DISTILLERS BYPRODUCT COMPARED TO OTHER NITROGEN SOURCES AS A FERTILIZER FOR CORN

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Distillers Byproduct Compared to Other Nitrogen Products as a Fertilizer for Corn

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Corn (*Zea mays* L.) based ethanol and associated byproducts like wet (WDG) production has increased over the past decade. Research was conducted in five environments in North Dakota to determine the nitrogen (N) fertilization value of WDG compared to five other N fertilizer sources. In fertilizer responsive sites, 25% more WDG were required based on N equivalent than other N sources to obtain a similar yield and grain protein when applied in the spring. Effectiveness of WDG were reduced when applied to no-tilled corn. Utilizing WDG as a nitrogen source is not economical at the current product prices of WDG and urea.

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LIST OF ABBREVIATIONS

ADF	anaerobically digested fiber
C/L	compost/ litter mixture
CDS	condensed distillers soluble
DCD	dicyandiamide
DDG	dry distillers grain
DG	distillers grain
ESN	Environmentally Smart Nitrogen™
MM	mustard meal
N	nitrogen
nBTPT	N-(n-butyl)-thiophosphoric triamide
NH_4^+	ammonium
NO_3^-	nitrate
OM	organic matter
PB	Perfect Blend 7-2-2
PCU	polymer coated urea
PL	poultry litter
TProtein	total protein
UAN	urea ammonium nitrate
WDG	wet distillers grain

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INTRODUCTION

Demand for corn (*Zea mays L.*) based ethanol has increased over the past decade as the United States strives toward energy independence from fossil fuels. As a result, nationwide the amount ethanol produced and its associated byproducts, including distillers grain (DG), has tripled in the past 10 years. There are three main types of DG products that are available: wet distillers grain (WDG), dry distillers grain (DDG) and condensed distillers solubles (CDS).

Distillers grain is highly valued as a protein source for livestock. In North Dakota, the amount of DG produced for animal consumption currently far exceeds the amount needed within the state. Therefore, most DG are shipped out of the state, mainly China and Mexico where they are used for livestock feed. In the past 15 years, import restrictions on genetically modified organisms (GMOs) have made exporting more difficult. A limitation for WDG is its short storage life due to its high moisture content. The product can be dried, however this would demand more storage space as well as an increased cost to the ethanol producers for both the act of drying the product as well as storing it. As a result, the WDG, as it is, must be used within a few days due to the risk of molding and other spoiling factors. In turn, excessive surpluses can reduce pricing.

Corn typically needs to be fertilized to produce the desired yield. For the best utilization of fertilizers, the 4 R's should be followed: right rate, right time, right place, and right source. The right rate matches the amount of fertilizer to the crop needs, the right time is used to match the nutrients' availability to the crop's demand, the right place ensures the nutrients are kept where the crop can use them, and the right source means using the fertilizer type that will be most effectively used. The main focus in this study is to evaluate if WDG can be used as an acceptable "right source" of N for corn production. Since the majority of N in DGs are in organic forms, the timing of the application and the amount applied is dependent on the climate, the soil environment and the mineralization potentials of the organic-N forms within the DGs. The research question for the following study was “can WDGs be used as an N fertilizer for corn?” The null hypothesis for this study is that there is no difference in corn yields whether N comes from inorganic or organic sources. The objective of this study was to determine if DGs can be used as N fertilizer for corn.

LITERATURE REVIEW

Nitrogen Use Efficiency

Ideally, N fertilization of agricultural crops should follow the 4-R's so that the N-use efficiency (NUE) by the plant is close to one (Johnson, 2011). A NUE of one means that the plant utilizes all the N that is applied which then maximizes economic gains and reduces losses to non-target areas. Unfortunately, uncontrollable soil and environmental factors usually yield NUEs much less than one. In 1996, the NUE in developed countries was .42 and .29 in developing countries. The world cereal grain NUE was .33 (Raun and Johnson, 1999).

There are many studies that have addressed the 4-R's (Cassman et al. 1998; Cassman et al. 2002; Vetsch and Randall, 2004) and investigations into "right sources" is very active (Noellsch et al. 2009; Carrow, 1997). For example, the use of slow release sources to reduce losses to non-target areas and to provide plant N when the plant optimally needs it. Slow release fertilizers can be either organic or inorganic N. If inorganic, then they are coated or conditioned with low-solubility compounds. Organic compounds rely on mineralization processes to release N bound in organic molecules to NH_4^+ (Havlin et al., 2014). Slow release and N forms that are protected to stay in the NH_4^+ form may be considered as a "right source" in areas where N loss is prevalent, such as in coarse-textured soils where leaching is common or in soils that are commonly wet, thus promoting denitrification (Cassman et al. 2002).

NUE Improvement Sources

An example of an inorganic, slow release N fertilizer is Environmentally Smart Nitrogen (ESN) (Agrium Inc. 2017). This is a polymer-coated urea (PCU) product which delays the release of the urea into the soil solution and thereby potentially reducing the risk of loss during the early part of the season and ensuring its greater availability when crop demand is greatest.

ESN contains 44% N and releases its N slowly, typically during 8-14 wks. The coatings on these products consist of organic polymers, resins, and inorganic materials such as S (Golden et al., 2010).

The effectiveness of ESN as a fertilizer has been well documented. For example, across seven different soils from Arkansas, 40 d after incubation approximately 80% of the total N was released. Overall, soil temperature was considered as a factor having the greatest influence on N release. Soil water content was not a good predictor of release rate (Golden et al., 2010). Another is from a 15 site-year experiment performed across the northern Great Plains and Pacific Maritimes of North America. Overall the ESN had higher grain N concentration than when compared to the non-coated urea. There was also a small lag in yield in a few of the environments; this was attributed to the slow release properties of the coated urea that limited the amount of N the corn crop had available in the early stages of growth (Grant et al., 2012).

Other potential slow-release N sources are DGs. Dry distillers grain (DDG), WDG, and CDS contain varying amounts of plant essential nutrients. These are byproducts of the conversion of corn, or other grains, to ethanol (Figure 1). These products can be used as feed for livestock or as fertilizer sources. The variation in nutrient content (Table 1) in the byproducts is attributed to the variation associated to how ethanol is produced by the respective ethanol plant, how the byproducts are handled, and where the byproduct exits the ethanol production process. Distillers grain originate from the whole stillage that enters into the centrifuge (Figure 1) where the CDS is separated from the WDG. The process to separate the wet grain and the thin stillage from the whole stillage is not a precise process (Belyea et al. 2004). Once the WDG is out of the centrifuge the product is either sold as is, or is put into a dryer drum (Figure 1) where the moisture is evaporated out of the product resulting in DDG. The differences between the two products' nutrient content is due to the water content of the product (Cihacek, 2015).

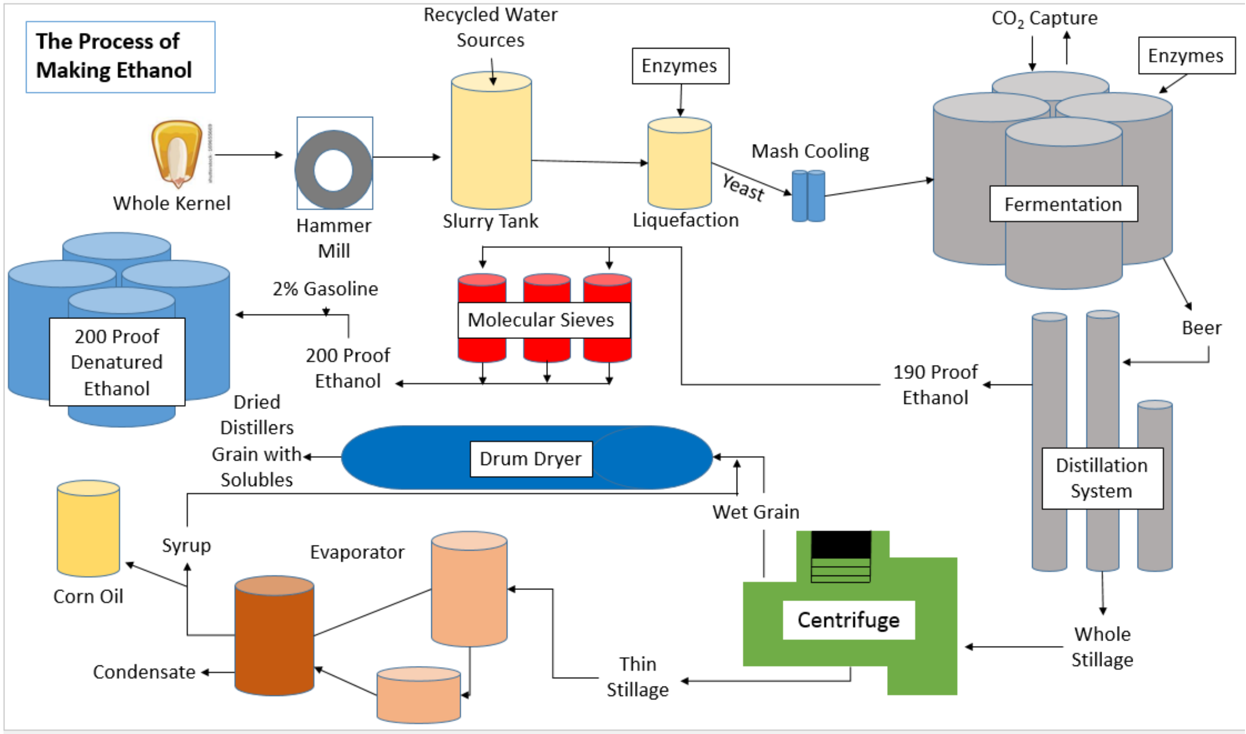

Figure 1. Steps and sequence in the production of ethanol and associated byproducts.

Table 1. Ethanol byproduct nutrient composition on a dry weight basis.

DG type	N	P	K	S	Water	Reference
			%			
WDG	1.45- 2.39	0.25-0.41	0.33- 0.55	0.31- 0.34	48.0- 68.6	(Cihacek, 2015)
DDG	3.78- 3.81	0.72-0.77	0.97-1.04	0.61- 0.89	14.7- 15.4	(Cihacek, 2015)
CDS	0.95- 1.24	0.32-1.40	1.75-2.25	0.37-0.70	70.9- 74.7	(Lardy, 2014) (Cihacek, 2015)

Distillers Grain as a Nutrient Source

Utilization of DDGs as a N fertilizer in corn was evaluated by Shroyer et al. (2011) in Kansas over a three-year period, 2007-2009. They found that DDGs could be an adequate replacement for urea as it performed similarly at similar rates of applied N. They found similar grain yields over three site years between the DDGs and urea in both tilled and no-tilled environments. In the fourth site year, however, the DDGs and urea performed similarly when tillage was used, but urea performed better than DDGs when no tillage was used. The authors did not determine the reason for this response, but speculated that the DDG applied to the surface mineralized more slowly as they did not have access to moisture, and would dry more quickly being out of the soil, as well as the reduced access to microbes compared to the material that was incorporated. This limited microbial contact may be further reduced in a no-till system as the DDGs would likely be on top of residue. Mineralization in no-till is affected greater by environmental constraints such as water and temperature, compared to urea or DDGs in tillage.

An analysis was done using values taken from a variety of biofuel byproducts and using the Oregon State University Organic Fertilizer Calculator to estimate the amount of plant available N (PAN) for most climates and soils over a growing season (Moore, 2011). The PAN for the tested materials are as follows: DDG (50%), soybean (*Glycine max*) meal (75%), canola (*Brassica napus*) meal (70%) and mustard (*Brassica juncea*) meal (71%).These estimates predict that the availability of N from biofuel byproducts is marginally less than most chemical fertilizer sources of N that are assumed to be available to the plant shortly after application. A closer look at the DDG showed they had a C:N ratio of 12. There was 41g kg^{-1} of total N in the DDG sample. The PAN for 8-14d after the incubation was 17%, the PAN for 15-28d was 31%, the PAN for 29-56d was 46% and lastly, the PAN for 57-126 was 55% (Moore, 2011).

Qian et al. (2009) found that the N uptake by canola, from equivalent rates of N from DDGs and WDGs, was 80-90 % of that of urea, even with similar or higher yields. Nutrients such as P and S may have also contributed to the increased yields in the DDG treatments, as there was a greater uptake of these macronutrient in the DDG treatment relative to urea. A larger C:N ratio in the WDG resulted in a slower N release rate over a 5 week period when compared to DDG resulting in a smaller difference when comparing WDG to urea than DDG to urea.

The cost of the fertilizer product is a critical factor when deciding what product to use. A cost comparison between urea, SuperU (Koch, 2017), ESN, and DDG, WDG, condensed distillers soluble (CDS) can be found in Table 2. SuperU is a granular fertilizer product with 46% N stabilized with nBTPT. The price of the distillers byproducts is most directly influence by the price of corn and soybean meal as well as the DG energy and protein content. This is important as the primary focus of DGs is largely as an animal feed. There is also a small correlation between the product price and the price of corn in the market at the time (Irwin et al., 2013).

Table 2. Price comparison between urea, SuperU, ESN, DDG, WDG, CDS and UAN in 2017.

Product	N content	Cost		Source
	%	$ ton$^{-1\dagger}$	$ kg^{-1} N	
Urea	46	334	0.80	Wheat Growers, Forman, ND (1/3/17)
SuperU	46	445	1.07	Company Rep (1/30/17)
ESN	44	450	1.13	Wheat Growers, Forman, ND (1/3/17)
DDG	3.78-3.81	100	2.92-2.89	Tharaldson Ethanol, Casselton, ND (2/16/17)
WDG	1.45-2.39	40	7.60-1.84	Tharaldson Ethanol, Casselton, ND (2/16/17)
CDS	0.95-1.24	5	0.44-0.58	Tharaldson Ethanol, Casselton, ND (2/16/17)
UAN	28	225	0.86	Wheat Growers, Forman, ND (1/3/17)

†This cost is recorded in Imperial ton, dry basis as that is what it is commonly sold to the producers in the United States.

Current Practices

In the Red River Valley of the North, corn is most commonly fertilized at or near planting. After planting, N can be side dressed during the four to six leaf stage using urea, urea-ammonium nitrate (UAN) solution, or anhydrous ammonia, if the equipment is available. Care must be taken, however, to minimize the contact of UAN with leaves to avoid leaf burn. Corn is particularly susceptible to this damage. Leaf burn can be minimized when UAN is applied under cool, wet conditions as burning from UAN is due to the high salt concentration of the solution per kg of product; it has a high osmolality value (Holland, 2016).

An alternative application timing for N is in the fall. A half or full rate of N can be applied with the anticipation that most or all will be available for crop uptake in the spring. Anhydrous ammonia is a preferred source for soil application in the fall as it is less susceptible to immediate conversion to nitrate. However, the rate of N should be increased by 5% in anticipation of losses. Applying nitrate (NO_3^-) forms of N in the fall is not recommended as they have a risk for leaching and denitrification. Fall applications of N should be avoided on sandy or other soils where leaching is likely, or water ponding or surface drainage delays are prevalent. Lastly, the use of nitrification inhibitors can reduce the risk for losses through denitrification or leaching, however they are less effective when used in the fall than when compared to the application in the spring (Shaver et al., 2013).

Wet DG and ESN could fit into the current system with a potential to apply the product once, in the fall or spring, and avoiding losses. Because WDG is an organic source, the nutrient release time is delayed and is directly related to rate of microbial activity in the soil. With this delay in release, there would not be a need for a split application. Similarly with ESN, there is a delay in nutrient release as PCU products are designed to release N over a period of weeks. This staggering of the nutrient release, whether due to a polymer coating or from being an organic source, is ideal for locations that have a low NUE and is susceptible to losses. This would also reduce or eliminate the need for a split application of fertilizer.

Wet Distillers Grain

C: N Ratio

Carbon to N ratios are used to quantify the relative amount of carbon and N in a given residue. For the N mineralization processes to proceed the ideal ratio is 20:1 or less (Moore et al., 2010). If the residue has a ratio greater than 20:1, the soil N is immobilized during the process of initial decomposition. Whereas if the residue is less than 20:1 then there is a mineral N release early in the decomposition process. The C:N ratios of DG can vary depending on the ethanol plant and batch. On average the C:N ratio for DGs is about 7:1 and the WDG, on a dry basis, have a C:N ratio of about 14:1 (Qian et al., 2009). This means that both the DG and WDG would have an early mineral release as there is little propensity for immobilization at these ratios.

Other factors in addition to C:N ratios that influence the amount of time needed for the residue to decompose include the amount of organic material in the soil, degree of incorporation, inorganic soil N supply, resistance of the residue to microbial attack, soil moisture and temperature (Havlin et al., 2014). When too high of an N fertilizer rate is applied, it has been found to decrease microbial biomass due to NH_3^- toxicity or possibly a salt effect. This suppresses the microbial activity to break down the organic matter, further reducing the rate of N released from the OM (Riggs and Hobbie, 2016). If the soil is originally deficient in N, the addition may stimulate microbial activity and increase the breakdown of soil organic matter. However, insufficient inorganic N can result in microbes immobilizing plant N. Immobilization can be avoided as a result of N fixation which results from high C:N ratios if large amounts of organic matter (OM) is present. When organic materials contain a C:N ratio no greater than 25, few problems with immobilization will be encountered whether it is fresh or well- composted. If the C:N ratio is higher than 25, additional N will be needed if N is to be readily released from the OM (Allison, 1973).

Effect on Soil Properties

Through the addition of DGs to a cropping system as an N source, additional benefits could arise as a result. One such benefit is the N from DG could be attributed to increased N availability to subsequent crops. The residual N, in general, exists primarily in the organic form in the soil (Qian et al., 2009). Another benefit that is of interest is the weed suppressant properties of DGs. The mechanisms for this suppression is poorly understood at this time and further research is needed to better understand this issue (Moore, 2011). Adding DGs to the soil also adds organic matter. This can assist in aggregation, soil aeration, water infiltration, and water availability in the soil.

Concerns with Distillers Grain as a Livestock Feed

The primary use of DGs is for livestock feed and is considered a filler in the animal’s diet due to the fact that DDGs have a high energy and fiber content which is difficult for non-ruminant animals to digest (Rausch and Belyea, 2006). When used as an animal feed there is also a large concern with its high concentration of P (Morse et al., 1992; Moore, 2011). The P concentration exceeds the nutritional requirements for most ruminants and is higher than other corn grain products commonly used for feed. The P that is not utilized by the animal is excreted in the manure that is generally applied as fertilizer to nearby fields. The P could then be utilized in the crop. When manure with high P levels is not properly applied, the excess P can be transported via a concentrated flow area, stream, or wind to a waterway where it can pollute surface waters, activating excessive algal growth. This then depletes the oxygen dissolved in the water, thus negatively impacting aquatic plants and animals, potentially creating an area referred to as a dead zone (Moore, 2011).

Another concern with DGs as a feed source is the variability of the nutritional composition, particularly with regards to protein. Protein content can vary from 25-35% depending on the batch (Belyea et al., 1989). This variation can affect the quality of the animal's health as well as the finished product. Some factors affecting the variability in the chemical composition of DG include differences in feedstock as well as composition, differences in processing methods and parameters, the amount of CDS that is added to WDG, the effect of fermentation of yeast, as well as the methods to analyze the products (Liu, 2011).

Other concerns with DGs in the feed ration is its high S content which can stimulate thiamine deficiencies in animals (Rausch and Belyea, 2006). There is also a risk DGs produced from poor quality grain may be tainted as carcinogenic aflatoxins that could concentrate in the DDGs (Blanco- Canqui et al., 2002).

Product Availability

The Energy Independence and Security Act of 2007 mandated that by 2022, 136 billion L of biofuels be produced for consumers in the United States. With this mandate comes not only an increase in the production of more ethanol but also its associated byproducts. There is concern that the improper disposal of the byproducts could cause future economic and ecological problems. Ethanol plants in North Dakota produce 10.6 liters of ethanol, 8.2 kg of CO_2, and 8.2 kg of DGs for every 27.2 kg of corn processed (Wiese, 2016). In 2008, livestock in the United States consumed 27 million Mg of DGs. (Shroyer et al., 2011). The market value of DGs is highly dependent on the consistency of their fat and protein content.

The DGs are marketed by corn producers with a conservative nutrient value estimate to ensure label specifications are met. This conservative nutrient marketing can be lower than the true value of the DGs. A product with high fat (12.6%) and protein (33.3%) can be sold for $5 to $20 Mg^{-1} more than a batch containing lower fat (10.9%) and protein (28.0%) content (Belyea et al., 2004). Comparatively, on December 20, 2016, the USDA-MO Department of Ag Market News reported that a Mg of DDG sold for $96.52 to $106.69 in Minnesota and in South Dakota $87.38 to 108.72 Mg (ERS, 2016).

The amount of DGs relative to traditional fertilizer sources needed may also present a challenge to its utilization. Distillers grain must be applied at a much higher rate (55 kg kg^{-1} N) to achieve the equivalent amount of N from an application of urea. The high rate of product needed, its cost, and the cost of its transportation could be a serious constraint to its use (Shroyer et al., 2011). As of 2016, there are five ethanol plants in ND. Each year these ethanol plants produce between 1 016 047 and 1 320 861 Mg of distillers grain. Currently, 80-90% of all DG are exported out of ND primarily to China, Canada, Mexico, and Texas (Wiese, 2016).

In attempts to find a profitable utilization for the available distillers byproduct, research was conducted to determine their effectiveness as a nutrient source for crops. A variety of traditional N sources, modified release produces, and WDGs were analyzed. The objectives of this field research were to determine the N fertilizer equivalency of DGs to other forms of N in corn production.

MATERIALS AND METHODS

Field experiments were conducted in 2015 and 2016 near the ND towns of Casselton, Carrington and Hope. The soil types at these locations are described in Table 3.

Table 3. Soil series, taxonomy and slope at research sites in Casselton, Carrington, and Hope, ND in 2015 and 2016[†].

Location	Year	Soil Series	Soil Taxonomy	Slope %
Castleton	2015, 2016	Kindred-Bearden	Kindred: Fine-silty, mixed, superactive, frigid Typic Endoaquolls; Bearden: Fine-silty, mixed, superactive, frigid Aeric Calciaquolls	0-2
Carrington	2015, 2016	Heimdal-Emrick	Heimdal: Coarse-loamy, mixed, superactive, frigid Calcic Hapludolls; Emrick: Coarse-loamy, mixed, superactive, frigid Pachic Hapludolls	0-3
Hope	2015	Heimdal-Emrick	Hemidal: Coarse-loamy, mixed, superactive, frigid Calcic Hapludolls; Emrick: Coarse-loamy, mixed, superactive, frigid Pachic Hapludolls	0-3 3-6
	2016	Fram-Wyard	Fram: Coarse-loamy, mixed, superactive, frigid, Aeric Calciaquolls: Wyard: Fine-loamy, mixed, superactive, frigid Typic Endoaquolls	0-3

[†] Based on USDA Natural Resource Conservation Service Web Soil Survey (Soil Survey Staff, 2016).

Experiments were designed as a randomized complete block with four replications. In 2015, treatments (19 in total) were comprised of a factorial combination of fertilizer rate (three), sources of N (six), plus an unfertilized control. In 2016, treatments were the same as those applied in 2015 experiment, with the addition of six treatments, consisting of three rates of both DG and urea, applied in the fall of 2015. The three rates of fertilizer used in all experiments were 75, 100, and 125 percent of the recommended N rate. The complete treatment list is summarized in Table 4. The N recommendation rate was based on a yield goal of 10.7 Mg ha^{-1}, a soil test of the top 61cm, and the previous crop credit (Table 5). The amount of N applied was calculated with the following equation utilized in North Dakota (imperial units are utilized in this formula as this is the published form use d by North Dakota growers): [(yield goal in bu *1.2 lbs) -

previous crop credit - NO_3^- in the top 24 in.] = base rate of total N (Franzen, 2014; Franzen et. Al., 2015). The amount of total N for the 100% rate is summarized in Table 6.

Table 4. Nitrogen fertilizer treatments at all experiment locations.

TRT#	Treatments applied in the spring in both 2015 and 2016.
1	75% Optimal Rate WDG
2	75% Optimal Rate (50% WDG:50% Urea)
3	75% Optimal Rate Urea
4	75% Optimal Rate ESN
5	75% Optimal Rate Super U
6	75% Optimal Rate (50% Urea at planting and 50% as UAN streamed at V6 leaf stage)
7	100% Optimal Rate WDG
8	100% Optimal Rate (50% WDG:50% Urea)
9	100% Optimal Rate Urea
10	100% Optimal Rate ESN
11	100% Optimal Rate Super U
12	100% Optimal Rate (50% Urea at planting and 50% as UAN streamed at V6 leaf stage)
13	125% Optimal Rate WDG
14	125% Optimal Rate (50% WDG:50% Urea)
15	125% Optimal Rate Urea
16	125% Optimal Rate ESN
17	125% Optimal Rate Super U
18	125% Optimal Rate (50% Urea at planting and 50% as UAN streamed at V6 leaf stage)
19	Check No-Nitrogen
Fall 2015 applied treatments, included in the 2016 experiment only.	
20	75% Optimal Rate WDG
21	75% Optimal Rate Urea
22	100% Optimal Rate WDG
23	100% Optimal Rate Urea
24	125% Optimal Rate WDG
25	125% Optimal Rate Urea

Table 5. Soil nitrogen, phosphorous, and organic matter levels for each environment 2015-2016.

Sampling Depth	2015			2016		
	N	P[†]	OM[†]	N	P[†]	OM[†]
Cm	kg ha^{-1}	ppm	%	kg ha^{-1}	ppm	%
	Hope Site[‡]					
0-61	31	19	2.5	36	10	4
	Carrington Site[§]					
0-61	50	10	3.9	12	6	3.6
	Casselton Site[¶]					
0-61	-	-	-	40	27	4

[†] P and OM values are for the top 30 cm only.

[‡] Previous crop was dry bean in 2015 and 2016.

[§] Previous crop was a legume in both 2015 and 2016

[¶] Previous crop was soybean in 2015 and hard red spring wheat in 2016.

Table 6. Total N for 100% rates for each location in 2015-2016.

Location	Total N Rate	
	2015	2016
	---------(kg ha^{-1})--------	
Casselton	-	161
Carrington	107	157
Hope	126	121

The experimental units in Hope and Casselton consisted of 4 corn rows with a 0.76 m spacing that were 5.9 m in length. This resulted in a net plot area of 9.06 m^{-2}. Plots in Carrington were of similar width but were 6 meters in length. The trials were planted with a two row John Deere planter at a rate of 87,968 seeds ha^{-1}. The fertilizers/DGs were uniformly broadcasted by hand which is done be walking up and down the plot scattering the product. The product was spread to the middle of each bordering tire track of the 3m width, which marks the edge of the plot and to the middle of each alley way. This ensured that the correct amount of product was available to the plot while taking into consideration that tillage slightly displaced the product. Once the treatment was broadcast it was immediately incorporated using an Edney Northstar SC-10 soil conditioner to a depth of about 15 cm in both the fall and spring. Dates of fertilizer application can be found on Table 7.

Table 7. Fertilizer application dates for Casselton, Carrington, and Hope, ND, 2015-2016.

Treatments	Casselton		Carrington		Hope	
	2015	2016	2015	2016	2015	2016
Fall †	-	10/15/2015	-	11/9/2015	-	10/14/2015
Spring	4/27	4/29	5/12 5/15	5/16	4/27	5/3
UAN	6/25	6/8	6/29	6/23/	6/18	6/9

†For fall application treatments evaluated in 2016.

The WDG used in the experiments were obtained from Tharaldson Ethanol in Casselton, ND. The amount of WDG used was based on a sample analysis performed by AgVise, located in Northwood, ND, for testing to ensure the correct amount was applied for the desired treatment. The Agvise report is shown in Table 8. The WDG were weighed out in the field by placing the WDG in 19-liter buckets and weighing them on a scale. The buckets were then taken to their designated experimental unit and distributed uniformly by hand as described previously. The WDG equivalent for the 100 percent N rate in Casselton in 2016 was 18.7 kg compared to 815.7 g of urea.

Table 8. Nutrient Analysis performed by AgVise of WDG Received from Tharaldson Ethanol in Casselton, ND, 2015.

Moisture	68%	
Dry Matter	32%	
	Dry Basis	As Received
	------------------------(%)------------------------	
Total Nitrogen (N):		1.80
Ammonium Nitrogen:		0.04
Phosphate (P2O5):	2.70	0.87
Potash (K2O):	2.00	0.66
Sulfur:	1.10	0.35
Sodium:	0.88	0.28
Calcium:	0.09	0.03
Magnesium:	0.63	0.20
	------------------------(ppm)------------------------	
Zinc:	82	27
Iron:	419	136
Manganese:	46	15
Copper:	16	5

Planting started as soon as field conditions were conducive for field work. Planting dates are summarized in Table 11. Stand count was taken shortly after emergence in early June. This was performed by counting the number of plants in the middle two rows of each plot. At Casselton, 2016 the planting date was May 2nd with the Pioneer variety P8673 at a seeding rate of 88,920 seeds ha^{-1}. In Carrington, 2015, seeding took place on May 13 with the Dekalb variety DKC33-78RIB, an 83-day variety, planted at a target population of as stated above. The 2016 growing season location was located on no till plots. Seeding took place on May 18th with a no till drill. The variety was the same as 2015, with a target emergence population of 79,040 plants ha^{-1}. Lastly, the Hope site was planted on April 27th in 2015 and May 3rd in 2016 with the same seeding rate and variety as the Casselton location in the respective years.

In treatments 6, 12, and 18, UAN was applied at the 6-leaf stage using a calibrated backpack system that dribbled the product between the rows on the soil's surface with hoses that dragged on the soil surface. Calibration of the CO_2 system was carried out to ensure the right amount of product was applied using the correct pressure and time spent in the plot. The same orifice and pressure was used causing the speed, or time spent in each plot, to change for the different rates in a location.

Regular scouting of plots for disease and weed pressures was done to ensure an accurate, uniform representation of the treatment affect. Any abnormality was recorded and handled according to best management practice. Actual plot lengths were also measured prior to harvest to provide a more accurate measure of the plot's size for use in calculating yield.

Plots were harvested using a Zurn 15 combine (Zurn Harvesting GmbH & Co., Schontal-Westernhausen, Germany) after the corn had dried to below 18 percent moisture. The moisture of the corn was evaluated by harvesting a boarder plot and testing a sample. Data were obtained from the electronics on the combine including moisture, test weight (volumetric weight) and yield. A subsample of each plot was taken to the lab for further analysis. Harvest dates are described in Table 9.

Table 9. Planting and harvest dates for each location in 2015-2016.

Location	Planting		Harvest	
	2015	2016	2015	2016
Casselton	-	5/2	-	10/11
Carrington	5/13	5/18	10/7	10/25
Hope	4/27	5/3	10/1	10/15

In addition, 1000 kernel weight and protein were determined. Protein was measured using a 1241 Grain Analyzer (FOSS, Hillerod, Denmark) which uses near infrared (NIR) technology. Protein, as it is not normally measured in corn but was used as an indicator of the available N in the environment. If there is a potential for N deficiencies, the protein could be an indicator as protein is first impacted by a lack of N. As N decreases, so does protein. Protein content was measured on a 0% moisture basis. Total protein (TProtein) was calculated by multiplying the yield (Mg ha^{-1}) by the percent protein. This measure takes into account both yield and protein. The TProtein is expressed on a 15.5% moisture basis, due to the moisture in the yield measurement.

Locations were analyzed separately due to the environments varying greatly from one site year to another (no-till, conventional tillage, plot lengths etc.). Data were subject to an analysis of variance (ANOVA) using SAS 9.4 (SAS Institute, Cary, NC). Means were separated at a 95% confidence level (α=0.05) using Fisher's protected least significant difference (LSD). There were three types of analysis performed; an overall analysis with all the treatments as a randomized complete block design to test for the effect of the no N check relative to all other treatments, an indication of the N responsiveness of the site. The data were also ran as two factorials, one to test for the effectiveness of the spring treatments and the second to test the spring vs fall application timing effectiveness of N availability. The spring factorial consisted of a factorial combination of N rate (75, 100, and 125% of optimum N) and N type. The N types used were previously described. The spring verses fall factorial consisted of two application timings (spring and fall), three rates (75, 100 and 125% of optimum N) and N types as previously described.

RESULTS AND DISCUSSION

Environment Overview

Data for the environmental factors influencing growth such as average monthly air temperatures and amount of rainfall are shown in Table 10 (NDAWN, 2017). Data were collected for the Casselton location from the Prosper weather station that is located approximately 23 km away from the trial location, the Carrington weather station that was near the Carrington plots and the Pillsbury weather station was used for Hope as it is located approximately 18 km from the research location.

2015

In Carrington, the 2015 growing season (13 May- 7 October) had a mean air temperature of 14°C; in Pillsbury located near Hope, (27 April- 1 October) it was 16°C; and in Prosper, near Casselton, (27 April- October 2) it was 15°C. The 30 year average temperature was 14°C across all three locations. All the monthly means were at or near the 30 year average temperatures during the growing season (Table 11). Growing degree days (GDD) for corn in 2015 during the growing season were below normal in Carrington, near normal in Pillsbury, and above normal in Prosper (Table 12). In Carrington the GDD were 1183 [°C] below the normal of 1201 [°C]. Accumulated GDD in Pillsbury were 1293 [°C] which was very close to the normal of 1306 [°C]. Finally, the GDD in Prosper during the growing season were 1356 [°C] which was above normal for that location, 1316 [°C] (NDAWN, 2017).

Rainfall in the 2015 growing season was 380 mm, 458 mm, and 456 mm for Carrington, Pillsbury, and Prosper, respectively (NDAWN, 2017). Carrington and Prosper were both below average rainfall for the growing season while Pillsbury received above the normal amount (Table

11). All locations received above average monthly rainfall in May. In addition, Pillsbury received higher than normal rainfall in June and July as well.

2016

For the 2016 growing season in Carrington (18 May- 25 October) the mean air temperature was 13°C and the total rainfall was 413 mm (NDAWN, 2017). At Pillsbury (3 May-15 October) the mean air temperature was 15°C with the total rainfall being 517 mm (NDAWN, 2017). Prosper (2 May- 11 October) had an average air temperature of 16°C and the total rainfall was 386 mm (Table 10) (NDAWN, 2017).

The corn GDDs for 2016 in Carrington were 1229 [°C], near the normal of 1201 [°C] for the same period of time. Similarly, the corn GDD in Pillsbury were 1324 [°C], relatively similar to the average of 1306 [°C]. Prosper was above average with 1402 [°C] compared to the mean of 1316 [°C] (Table 11) (NDAWN, 2017). Rainfall was similar to average in Carrington, above average in Pillsbury, and below average in Prosper (Table 11). Casselton had minor hail damage that occurred around the 3rd leaf stage. Because of a fertilizer application error, only three replications of the data were used in the analysis.

Table 10. Average air temperatures and rain totals at the Prosper, Carrington, and Pillsbury, ND, weather station, 20015-2016.

Location	Month	Average air temperature			Total rainfall		
		2015	2016	30 Year Average[†]	2015	2016	30 Year Average[†]
		---------------°C---------------			---------------mm-------------		
Carrington	April	6	5	6	11	69	30
	May	11	14	13	115	29	70
	June	18	18	18	53	45	96
	July	21	21E[‡]	21	113	115	86
	August	19	20	20	43	93	59
	September	16	15	14	21	45	49
	October	8	8	7	25	16	15
	Total				382	413	404
Pillsbury	April	7	4	6	13	59	24
	May	12	14	13	158	88	71
	June	19	19	18	102	48	81
	July	21	21	21	98	119	77
	August	19	19	20	39	79	67
	September	17	15	15	22	97	62
	October	9E[‡]	8	6	26	27	46
	Total				458	517	429
Prosper	April	8	6	6	20	43	37
	May	12	15	13	149	82	78
	June	19	20	19	110	38	100
	July	21	21	21	88	88	88
	August	19	20	20	36	26	67
	September	17	16	15	22	61	66
	October	9	8E[‡]	7	31	49	62
	Total				456	386	496

[†] 30 year average taken from each location each month from 1985- 2016.

[‡] E indicates an estimate of the value as not a precise number was recorded.

Source: NDAWN, 2017

Table 11. Growing degree days (GDD) for Carrington, Pillsbury, and Prosper in 2015 and 2016, for the months of April to October (NDAWN, 2017).

	Carrington			Pillsbury			Prosper		
Month	2015	2016	30 year average	2015	2016	30 year average	2015	2016	30 year average
	°C								
April	NA	NA	NA	20	NA	12	21	NA	12
May	91	117	110	137	187	169	149	203	171
June	253	249	248	270	278	254	288	284	264
July	328	322	354	350	337	357	352	348	358
August	282	297	311	284	295	331	295	322	326
September	229	178	178	232	183	183	251	208	185
October	18	66	25	3	44	4	8	37	8
Total	1183	1229	1201	1293	1324	1306	1356	1402	1316

Average Crop Yield

The county yield averages in 2015 for Foster Co. was not available. However, Steele Co. had an average yield of 9.3 Mg ha^{-1}. In 2016, the average yield for Cass Co. was 11.5 Mg ha^{-1}, Foster Co. was 9.6 Mg ha^{-1} and Steele Co. was 10.8 Mg ha^{-1}. Comparably, the average yields in these counties since 2010 are 8.7 Mg ha^{-1} in Cass Co., 7.9 Mg ha^{-1} in Foster Co., and 8.4 Mg ha^{-1} in Steele Co. (NASS, 2017). Rainfall, growing degree day accumulations and other conditions were very favorable for corn production.

In Casselton 2016, Carrington 2015 and Hope 2016 there were no significant differences between the no N check plots and the other treatments. Apparently, there was enough N for high yield to be achieved in these environments that rendered the added N treatments insignificant.

Spring Applied Fertilizer Factorial Analysis

Casselton

Yield, protein and total protein did not differ significantly in Casselton, as seen from the ANOVA (Table 12, 13, 14). This could be due to a high mineralization rate, and optimal growing conditions for corn. These data suggest that even the lowest rate of fertilizer applied, regardless of type was adequate for optimum yield. This is the only environment that did not have a response to fertilization.

Table 12. Factorial ANOVA for yield for experiments conducted in Casselton, Carrington, and Hope, 2015-2016.

Source	DF	Casselton		Carrington				Hope			
		2016		2015		2016		2015		2016	
		F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
Rate	2	0.76	0.48	0.67	0.52	2.51	0.09	3.93	0.03*	56.08	<0.01**
Fertilizer	5	0.76	0.58	2.39	0.05*	1.64	0.17	0.81	0.55	4.05	0.01**
Rate x Fertilizer	10	0.81	0.62	0.46	0.91	2.42	0.02*	1.70	0.11	3.16	0.01**

Table 13. Factorial ANOVA for protein for experiments conducted at Casselton, Carrington, and Hope, 2015-2016.

Source	DF	Casselton		Carrington		Hope			
		2016		2016		2015		2016	
		F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
Rate	2	3.10	0.06	8.29	0.01**	5.58	0.01**	1.44	0.25
Fertilizer	5	1.56	0.20	6.34	0.01**	6.12	0.01**	5.73	0.01**
Rate x Fertilizer	10	0.49	0.88	1.27	0.27	0.78	0.65	0.67	0.74

Table 14. Factorial ANOVA for total protein for experiments conducted at Casselton, Carrington, and Hope, 2015-2016.

Source	DF	Casselton		Carrington		Hope			
		2016		2016		2015		2016	
		F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
Rate	2	0.31	0.74	6.16	0.01**	8.61	0.01**	37.43	<0.01**
Fertilizer	5	0.81	0.55	3.60	0.01**	4.76	0.01**	5.88	0.01**
Rate x Fertilizer	10	0.78	0.65	2.26	0.02*	1.35	0.23	2.27	0.03*

Carrington

In Carrington in 2015, there was no significant difference between fertilizer rates nor was there a significant rate by fertilizer type interaction for yield. Fertilizer types, however, differed significantly as indicated in the ANOVA (Table 12). This difference was due to the WDG yielding significantly more than the 50Urea plus 50UAN treatment (Table 15). The UAN application may not have made it into the soil in this environment due to not enough rain to incorporate the UAN into the soil profile or it could have volatilized after being converted to NH_3^-.

Table 15. Effects of fertilizer type on grain yield, Carrington in 2015.

Fertilizer Type	Yield
	Mg ha^{-1}
WDG	9.2
50WDG 50Urea	9.5
Urea	9.0
ESN	9.0
SuperU	9.1
50Urea 50UAN	8.6
LSD= 0.05	0.6

In 2016 at Carrington, the factors that were significant were the rate by fertilizer interaction for yield and total protein, and the rate and fertilizer type for protein. However, the rate by fertilizer interaction was not significant for yield, protein, or total protein. In 2016, the yield differed significantly between the WDG and the 50WDG plus 50Urea treatments (Figure 2). There was over a two Mg ha^{-1} increase when using 50WDG plus 50Urea at the 100% N rate when compared to the WDG 100% N rate. This difference was reduced when the amount of N increased to 125% N. There was no statistical significance between any of the treatments at the highest rate of fertilization. This would indicate that there was not enough N released from the WDG in the amount of time from when it was applied and when it was needed by the crop when compared to urea which was largely all available at the time of application.

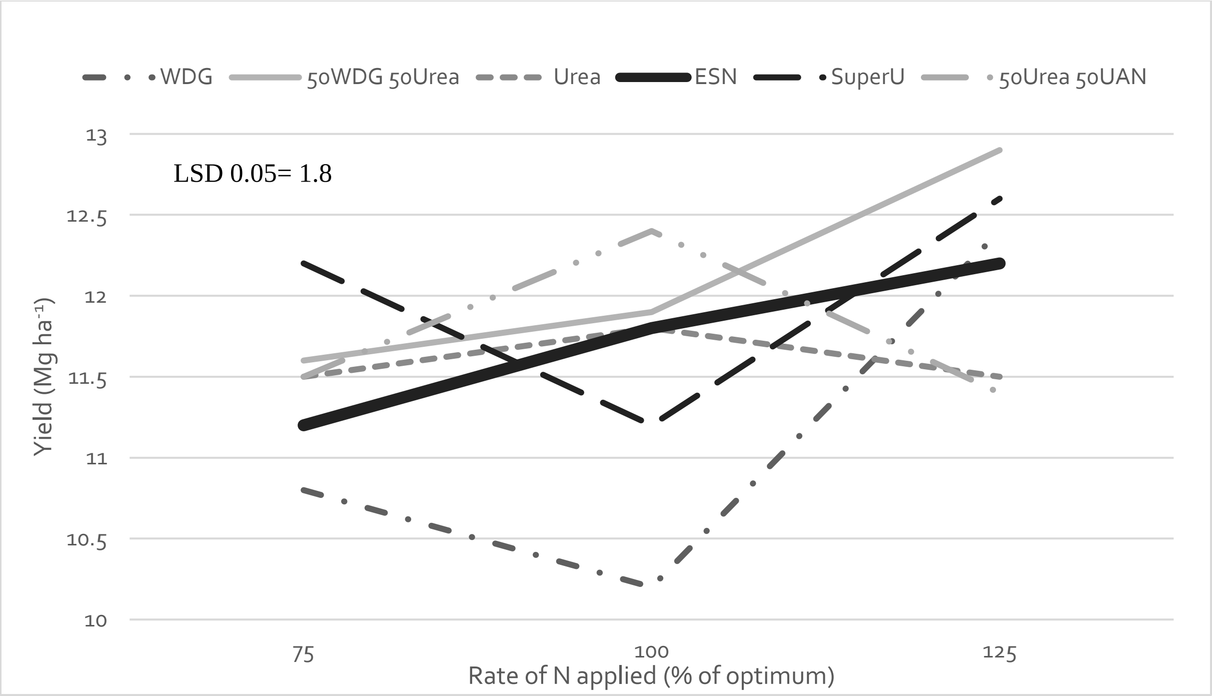

Figure 2. The effect of fertilizer type and N rate on yield at Carrington, ND, 2016. The 100% rate of N at this environment was 157 kg ha^{-1}. The LSD value allows for the comparison of all means across rates and fertilizer types.

Protein content was significantly impacted by N rate (Table 12). Protein content at the 125% rate of N was significantly greater than the other two rates (Table 16). This indicates that in order to achieve a higher protein, additional N was needed to insure that N is not a limiting factor for corn grain protein. There was also a significant response in protein to the fertilizer types (Table 12). The WDG treatments, whether with urea or alone, were lower in protein comparable to the other types. Furthermore, the 100% WDG were significantly lower in protein than all the other treatments. When the urea was added in the 50WDG plus 50Urea treatments, it was statistically similar to ESN and 50Urea plus 50UAN, but had less protein that the urea and SuperU treatments. The WDG treatments may need more time to release their N, thus reducing their effectiveness in the year of application if applied in the spring. This was also a no-till environment which likely reduced the nutrient breakdown from the soil microbes as compared to the other environments due to low soil to material contact (Shroyer et al., 2011). The N could have also been immobilized by the soil microorganisms and may become available in the subsequent growing seasons at that environment, however, more research needs to be conducted on this topic (L. Cihacek, personal communication, 2017).

Table 16. The effectiveness of N rate and fertilizer source on grain protein, Carrington, 2016. The 100% rate of N at this location was 157 kg ha^{-1}.

Fertilizer type	Rate of N (% of optimum)			
	75	100	125	Average†
	------------------- % ------------------			
WDG	8.9	9.1	9.5	9.1
50WDG 50Urea	9.3	9.5	9.5	9.4
Urea	9.8	9.3	9.8	9.7
ESN	9.5	9.6	9.8	9.6
SuperU	9.5	9.8	10.1	9.8
50Urea 50UAN	9.4	9.6	9.7	9.6
Rate Average‡	9.4	9.5	9.7	

† LSD 0.05 for comparing rate means= 0.2.

‡ LSD 0.05 for comparing fertilizer means= 0.3.

There was a significant interaction between the rate of N and the type of fertilizer applied for total protein (Table 13). Total protein follows a similar trend as to its significance as did protein in Carrington in 2016 (Figure 3). The lower rates of WDG were not sufficient in providing N to the environment due to a lack of availability either in the amount or in the release of the product (Shroyer et al., 2011). A higher rate of WDG (125% N) is needed provide the equivalent of available N as the other products at the 100% rate. The ESN treatments seemed to have the most linear trend amongst all the products.

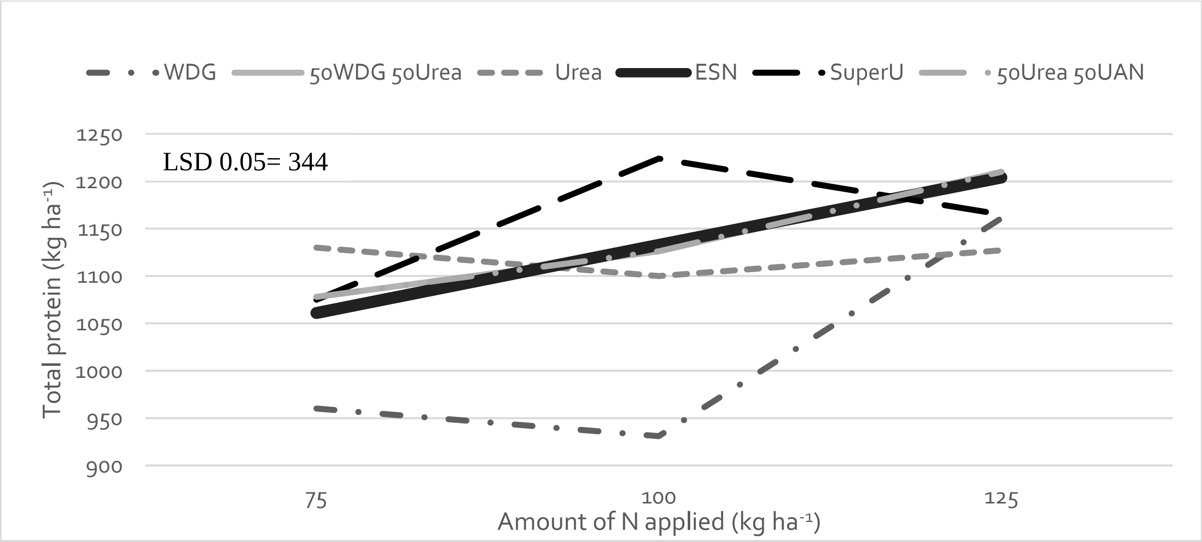

Figure 3. Total Protein as affected by rate of N and N type at Carrington, ND, 2016. The 100% rate of N at this environment was 157 kg ha^{-1}. The LSD value allows for the comparison of all means across rates and fertilizer types.

Hope

Nitrogen rate significantly affected yield at Hope in 2015 (Table 12). There was a positive yield response to increasing the amount of N applied when averaged across all fertilizer types (Figure 4). The 75% N was statistically lower than the 125% rate, however, the 100% rate was statistically similar to both. This shows that N was limiting yield at the lower N rate.

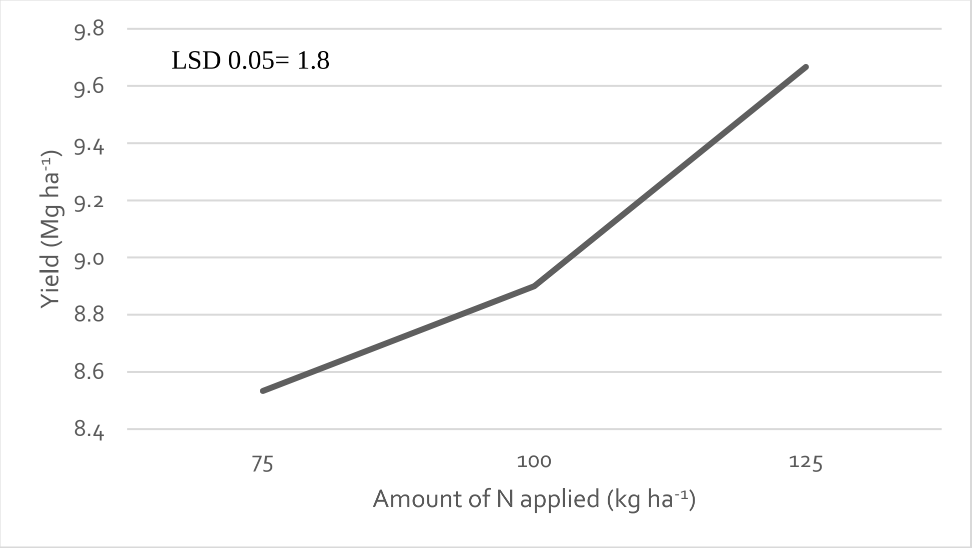

Figure 4. Effects of fertilizer rate on corn yield at Hope, ND, 2015.
The 100% rate of N at this environment was 126 kg ha-1. The LSD value allows for the comparison of all means across rates and fertilizer types.

Protein was significantly impacted by N rate and fertilizer type at Hope in 2015 (Table 12). The protein content was lower in the 75% rates when compared to the 100% and 125% rates of N (Table 17). When considering the differences between sources, the WDG treatments had lower protein than the other fertilizer types. Furthermore, the WDG alone was significantly lower than the 50WDG plus 50Urea treatment. This protein reduction could be attributed to the lack of N being available or the rate of N release was inadequate to meet the needs of the crop. The WDG treatments would need more time to mineralize N to become available to the plant. The WDG plus urea treatment had higher protein due to 50% of the N in the urea treatment being available shortly after application.

Table 17. The effect of fertilizer type and rate on protein at Hope, ND, 2015. The 100% rate of N at this environment was 126 kg ha^{-1}.

Fertilizer type	Rate of Amount (% of optimum)			
	75	100	125	Average[†]
	------------------------%--------------------------			
WDG	7.0	7.2	7.5	7.2
50WDG 50Urea	7.5	9.2	9.0	8.6
Urea	8.7	9.4	9.6	9.2
ESN	8.0	9.4	9.8	9.1
SuperU	8.3	9.7	9.8	9.3
50Urea 50UAN	9.2	9.0	9.1	9.1
Average[‡]	8.1	9.0	9.1	

[†] LSD 0.05 for comparing rate means= 0.7.

[‡] LSD 0.05 for comparing fertilizer means= 0.5.

The 100% rate of N was 126.

Total protein was significantly affected by the rate of N and fertilizer type, however, there was interaction in Hope in 2015 (Table 14). The effect of fertilizer rate and type had similar effects on total protein as seen for yield and protein. The 75% was lower than the 100% and the 125% N rates (Table 18). With regards to the type of fertilizer used, the ESN and 50Urea plus 50UAN treatments were higher in total protein when compared to the WDG treatments. There was no statistical difference between the urea, ESN, SuperU, and 50Urea plus 50UAN. These data show that treatments containing WDG were limited for N, impacting both yield and protein.

Table 18. Effect of fertilizer type and rate on total protein in Hope, ND, 2015. The 100% rate of N was 126 kg ha^{-1}.

Fertilizer type	Rate of Fertilizer (% of optimum)			
	75	100	125	Average[†]
	----------------------kg ha^{-1} -------------------			
WDG	498	568	784	617
50WDG 50Urea	654	688	922	755
Urea	723	866	810	800
ESN	801	831	892	841
SuperU	612	890	928	810
50Urea 50UAN	769	905	875	850
Average[‡]	676	791	869	

[†] LSD 0.05 for comparing rate means= 85.

[‡] LSD 0.05 for comparing fertilizer means= 60.

In 2016 at the Hope environment there was a significant interaction between the rate of N applied and the type of fertilizer used for yield (Table 12). This interaction resulted from the 50Urea 50UAN at the 75% rate of N yielding more than the other fertilizer types at the same rate, but similar to these other types at higher rates (Table 19).

Table 19. Yield rate by fertilizer type interaction, Hope, ND, 2016. The 100% rate of N was 121 kg ha^{-1}.

Fertilizer Type	Fertilizer Rate (% of optimum)		
	75	100	125
		-------------Mg ha^{-1} ----------	
WDG	14.8	16.1	16.3
50WDG 50Urea	14.4	16.6	16.3
Urea	14.6	16.4	16.1
ESN	14.7	16.3	15.9
SuperU	15.3	16.6	15.6
50Urea 50UAN	16.3	16.8	16.1
LSD 0.05		1.1†	

† LSD value is for comparing all means in the table.

The ANOVA at Hope in 2016 showed a significant response to fertilizer type effecting protein (Table 13, 14). There was also an interaction between rate and fertilizer type on total protein. The protein was significantly lower for the WDG treatment, as was seen at other locations (Table 20). The 50WDG plus 50Urea was lower than the other treatments as well with SuperU having the highest protein content. For total protein, the WDG lagged behind again. All the treatments followed a similar trend, however, throughout the increasing rates of product. Based on the protein and total protein contents, the 50WDG plus 50Urea would be a competitive alternative to the other N sources, specifically in areas susceptible to losses.

Table 20. Effect of for fertilizer type on protein and fertilizer type and rate on total protein for Hope, ND, 2016. The 100% rate of N was 121 kg ha^{-1}.

Fertilizer Type	Protein	Total Protein by Fertilizer Rate (% of optimum)		
		75	100	125
	%	-----------------kg ha^{-1}----------------		
WDG	9.2	1371	1457	1498
50WDG 50Urea	9.5	1344	1590	1557
Urea	9.6	1388	1589	1540
ESN	9.6	1375	1547	1553
SuperU	9.7	1480	1607	1515
50Urea 50UAN	9.6	1548	1620	1556
LSD= 0.05	0.1†		80‡	

† LSD value is for comparing (type by rate) protein means in the table.
‡ LSD value is for comparing all (type by rate) total protein means in the table.

Spring vs. Fall Fertilizer Application Timing Analysis

The spring vs fall fertilizer application timing comparison were limited to three environments due to the project's start date. The project was planned during the winter after the 2014 growing season so no applications of fall treatments could be made for the 2015 growing season.

Casselton

There were no significant differences or interactions among the treatments at this location as seen in the ANOVA (Table 21). Timing was to not significant for corn production at this environment (Vetsch and Randall, 2004). The environment was conducive to N mineralization and maximum plant uptake. The soil provided enough nutrients and the crop received enough rainfall to adequately support the growth of high yields even when N was not added to the system as found in the overall analysis previously discussed. There weren't any environmental stresses such as excessive pests or flooding. There was, however, minor hail damage early in the growth of the crop during the two to three leaf, but the impact on yield was thought to be minimal.

Table 21. Yield, protein, and total protein ANOVA for spring vs. fall timing of fertilizer application at Casselton, ND, 2016.

Source	DF	Yield		Protein		Total Protein	
		F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
Timing	1	0.03	0.87	0.06	0.81	0.02	0.88
Rate	2	1.23	0.31	1.81	0.19	2.64	0.09
Rate x Timing	2	0.77	0.48	0.17	0.84	0.32	0.73
Fertilizer type	1	0.56	0.58	0.42	0.66	0.77	0.47
Fertilizer type x Timing	1	0.31	0.59	0.47	0.50	0.41	0.53
Rate x Fertilizer type	2	1.00	0.38	0.56	0.58	1.31	0.29
Rate x Fertilizer type x Timing	1	0.10	0.76	0.08	0.78	0.0	0.97

Carrington

At Carrington, fertilizer application rate by timing and rate by timing by fertilizer type interactions were significant for yield (Table 22). The three way interaction was due to the two lowest rates of urea applied in the fall compared to all the other treatments responding differently from the higher rates. The fall applied 75% and 100% urea lagged in yield compared to the fall 125% urea, spring 75% and 125% WDG, and the spring 75% and 100% urea. Moreover, WDG at the 125% fall applied rate resulted in a higher yield than the 100% fall urea treatment when applied in the fall (Table 23). This would suggest that some of the N may have been lost to the environment, reducing the available amount of N throughout the growing season.

Table 22. Yield, protein, and total protein ANOVA for spring vs. fall timing of fertilizer application in Carrington, ND, 2016.

Source	DF	Yield		Protein		Total Protein	
		F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
Timing	1	1.31	0.26	0.35	0.56	1.16	0.29
Rate	2	0.75	0.48	11.44	0.01^{**}	5.28	0.01^{**}
Rate x Timing	2	3.50	0.04^{*}	1.83	0.18	0.98	0.39
Fertilizer	1	1.05	0.31	22.80	$<0.01^{**}$	9.83	0.01^{**}
Fertilizer x Timing	1	1.36	0.25	0.01	0.93	0.62	0.44
Rate x Fertilizer	2	2.18	0.13	1.89	0.17	2.35	0.11
Rate x Fertilizer x Timing	1	4.15	0.03^{*}	1.13	034	1.64	0.21

Table 23. Spring vs. fall application timing, rate of N and fertilizer type interaction significance in Carrington, ND, 2016. 100% total N is 157 kg ha^{-1}.

Fertilizer Type	Rate	Yield	
		Fall	Spring
	% Optimum N	---------- Mg ha^{-1} --------	
WDG	75	11.2	11.8
	100	11.3	11.0
	125	11.6	12.0
Urea	75	10.5	11.8
	100	10.4	11.7
	125	11.8	11.1
LSD 0.05		1.0†	

† LSD is for comparing all values in the table.

Both the rate and the fertilizer type was significant for protein and total protein (Table 22). The WDG had lower protein overall when compared to urea. The WDG had 9.2% whereas urea had 9.5% protein. The rates also had an effect on protein with the 75% optimum N rate significantly lower than the 125% optimum N rate (Table 24). The WDG was lower in total protein as well with 1058 kg ha^{-1}, compared to 1062 kg ha^{-1} in the urea treatment. All three of the rates were significantly different from each other with 75% optimum N having the lowest total protein of 1036 kg ha^{-1} and 125% optimum N had 1062 kg ha^{-1} of total protein (Table 24).

Table 24. Effect of rate of N and fertilizer type on protein and total protein in Carrington, ND, 2016.

Fertilizer Type	Fertilizer rate	Protein		Protein Averages		Total Protein		Total Protein Averages	
		Fall	Spring	Fert	Rate	Fall	Spring	Fert	Rate
	% Optimum N	--------------- % ------------				------------------- kg ha^{-1} -----------			
WDG†	75	8.9	9.0	9.2	9.2	997	1062	1058	1036
	100	9.0	9.7		9.4	1017	1067		1044
	125	9.8	8.9		9.5	1137	1068		1101
Urea	75	9.4	9.3	9.5		987	1097	1062	
	100	9.3	9.6			967	1123		
	125	9.4	9.8			1109	1088		
LSD 0.05=		NS	NS	0.2	0.3	NS	NS	4	6

†WDG= Wet distillers grain

Hope

At Hope yield was significantly affected by rates in 2016 (Table 25). Furthermore, there was a significant rate by timing interaction. The spring application of 75% optimum N yielded significantly lower than all the other treatment rates at either application timing. There either was not enough product applied to release the needed amount of N, as could be the case for the urea, or there was not enough time for the N to be released from the product, that could be observed for the WDG. There was also above average rainfall in April, May, July, August, and September. The fall 125% optimum N yielded lower than the 100% fall and spring applied fertilizer timings (Table 26). There is not a logical reason as to why this occurred. Protein was significantly different between the fertilizer types. The urea treatments were higher than those with DG across the rates and timings (Table 27).

Table 25. Yield, protein content, and total protein ANOVA for spring vs. fall timing of fertilizer application at Hope, ND, 2016.

Source	DF	Yield		Protein		Total Protein	
		F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
Timing	1	0.18	0.67	0.00	1.00	0.10	0.76
Rate	2	15.49	<0.01**	0.90	0.42	10.11	0.01**
Rate x Timing	2	11.78	0.01**	0.84	0.44	4.18	0.02*
Fertilizer	1	1.30	0.26	14.89	0.01*	3.10	0.09
Fertilizer x Timing	1	0.38	0.54	3.32	0.08	2.82	0.10
Rate x Fertilizer	2	0.40	0.67	1.01	0.38	0.40	0.68
Rate x Fertilizer x Timing	1	3.03	0.06	0.62	0.54	3.33	0.05*

Table 26. Effect of application rate and timing interaction on yield, Hope, ND, 2016. Total N rate for 100% is 121 kg ha^{-1}.

Fertilizer Rate	Yield	
	Fall†	Spring
(% Optimum N)	---- Mg ha^{-1} ----	
75	15.7	14.7
100	16.1	16.3
125	15.6	15.9
Average	15.8	15.6
LSD 0.05	0.5‡	

† Application timing.

‡ Comparing all means in the table.

Table 27. Effect of fertilizer type on protein content at Hope, ND, 2016.

Fertilizer Type	Protein
	%
WDG†	9.3
Urea	9.5
LSD 0.05	0.2

†WDG= Wet distillers grain

There was a significant interaction between fertilizer type, rate of N applied, and application timing for total protein (Table 25). There was less total protein in this environment with fall applied urea at the 75% and 100% N rates compared to the spring applied urea treatments at 100% and 125% rates of N. There is not enough product to maintain a high level of N in the environment due to physical amount of product and also N could have be lost to leaching or volatilization in the fall or early spring due to rainfall. The spring applied WDG had lower total protein compared to all other treatments, rates, and application times. In addition, the fall applied 100% optimum WDG had higher total protein when compared to the 100% optimum rate of WDG applied in the spring. This suggests that there was not enough time for the N to be released from the product (Table 28).

Table 28. Spring vs. fall application timing, fertilizer type and rate of N applied interaction significance in Hope, ND, 2016. Total N rate for 100% is 121 kg ha^{-1}

Timing	Fertilizer Type	Fertilizer Rate	Total Protein
		% Optimum N	kg ha^{-1}
Fall	WDG	75	1460
		100	1535
		125	1457
	Urea	75	1460
		100	1466
		125	1513
Spring	WDG	75	1376
		100	1449
		125	1500
	Urea	75	1387
		100	1591
		125	1546
LSD 0.05			81

Overall Trends

Individual locations showed a positive impact when using the WDG treatments, however, overall they were often out performed by the other fertilizers. There were two site years where urea plus UAN had a significantly higher yield, protein content and total protein value than WDG. WDG protein was significantly lower when compared to WDG plus urea (three site years), urea alone (three site years), and ESN and SuperU (two site years). Another trend was a higher total protein content was found in two years for urea when compared to WDG.

The ESN and SuperU showed no benefits compared to the urea in the environments of the study similar to what was found by Hillenbrand (2017). The environments had minimal N losses and optimum growing conditions that rendered the capabilities of the ESN and SuperU ineffective. It would be beneficial to extend the study into multiple additional environments to in order to test their effectiveness in an environment where N loss is considered significant.

SUMMARY AND CONCLUSIONS

The 2015 environments had near average yields and showed differences between treatments as well as a significant difference between the applied treatments and the no N check. The 2016 growing season, on the other hand, proved to be high yielding for corn growers in North Dakota with high yields in the Red River Valley of the North. Unfortunately, a good year for growing corn results in an unfavorable year for researching N responses. The moisture and temperatures, as were described in the section before, were conducive to N mineralization from the soil organic matter, so even the untreated checks yielded well. These data suggest that a producer only needed to apply minimal N to achieve the same yields as they did with high levels of added inputs. In 2016, the economics favored not adding any N inputs.

The use of WDG could be used as an N fertilizer source to increase N use efficiency in soils that are prone to N loss. There were several site years that the yield had no significant difference from the other fertilizer types. This would only prove to be economically beneficial if the land the product is applied to is within a reasonable proximity to an ethanol plant. This would reduce concerns due to transportation cost of such a large volume of product and the short window that is available before spoilage. The other aspect to be considered it the cost of N per kg of product, the byproduct prices must remain the same or decrease further, thus furthering the likelihood of utilization. It is also concluded that if WDG are to be utilized as a N source, one would need to apply 25% more of the equivalent amount of optimum N to achieve the same response as urea or other sources in the season it is applied.

In environments that are no-till, WDG effects have shown to be problematic in the year of application. Due to the no-till system, the effects of the WDG treatment would most likely observed in the next growing season or so. The product is not incorporated into the soil, therefore, it will take longer to be broken down by the microbial action and the N would be released from the fauna in a longer time frame than a conventional tillage system.

The modified release products such as ESN and SuperU did not show any significant differences in yield relative to the urea alone throughout the environments. This was a result of the environments not being susceptible to N losses overall and the specialty properties that the products offered were not needed in these growing seasons. It would be beneficial to continue to evaluate the product in more environments to understand their full potential in the agronomic system of the Red River Valley of the North.

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APPENDIX

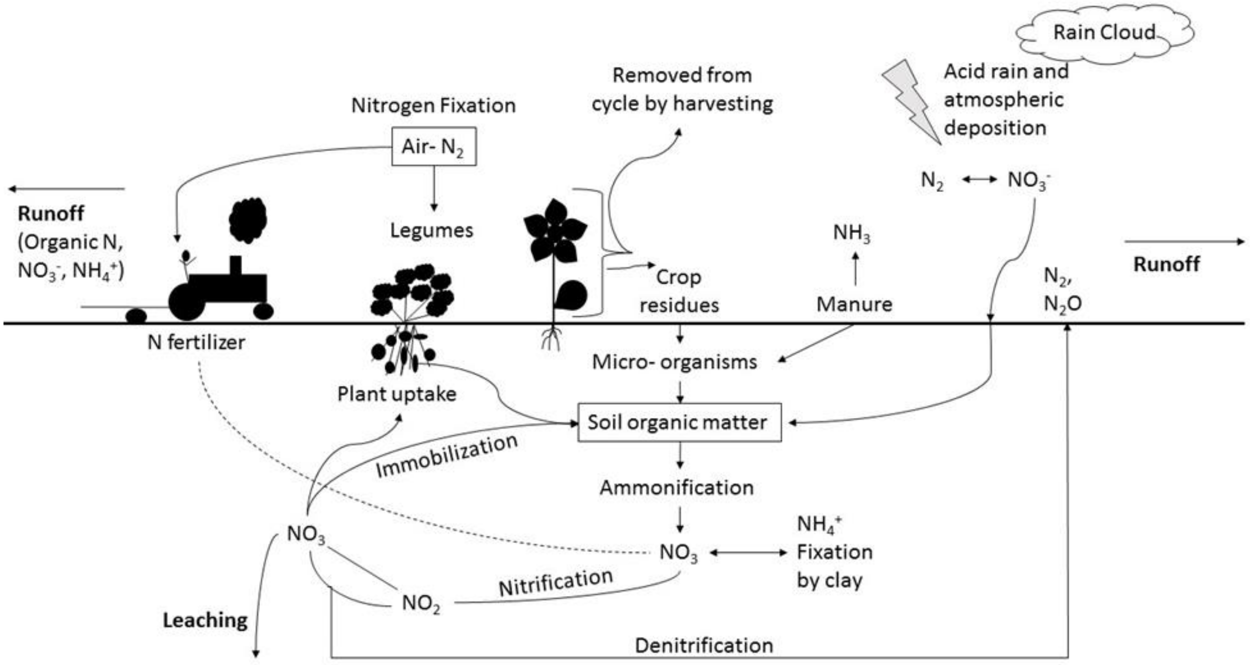


Figure A1. Nitrogen cycle.

Table A1. Yield, protein and total protein content for significant treatments at Casselton, ND, 2016.

Fertilizer Treatment	Yield	Protein	Total Protein
	(Mg ha $^{-1}$)	(%)	(kg ha^{-1})
DG + urea	15.34	8.6	1319
Urea + UAN	16.08	9.1	1464
DG Overall	15.33	8.9	1364
DG Spring	15.34	8.9	1365
DG Fall	15.33	8.8	1349
ESN	14.03	9	1263
SuperU	15.24	9	1372
Urea	15.64	8.8	1376
Untreated check	15.99	9	1439
Modified release	14.67	9	1320
Non-slow release	15.88	9	1429
Fall	15.47	8.9	1377
Spring	15.29	8.9	1361
Contrast			
WDG vs Urea Overall	NS	*	NS
WDG Spring vs Urea + UAN	NS	*	NS
WDG Spring vs Modified release	NS	*	NS

Table A2. Treatment means averaged over N rates for yield, protein, and total protein content for Carrington, ND, 2016.

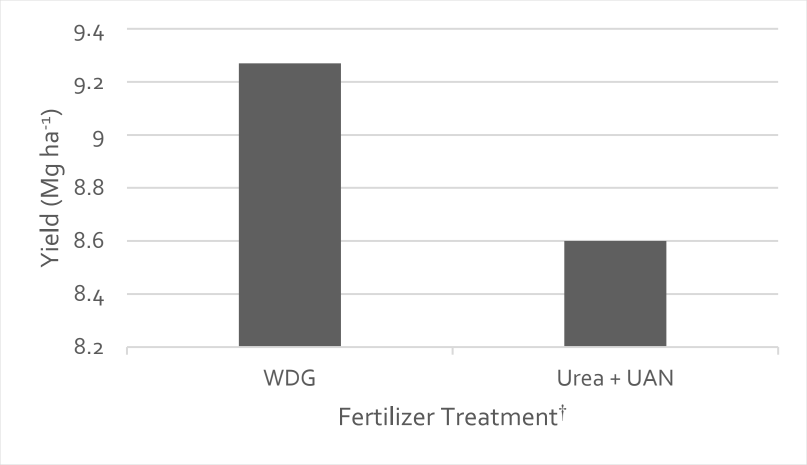
Fertilizer Treatment	Yield	Protein	Total Protein
	(Mg ha^{-1})	(%)	(kg ha^{-1})
WDG + Urea	11.97	9.4	1125
Urea + UAN	11.75	9.6	1128
WDG Overall	11.34	9.1	1032
WDG Spring	11.03	9.1	1004
WDG Fall	11.62	9.2	1069
ESN	11.75	9.6	1128
SuperU	11.91	9.8	1167
Urea	11.59	9.7	1124
Untreated check	8.06	8.1	653
Modified release	11.83	9.7	1148
Non-slow release	11.54	9.4	1085
Fall	11.64	9.4	1094
Spring	11.66	9.5	1108
Contrast			
WDG vs Urea Overall	NS	*	*
Untreated check vs All	*	*	*
WDG vs WDG + Urea Spring	NS	NS	*
WDG vs Urea + UAN	*	*	*
WDG vs Modified release	*	*	*
WDG fall vs Modified release	NS	*	*

Table A3. Treatment means averaged across N rates for yield, protein, and total protein content for Hope, ND, 2015.

Fertilizer Treatment	Yield	Protein	Total Protein
	(Mg ha^{-1})	(%)	(kg ha^{-1})
WDG + urea	8.94	8.6	769
Urea + UAN	9.42	9.1	857
WDG	8.53	7.2	614
ESN	9.43	9.0	849
SuperU	9.14	9.3	850
Urea	8.73	9.2	803
Untreated check	5.37	6.5	349
Modified release	9.28	9.2	854
Non-slow release	9.28	9.2	854
Contrast			
WDG vs Urea	NS	*	*
Untreated check vs All	*	NS	*
WDG vs WDG + Urea	NS	*	*
WDG vs Urea + UAN	NS	*	*
WDG vs Modified release	NS	*	NS

Table A4. Treatment means averaged over N rates for yield, protein, and total protein content for Hope, ND, 2016.

Fertilizer Treatment	Yield	Protein	Total Protein
	(Mg ha^{-1})	(%)	(kg ha^{-1})
WDG + urea	15.76	9.5	1497
Urea + UAN	16.42	9.6	1576
WDG Overall	15.84	9.2	1457
WDG Spring	15.76	9.2	1450
WDG Fall	15.80	9.3	1469
ESN	15.63	9.5	1485
SuperU	15.83	9.7	1536
Urea	15.69	9.6	1506
Untreated check	16.09	9.1	1464
Modified release	15.73	9.6	1510
Non-slow release	16.05	9.6	1541
Fall	15.79	9.4	1484
Spring	15.85	9.5	1506
Contrast			
WDG vs Urea Overall	NS	*	NS
Untreated check vs All	NS	*	NS
WDG spring vs WDG + Urea	NS	*	*
WDG vs Urea + UAN	*	*	*
WDG fall vs Modified release	NS	*	NS
Urea vs Modified release	NS	NS	*
Modified release vs non-slow release	*	NS	NS



[†]Treatment means averaged over the rates of N.

Figure A2. A comparison between WDG and urea + UAN treatments means averaged over N rates for yield Carrington, ND, 2015.