure of the treatments to impact wheat yields was potentially due to abundance of N in the soil at the time of experiment establishment. Good moisture early in the season coupled with little excess moisture later in the season may in fact have been favorable for N mineralization and limited loss through leaching and denitrification.

Table 3. Probability levels from ANOVAs for the variable yield from winter wheat trials at three locations in North Dakota, 2014.

Source of variation	DF	Carrington	Forman	Prosper
Timing/method	2	0.27	0.15	0.02*
Additive/type	3	0.64	<0.01**	0.02*
Timing x Additive	6	0.21	0.59	0.40
Rate	1	0.30	<0.01**	<0.01**
Timing x rate	2	0.26	0.69	0.22
Additive x rate	3	0.85	0.09*	0.77
Timing x add x rate	6	0.77	0.53	0.14

*, **; significant at the p≤0.1 and p≤0.01 levels of significance, respectively.

At Forman, yield was significantly influenced by additive/type, N rate and the interaction between additive/source and N rate (Table 4). The interaction between additive/source and N rate was an interaction of magnitude, with all non-urea treatments being superior to the urea treatment at the higher N rate while at the lower N rate all additive/source treatments were similar. At an application rate of 123 kg N ha^{-1}, ESN, urea + inhibitor, and the urea:ESN blend treatments were higher yielding than the urea alone. This indicates that the ESN, urea + inhibitor, and urea:ESN blend provided some protection from N loss through denitrification and/or leaching during the high precipitation season. The yield obtained with ESN treatments at an application rate of 62 kg N ha^{-1} was similar to yields obtained with the low N rate and high N rate of urea + inhibitor. There were also no differences in yield among any treatments at an application rate of 61 kg ha^{-1}, nor were the yield from the low N rate treatments different from urea at the high N rate of 123 kg ha^{-1}.

Table 4. Effects of N fertilizer additive/type and N rate on wheat yield at Forman, ND, 2014.

Rate of N	Urea		ESN		Urea +Inhibitor		25:75 Urea:ESN	
(kg ha^{-1})	----------------------(kg ha^{-1})--------------------							
62	2110	c†	2290	bc	2190	bc	2100	c
123	2180	c	2540	a	2380	ab	2520	a

† Means with the same letter are not significantly different ($p \leq 0.10$)

At Prosper, the main effects of rate, timing and additive type were statistically significant, but the interactions were not. Averaged across other factors, the 123 kg N ha^{-1} rate was higher yielding than the 62 kg ha^{-1} N rate. The difference between the two rates was 220 kg wheat ha^{-1} when averaged across all locations (data not shown). A similar difference was also recorded at Forman. Within the main effect of additive/source, the urea + inhibitor treatment was higher yielding than ESN and the urea:ESN blend treatments (Table 5).

Table 5. Effects of nitrogen additive/type on the grain yield of winter wheat, averaged over N rates, at Carrington, Forman, and Prosper, ND, 2013/14.

Additive/Type	Carrington		Forman		Prosper	
	----------------------------- kg ha^{-1} -----------------------------					
ESN	3910	a†	2410	a	2710	b
Urea:ESN 25:75	3870	a	2310	a	2770	b
Urea + inhibitor	3780	a	2290	a	2980	a
Urea	3890	a	2140	b	2830	ab

† Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$).

However, yields with urea alone were not statistically different from any of the other treatments. This was the opposed to what was recorded at Forman, where the urea treatments were significantly lower yielding than the other treatments. This may be due to the lower clay content of the soil and increased slope at Forman which may have increased leaching and possibly N run off with the above average precipitation received throughout the growing season.

Prosper was the only location that had significant yield differences due to timing and method of application (Table 6). However, the late fall broadcast treatment was the only treatment that resulted in lower yields. This may have been due to precipitation experienced in all earlier fall applications, while the late application received little rainfall before freeze-up. Also, all other applications were applied well before the soil was frozen or after the spring thaw giving the urea more time to be incorporated by moisture to soil depths that would not allow for volatilization.

Table 6. Effects of application timing on grain yield of winter wheat at Forman, Prosper, and Carrington, ND, 2014.

Application	Carrington		Forman		Prosper	
			kg ha^{-1}			
Late fall broadcast	3810	a †	2250	a	2650	b
Spring broadcast	3800	a	2360	a	2930	a
Band at planting	3860	a	2220	a	2870	a
Broadcast at planting	3990	a	2320	a	2840	a

† Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$)

Winter Wheat Protein

At all locations, the higher N rate increased grain protein relative to the lower rate (Table 7). At all three locations all treatments increased protein compared to the untreated check (data not shown). There were no other significant differences in grain protein between any of the other treatments at Carrington; only N rate impacted protein at this location (Table 7).

There was a significant interaction between additive/source and application timing/method at Forman in 2014 (Table 8). Spring applications of all additive/sources except the urea + inhibitor treatment had higher grain protein than banding fertilizer before planting.

This may have been be due to greater N loss from the banded treatment, though the fact that the pre-plant broadcast treatment yield was also greater than that of the fall banded treatment does not support this, as one would expect losses to be similar or greater from this surface application.

Table 7. Probability levels from ANOVAs for the variable grain protein for winter wheat trials conducted in three locations in North Dakota, 2014.

SOV†	DF	Carrington	Forman	Prosper
Application timing	2	0.29	<0.01**	0.03*
N additives/types	3	0.73	0.01**	0.06*
App by timing	6	0.33	0.01**	0.19
Rate	1	<.01**	<0.01**	<.01**
App by rate	2	0.25	0.18	0.88
Rate by add	3	0.46	0.52	0.27
App by rate by timing	6	0.86	0.76	0.66

†SOV = source of variance, * ** at $p \leq 0.10$ and $p \leq 0.01$, respectively.

The interaction might be partially explained by the fact that fall applications of ESN that were broadcast had higher protein than other non-ESN containing treatments while all treatments had similar protein when applied in the spring. This may suggest that there was more N available later in the season from the ESN treatments that were broadcast in the fall. The ESN late fall and spring application timings had higher grain protein than broadcast or banding at planting. Broadcasting urea + inhibitor at planting had lower grain protein than late fall or spring application of fertilizer. The earlier timing of these applications may have led to earlier release of N and consequently the N was taken up by the wheat earlier in the season and may have been lost later in the season due to denitrification and/or leaching. Spring application of the urea:ESN blend had higher protein than the other three applications or fertilizer sources. Late fall application of ESN and the urea:ESN blend had higher protein than urea alone. The later season ESN release may have occurred at a more optimal time for plant uptake and experienced less risk of N loss. When banding, additive/source did not significantly affect grain protein. ESN had higher grain protein than urea + inhibitor when broadcast at planting, however ESN was not different than the other nitrogen additives at the same application timing.

Table 8. Effects of nitrogen additive/type by application timing/method interaction on grain protein level at Forman, ND, 2014.

Timing of application	Urea		ESN		Urea+Inhibitor		Urea:ESN Blend	
	-----------------(%)------------------							
Broadcast pre-plant	12.9	defg†	13.0	def	12.5	gh	12.8	defgh
Band pre-plant	12.5	gh	12.6	fgh	12.7	efgh	12.5	gh
Late fall broadcast	12.5	h	13.4	abc	13.0	def	13.0	bcde
Spring broadcast	13.2	abcd	13.5	ab	13.0	cde	13.6	a

† Any of the means with the same letter are not significantly different ($p \leq 0.05$).

At Prosper, all main effects affected protein (Table 9). For the main effect of N additive/timing, the broadcast at planting and the spring broadcast had significantly higher protein compared to the band application. However, only the spring broadcast treatment had higher protein than the late fall broadcast treatment, indicating that the spring application was more effective than other timings in providing N when it was critically needed for protein formation. At Prosper, the additive/source differed significantly for protein (Table 10). ESN and urea:ESN treatments had higher protein than urea treatments. This is probably due to late season N release from ESN that was available to the wheat during the time of kernel protein development. While the urea + inhibitors treatment did not have an effect on protein compared to any treatments, it was higher yielding suggesting that more N may have been available compared to urea alone earlier in the season. With the higher yield, N was used to increase yield at the expense of lower protein. Therefore, there were no significant difference in protein levels, even though more total N was taken up by the plant in that treatment.

At the Forman location the spring broadcast application had significantly higher protein than all other treatments. The broadcast at planting and the late fall broadcast did not differ significantly in protein. However, both were significantly higher than the band application.

Table 9. Effects of timing/method of fertilizer application on grain protein levels (%) at Carrington, Forman, and Prosper ND, 2014.

Timing/Method	Carrington	Forman	Prosper
		-----------------(%)-----------------	
Band at planting	15.0 a†	12.6 c	13.3 c
Late fall broadcast	15.0 a	13.0 b	13.4 bc
Broadcast at planting	15.0 a	12.8 b	13.5 ab
Spring broadcast	15.2 a	13.3 a	13.6 a

† Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$).

Table 10. Effects of fertilizer and amendments on grain protein levels at Carrington, Forman, and Prosper ND, 2014.

Application	Carrington	Forman	Prosper
		-------------(%)------------------------	
ESN	15.0 a†	13.1 a	13.5 a
Urea:ESN blend	15.1 a	13.0 ab	13.5 a
Urea + Inhibitor	15.1 a	12.8 bc	13.4 ab
Urea	15.1 a	12.8 c	13.3 b

† Means followed by the same letter in the same column are not significantly different ($p \leq 0.1$).

Protein Yield

Protein yield was derived in this study by multiplying the yield mass times the percent grain protein. The resulting value allows an analysis of the treatment effects on the total protein per unit area. There is typically a negative relationship between yield and protein content, so by combining both traits, one can determine treatments that favor the production of both yield and protein. A treatment with high protein but low yield may be lead one to believe that N was more than adequate for the environment. However, one may also gain yield but sacrifice protein or the opposite may occur where you have high protein but sacrifice yield due to variety selection.

At Carrington there were no significant differences between treatments in protein yield, even when compared to the untreated check (data not shown). None of the factors included in the experiment had a significant effect on protein yield at Carrington, as discussed previously in light of the high preplant nitrate N soil levels and favorable seasonal conditions for additional N mineralization. However, at Prosper and Forman the main factors of timing/method, additive/ source and N rates were all significant, but none of the interactions (Table 11). The lower rate of 44 kg ha^{-1} N produced significantly less protein yield than the higher rate of 88 kg ha^{-1}. Averaged across all locations there was a difference of 38 kg ha^{-1} protein yield. Timing/method and additive/source treatment means also differed significantly (Tables 12).

Table 11. Probability levels from ANOVA for winter wheat protein yield at Carrington, Forman, and Prosper ND 2014.

SOV†	DF	Carrington	Forman	Prosper
Timing/method	2	0.422	0.032*	0.006*
Additive/type	3	0.687	0.004**	0.029*
Timing x additive	6	0.123	0.664	0.559
Rate	1	0.092	<.001**	<.001**
Timing x rate	2	0.313	0.430	0.422
Add x rate	3	0.907	0.764	0.482
Timing x add x rate	6	0.776	0.740	0.203

†SOV = source of variance, * ** at $p \leq 0.05$ and $p \leq 0.01$, respectively.

Timing/method had a similar response on protein yield as it did on protein. The band treatment was significantly lower than all other treatments in Forman (Table 12). At Prosper the late fall application treatment had the lowest protein yield. At both Forman and Prosper, the highest protein yield was achieved with the spring broadcast application.

Table 12. Effects of application time/method on winter wheat protein yield at Forman, Prosper, Carrington, ND 2014.

Application	Forman		Prosper		Carrington	
Spring broadcast	382	a†	397	a	575	a
Fall broadcast	377	a	382	a	598	a
Late fall broadcast	366	a	354	b	572	a
Band	344	b	378	ab	579	a

† Means followed by the same letter in the same column are not significantly different at $p \leq 0.05$.

Nitrogen type had opposing results with ESN producing the highest protein yield at Forman and the lowest protein yield at Prosper. At Forman, the treatments except SuperU produced more protein yield than urea alone (Table 13).

Table 13. Effect of fertilizer type on winter wheat protein yield at Forman, Prosper, and Carrington, 2014.

Type	Forman		Prosper		Carrington	
	---------------------------------------		--kg ha^{-1} ----------------------------------			
ESN	389	a†	362	b	589	a
Blend	376	ab	374	a	583	a
SuperU	360	bc	398	a	569	a
Urea	342	c	376	a	583	a

† Means followed by the same letter in the same column are not significantly different at $p \leq 0.05$.

Spring Wheat Trials

Weather Conditions

The spring of 2014 had above average rainfall, both at Red Fake Falls and Argyle. In Red Lake Fall, April rainfall was 53mm, which was 21mm above normal. In Argyle, April rainfall was even greater, with 64mm, which was 38mm above normal. The wet conditions coupled with below normal air temperatures delayed planting about two weeks beyond the optimum date. Argyle received a total of 297 mm during the rest of the growing season which was 63 mm above average. Similarly, rainfall at Red Lake Falls was 35 mm above average during the remainder of the growing season. There was limited water stress affecting plant development and yields were well above average for the region at both locations. On the downside, the higher than normal rainfall probably resulted in N loss at both locations through nitrate leaching and/or denitrification.

N Fertilizers Applied with the Seed

Plant Stand

At the lower fertilizer rates regardless of ESN in the fertilizer blend, plant stands were not adversely affected compared to the treatment where no fertilizer was applied with the seed (this treatment that was not included in Table 14 but the check plant stand was 3.0 million plants ha^{-1}). When fertilizer blends were applied with the seed, there was a significant effect for ratios, but not for rate or for the interaction between rate and ratios. Plant stand was reduced significantly with the 50%:50% blend when compared to the 100% ESN and the 75:25 ESN:urea blend, where even at the highest fertilizer rate, these two treatments had no effect on stand. Current recommendations limit the amount of ammonium-/urea-N that can be safely applied with the seed when using a double disc opener and a 19 cm row spacing similar to that used in these experiments to 21 to 31 kg N ha^{-1} (Franzen 2015). These recommendations were established from research showing that the rate of N plus K_2O can damage small grain seed and reduce stand (Franzen, 2015). One consequence of too much ammonium-N with the seed is due to ammonia toxicity as ammonia is released from urea through urease enzyme activity. The second is due to salt damage. The polymer coating that encapsulates ESN delays the release of urea sufficiently so that it is not toxic to the seeds/seedlings until they are larger and less sensitive to it (unless the ESN has been extensively damaged through poor transfer from the factory through the supply chain to the field). With the 50:50 ESN:urea blend and at the 125% rate, there was sufficient urea in close contact with the seed that stand counts were noticeably impacted. Qin et al. (2014)

found that 60-90 kg N ha^{-1} of ESN, could be applied with the seed without causing significant plant stand reduction. This was three times the safe rate they found for urea alone. The safety provided by ESN broadens the potential application methods available to farmers. Applying fertilizer with the seed is particularly advantageous for no-till systems where incorporation of fertilizer that is not placed with the seed requires specialized equipment.

Yield

In the ANOVA, yield differed significantly between N rates. Blends and the blend by N rate interaction were not significantly different. Yield increased in a linear fashion as N rates increased, indicating that N loss was experienced after application. The highest yield numerically was achieved with the highest rate of the 75%:25% blend. Even though stand was reduced by the highest rate of the 50:50 blend, it did not result in a a yield reduction.

Protein

In the ANOVA, N rate produced significant differences in protein; blend was significant at the 13% level and the rate by blend interaction was not significant. Unlike with grain yield where yield increased with each increase in N applied, protein values were similar at the two lowest N rates. At higher N rates, grain protein increased with each additional N increment. These trends were across blends used. However, the 75% ESN:25% urea blend consistently had the highest protein across N rates. This combination may have provided protection to the urea coming from the ESN, while the urea provided more N earlier so that yield was not negatively impacted. While the 50:50 ESN:urea may have supplied enough N earlier in the growing season for yield, there was less available later to have the same impact on protein as the 75:25 blend and some available early in the season was probably exposed to loss processes. The opposite was the case with the 100% ESN. Its early release may have been inadequate to provide for the early needs of the crop, thereby limiting the yield potential of the crop, but providing enough to meet the N requirement for high protein later in the season.

Table 14. Effect of rate and different ESN:urea blends combined over locations on stand, yield protein and protein yield of spring wheat, 2014.

	Ratio ESN:Urea			
	Stand (plant in millions ha^{-1})			
Rate†	100	75:25	50:50	Mean
50	3.06	3.16	2.95	3.06
75	3.15	2.98	2.79	2.97
100	3.19	3.28	2.95	3.14
125	2.99	3.04	2.61	2.88
Mean‡	3.10a	3.12a	2.82b	

	Yield (kg ha^{-1})			
Rate	100	75:25	50:50	Mean†
50	6050	5920	6160	6040c
75	6530	6510	6400	6480c
100	6870	6980	6750	6870b
125	6960	7530	7160	7220a
Mean	6600	6740	6620	

	Protein (%)			
Rate	100	75:25	50:50	Mean†
50	13.0	12.7	12.5	12.8c
75	12.7	13.0	12.7	12.8c
100	13.0	13.7	13.1	13.3b
125	13.9	14.2	13.8	14.0a
Mean	13.2	13.4	13.0	

	Protein Yield (kg ha^{-1})			
Rate	100	75:25	50:50	Mean†
50	786	754	770	770c
75	831	849	810	830c
100	847	956	887	897b
125	969	1068	983	1007a
Mean	858	907	863	

†Rate is percent of optimum N rate.
‡Means within a column or row (main effects) for a given trait followed by the same letter were not significantly different at the 5% level using LSD.

N Fertilizer Broadcast Trial

Yield

All treatments resulted in higher yielding than the unfertilized check. Furthermore, spring applied treatments as a group tended to be higher yielding than fall applied treatments, though there were important exceptions. The most notable was the spring applied urea with added Instinct which had lower yields compared to other spring treatments and some of the fall treatments, and the 50:50 blend of ESN:urea that was the highest yielding treatment of the experiment. The 100% fall applied ESN treatment was slightly better than the same timing for 100% urea, but similar to the fall applied urea with Instinct added. Fall applied ESN:urea blends did not follow a predictable trend. The 50:50 blend of ESN:urea applied in the spring yielded less than the 100% urea treatment, suggesting little advantage of blending ESN with a spring urea application. Similarly, splitting the application of N in the spring did not improve yield.

Protein and Protein Yield

When N treatments where compared to the unfertilized control, there were few that increased grain protein. The highest protein level was achieved with the spring application of urea and the fall application of ESN. Generally, protein with spring applications were higher than those in the fall, indicating greater availability of N later in the growing season from spring application. Protein yield followed a similar trend as yield, and many of the highest yielding treatments had higher than average protein. Normally the relationship between yield and protein is negative because when the grain adds more starch it dilutes the protein that is fixed early in kernel development. The exception to this trend indicates that adequate nitrogen was supplied by these treatments for both yield and protein. Fall applied ESN (100%) had greater protein and protein yield than fall applied urea (100%). Fall applied ESN (100%) also had higher protein than the other fall applied treatments but not protein yield. The ESN treatment was perhaps able to protect N losses when applied in the fall from leaching and denitrification so that more was available when the plant needed it for protein development. With above average rainfall the nitrate developed from unprotected urea would have possibly been leached out of the soil or lost through denitrification by the time of protein development.

Table 15. Effect of fertilizer timing and type on protein, yield, and protein yield of spring wheat, combined over locations, 2014.

Treatments	Protein	Yield	Protein Yield
	(%)	(kg ha^{-1})	(kg ha^{-1})
Check (no applied fertilizer)	12.3	4240	520
Fall-100% N rate broadcast-100% ESN	13.7	6460	880
Fall-100% N rate broadcast-100% Urea	12.3	6210	760
Spring-100% N rate broadcast 50% ESN:50% Urea	13.3	6710	890
Spring-100% N rate broadcast-100% Urea	14.0	6900	970
Spring-100% N rate broadcast- plus Instinct	12.5	6420	800
Spring-50% urea broadcast:50% UAN at 4 lf stage	13.0	6500	850
Fall-100% N rate broadcast-50:50 ESN:Urea	13.0	6970	910
Fall-100% N rate broadcast-75:25 ESN:Urea	12.6	6140	780
Fall-100% N rate broadcast- plus Instinct	12.6	6500	820
Mean	12.9	6305	818
LSD 0.05	0.8	489	87

Nitrogen Release Study

Environment

The afternoon after placement of the first set of bags (11 Oct) there was 13 mm of rainfall (NDAWN 2018). The surface placed bags (treatments) were visually inspected the next day, and all prills in the urea treatments had been dissolved and the bags were empty. However, no visual changes could be seen to the ESN. Rainfall during October and November was above average and readily dissolved the urea prills, providing opportunity for the release of urea in the ESN prills that had been cracked or that otherwise allowed for moisture penetration. During the winter months, temperatures were below average and usually were below 10 C°, the threshold when the coating on the ESN prills is most likely to stop degrading (Engel et al., 2011). However, others have suggested that colder temperatures might also crack the coating if moisture was able to penetrate the coating prior to the freezing event (Killorn and Moore, 2006).

Rate of Urea Release from ESN

By the time of the first removal date, there was no trace of urea regardless of sampling date or depth of placement. Therefore, urea was excluded from any further statistical analysis and discussion. The rainfall received between the time of the placement of the bags and the first sampling date was adequate to dissolve all the urea in the bags at all depths. Depth and timing of placement significantly impacted the amount of urea release from the ESN prills (Table 16). The interactions between date of removal and time of placement and depth of placement by time of placement were also significant.

Table 16. Probability levels for the ANOVA from the measured variable of the percent of ESN remaining in the prill, Fargo, North Dakota, 2013 and 2014.

SOV†	DF	Pr>F
Depth	1	<0.01**
Timing	5	<0.01**
Depth x timing	5	0.10*
Date	1	0.40
Date x depth	1	0.84
Date x timing	5	<0.01**
Date x depth x timing	5	0.17

†SOV = source of variance * ** indicate significance at p≤0.05 and p≤0.01, respectively.

The depth of placement by date of sampling interaction was not significant; the buried ESN was always greater than the surface treatment throughout all of the sampling dates (Table 17). However, in the spring timings the buried always had significantly less reduction than the surface applied, extending the longevity before release by two or more weeks. There was a significant linear reduction of ESN remaining in the bags from one sampling date to the next. The regression equation for the buried ESN treatments was $y = 0.1503x - 0.0391$ ($r^2 = 0.84$) and for the surface applied ESN treatments $y = .206x - 0.0517$ ($r^2 = 0.76$) where y=percent product remaining and x=days after placement.

Table 17. Depth of placement of bags containing ESN prills by date of sample retrieval interaction for urea remaining in the ESN prills, Fargo, 2014.

Date of retrieval†	Buried		Surface	
	------------ (Percent remaining) ------------			
25 Oct & 8 Nov	93	a‡	91	a
8 Nov & 29 April	78	b	71	bc
29 April & 13 May	65	cd	49	ef
13 May & 27 May	58	de	37	fg
27 May & 10 June	45	f	30	g

† Data in this table are averaged over the two dates of removal indicated below. These dates represent the first removal dates for the two different placement timings.
‡ Any of the means with the same letter are not significantly different ($p \leq 0.1$). Means represent percent of ESN remaining.

While there was a significant interaction for time of placement by date of removal, this interaction is one of magnitude with more rapid release of ESN with the earlier placed packets than the later placed packets. This is not surprising as on a given date, the earlier placed packets had been exposed to the degrative impacts of the environment for two weeks longer than the later placed packets (Table 18). The actual rate of release for the two dates were similar. Every two weeks a continual decrease was noted (5 to 14 % reduction from the previous sample date) and during the time from the last fall retrieval to the first spring retrieval there was a 30% reduction in prill weight. The fluctuation from 5 to 14% reduction is most likely caused by differences in precipitation during sampling dates. These data indicated that during the winter months there is still some release of the urea from ESN prills. Additionally, at the last sampling date of this experiment, a substantial amount of ESN remained in some of the treatments, indicating that some of the applied N was still not available to the plant by early to mid-June (depending on when the ESN was applied). This suggests that a significant portion of the N was protected from loss, early in the season. It also could be a concern if the surface soil dries, leaving the unreleased N unavailable to the plant as it has not released urea, nor has N been moved to depths by water to areas explored by roots.

Table 18. The effect of date of removal of bags containing ESN prills and time of placement on release of urea from ESN, Fargo, North Dakota, 2014.

	Time of placement	
Date of removal	Oct. 11	Oct. 25
	---------(% of original remaining)------------	
25 October	89 a†	na
8 November	84 a	96 a
29 April	55 bc	65 b
13 May	50 c	59 bc
27 May	37 d	45 cd
10 June	na	38 d

† Means with the same letter are not significantly different ($p \leq 0.1$).

CONCLUSION

Winter Wheat

Not all the environments where these experiments were conducted were responsive to N fertilizer applications. This was probably due high levels of soil nitrate present in the soil at the beginning of the experiment and/or high rates of N mineralization during the season coupled with limited N losses and relatively low yield potential due to factors other than N requirement. Therefore, the conclusions on the type and timing of N fertilization are focused on “responsive” soils or soils that require will require N fertility management in order to reach optimum yields. For “responsive” environments, urea-based products which were protected from N loss (ESN and SuperU) improved yields compared to urea alone when fertilizing at the recommended N rate. The ESN treatments often resulted in higher protein levels and protein yield when compared to urea or SuperU, though this difference greater when 100% ESN was used; the 50:50 ESN:urea blend behaved more like urea than ESN. Since yield and protein were never lower when ESN was used in these studies, the use of ESN to enhance grain protein was consistent. Whether ESN would be profitable for the farmer for protein enhancement would depend on the economic gain from a protein premium/discount compared to the extra cost of ESN. Given the relatively small benefit observed of the ESN over urea alone, in most cases, substituting ESN for urea may not be cost effective.

The effect of N timing on yield and protein was variable across locations. However, spring applications resulted in consistently higher protein than from fall applications, regardless of fertilizer source. This would be consistent with current recommendations of applying N fertilizer close to the time of uptake by the plant. However, since surface applications can be subject to loss, their timing relative to rainfall, could be important in their effectiveness.

Spring Wheat

In the applications where the N was applied with the seed, the 50:50 urea:ESN fertilizer blend was found to reduce the stand, probably from toxic levels of ammonia gas released from urease activity that caused germination loss and seedling injury. However, with the 100% and 75% ESN fertilizer blends stands were similar to the check due to the polymer coating surrounding the urea prill which acts as a barrier between the seed and urea. Because the polymer allows for the N to slowly be released it reduces the chance of ammonia toxicity at any one moment. Higher yields and protein were also obtained when using the 75%:25% ESN:urea blend at the higher rates. This was probably related to the ESN releasing the N slowly so that more N was available when during later important plant stages of kernel and protein development., and with some urea being immediately available to promote early wheat vigor and adequate tillering. The 100% ESN and 50:50 ESN:urea blends either ran out of N too early in the season through losses and did not have enough to finish or not have enough N upfront at the time of tiller development and the timing of other developmental stages for the components of yield.

In the broadcast treatments, the spring applied treatments had higher yields than the fall applied treatments. The most notable treatment was the 50%:50% ESN:urea which had the highest yield. These results were probably due to the above average rainfall in the fall and early spring leading to leaching and denitrification of fall applied treatments. The fall applied 100% ESN yielded better than the fall applied 100% urea treatment and had the second highest protein treatment. This was due to the increased protection that the ESN would have given compared to the urea alone. The 100% spring applied urea treatment had the highest protein level.

Nitrogen Release

Nitrogen release from ESN is relatively minimal in the fall and gradual in the spring. A significant portion of the urea had not been released by the time the study was terminated in June. These data support the company's claims that N in ESN is protected from losses for several weeks after its application. The rate of release in these experiments in wetter than normal years probably paralleled the N requirement of the wheat plant well, so one would expect there is a reduced potential for losses to the environment. The rate of release would likely lag wheat plant N demand if the conditions had been drier and/or cooler. It would also seem possible that the release of N may result in some of the N being unavailable to the plant if the surface layer became dry before it is all released, as the urea in the prill would not be released under those conditions into the soil solution.

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