WINTER WHEAT RESPONSE to TOPDRESS NITROGEN APPLICATION METHOD and SOURCE

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Abstract: Winter Wheat (*Triticum aestivum*) is the main crop grown in much of the Southern Great Plains, with roughly 1.8 million hectares being planted in Oklahoma alone in 2017(USDA 2017). Nitrogen volatility is a significant concern when deciding on which topdressing source and method to use for wheat production in the Great Plains region. With the many options producers have for fertilizer application that is commercially available, it is of the utmost importance that research continues to be performed to develop different methods of improving nitrogen use efficiency with each option, while still remaining a viable option. This study was initiated to evaluate the impact of fertilizer source and placement on winter wheat grain yield and protein concentration. It was hypothesized that placing urea below the soil surface in season with the use of a grain drill would increase both final grain yield and protein concentration when compared to broadcasted urea, that the use of a protected urea source would have a positive effect on grain yield and protein when compared to the broadcast urea check, and that the grain drill would not have a negative effect on the wheat crop due to plant damage and disturbance. Trials were established in early January of 2017 and 2018 at the OSU Research Stations located in Perkins (central Oklahoma, Konowa and Teller Loamy fine sand), Lahoma (west central Oklahoma, Grant silt loam) , and Chickasha (South Central Oklahoma, Dale and Reinarch silt loam). Two drill types consisting of a single disk opener and a double disk opener, both applying urea, were compared to three sources of N broadcast. The sources consisting of Super U (protected urea source), untreated urea, and ammonium nitrate. All treatments received 67.25 kg ha^{-1} of actual nitrogen, excluding the check. Three timings were implemented, consisting of an early, mid, and late top-dress application, which were intended to represent a late January, early February, and late February applications. Out of 21 contrasts comparing grain drilled applied urea to broadcast urea, only one was found to be significantly positive. Similarly, the AN treatment was only significantly higher than broadcasted urea in one contrast while Super U was never statistically greater. While few methods statistically improved yield or protein above broadcast urea, across all locations the use of a grain drill resulted in a 5.5% higher yield than broadcast urea, while AN increased yield by 3% and Super U by 4%. The results suggested that the plant damage caused by the use of a grain drill did not have a negative impact on grain yield nor protein concentration in any of the site-years. In field observation of fertilizer placement and row closure based on drill type and soil environment suggest further research is needed to better understand the impact of grain drill type, soil conditions, and the factors controlling the probability of a positive response.

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CHAPTER I

INTRODUCTION

Nitrogen (N) fertilizer usage in winter wheat has evolved since its first synthetic production in terms of how it is used and applied. With rising input costs and thinner operating margins, the need to provide producers with methods that can improve the return on investment (ROI), while increasing yields for a growing population demanding an increase in food production, is more critical than ever (Walsh et al., 2012). Winter wheat is the largest grain crop grown in Oklahoma, with more than 1.8 million hectares planted in 2017. In recent years, research has evolved to look at methods to improve the low N use efficiency of cereals worldwide, which currently averages 33% (Johnson and Raun, 2003). Kanampiu et al. (1997) noted that as excess N was applied for higher yielding cropland, NUE decreased. With lower NUE, excess nutrients can become a problem, which can potentially lead to environmental problems (L. Stone et al., 1996). Springtime topdress N conditions can be highly conducive for losses through ammonia (NH_3) volatilization from urea, with springtime rains being common in the Southern Great Plains. This in turn can lead to increased hydrolysis and a resulting increase in losses. With this is mind, it is important to evaluate novel methods that could lead to increased NUE when applying increased rates of N, as they would be relevant to grain producers in the Southern Great Plains.

Soil pH and soil moisture both have a direct impact on the amount of NH_3 volatilization that can occur, and as soil pH and moisture increase, chances for losses increase as well (Volk, 1959). Rochette et al. (2013b), in a study designed to quantify the impact of N placement depth on a slightly acidic soil, stated that by applying 164 kg N ha^{-1} over 7.5 cm below the soil surface in a concentrated band resulted in negligible losses. NH_3 losses from surface applied were 50%, and a decrease of 7% per cm depth of incorporation was observed. The authors also stated that broadcasting N on the soil surface or incorporating in bands both resulted in an increased number of hydroxides, effectively increasing the soil pH. As a result of this, an application may result in increased ammonia volatilization if a rainfall event is not experienced after application and there is not sufficient soil cover. In a similar study, Rochette et al. (2009) studied the effects of incorporating 140 kg N ha^{-1} as urea in bands, broadcasting then incorporating, and broadcasting urea and leaving it on the surface on a slightly acidic soil. The lowest losses were 9% and were observed with broadcasted urea, followed by 16% from broadcast and incorporated urea, and were highest with banded, which lost 27% of the applied N. Losses were determined to be increased by placing the urea in areas of higher soil moisture, which increased hydrolysis, effectively increasing volatilization. Banded losses were highest due to increased hydrolysis along with a rise in soil pH from 6.0 to 8.7 from the concentrated band. Although there have been several studies conducted comparing both deep and shallow banded urea to broadcasted N products, it is not well documented how they apply to a winter wheat (*Triticum aestivum*) crop grown in Oklahoma on neutral to acid pH soils.

Similar research has been done using anhydrous ammonia (AA) knifed in along with dribbled urea ammonium nitrate (UAN) with dicyandiamide (DCD) added as a topdressing N source onto a standing Oklahoma wheat crop at Feekes growth stages 3 and 5 (Boman et al., 1995). It was found that no significant grain yield reduction was attained by wheat disturbance from the disc AA applicator and that both methods had similar outcomes when comparing final wheat yields. Slightly higher residual nitrate-N was observed from the subsurface application, and was attributed to bypassing the surface organic layer resulting in reduced immobilization or volatilization.

The primary objective of this study was to evaluate the impact of placing urea below the soil surface on final grain yield and protein concentration when compared to broadcasted AN, urea, and treated urea sources.

CHAPTER II

REVIEW OF LITERATURE

Nitrogen use in Agriculture

Nitrogen constitutes over 75% of the total material in the earth's atmosphere, which equates to about 78.4 million kg N ha^{-1} (Bear, 1951). Because of the strong triple bond of N_2 gas, it is not plant available unless converted through microbial N fixation or lightning into a form known as reactive N in which the N molecule is typically bonded to hydrogen, oxygen, or carbon (Nyle C. Brady, 2008). Without these conversion pathways, much of the earth would be without vegetation because N, as it is found in the soil, is an important constituent of plant protein and amino acids (Tan 2009).

The N cycle has been, and continues to be a deep area of study, as its understanding provides a solution for solving many of the world's issues in terms of water quality, vegetation growth, and environmental problems (Nyle C. Brady, 2008). The N cycle can have additions through N_2 fixation, industrial fixation, lightning and rainfall, the breakdown of plant and animal residues, and finally through fertilization. It can also have losses through plant loss, denitrification, leaching, and ammonia volatilization. These additions and losses as well as the pathways that connect each of them are visualized in Figure 1. Nitrogen is found in many forms, with only two forms, dissolved nitrate (NO_3) and ammonium (NH_4), being available for plant uptake (Nyle C. Brady, 2008). Nitrate and ammonium have opposite effects on the root rhizosphere, either raising or lowering the pH respectively.

This is due in part to the roots releasing an H^+ ion when NH_4^+ is absorbed and the opposite effect when NO_3^- is absorbed to balance the charge (Barber, 1984).

When an application of a synthetic N fertilizer is made to the soil, it is applied in a form that has undergone a transformation from N gas (N_2) to NH_3, typically through the Haber- Bosch process. Unless a producer is applying AA as an N source, they are using a derivative of it created by additions of other compounds. In the case of urea, a physically alkaline form of NH_3 is converted from NH_3 by the addition of CO_2 to form ammonium carbonate ($(NH_2)_2CO$) (Volk, 1959). By utilizing NH_3 and CO_2 to create urea, it provides a granular form of N that is not only safer and more stable than AA, but also easily handled and applied by the end user without risk of injury. In 1998 through 2014, the United States total N use was 403,287,894 Mg, with 21% of this total being applied as urea (USDA, 2018). When using a source known to create an environment conducive to losses, in a climatic region that increases the probability of loss, further research to improve efficiencies is required for the environment in which it will be applied in.

Nitrogen Volatilization

Ammonia volatilization is the process by which NH_3 is lost to the atmosphere through either soil or plant losses (Sharpe and Harper, 1996). The NH_3 volatilization from agricultural fertilizer applications can contribute up to 17% of the world's NH_3 emissions (Van der Weerden and Jarvis, 1997; Bouwman et al., 2002). Once a urea-based fertilizer is applied to the soil, it must undergo hydrolysis to become available for uptake by plants; a process driven by the urease enzyme. Under certain conditions, such as no-till production systems, urease is more abundant in the soil when compared to conventional tillage (Rochette et al., 2009). This increase in urease can result in faster hydrolysis, and in the case of no-till, it may result in more losses if the urea granule does not have contact with the soil to absorb the NH_{4+}. Equation 1 below details the transformation urea undergoes through hydrolysis once it is applied to the soil to become NH_4^+ (Jones et al., 2007).

$$(NH_2)_2CO + H^+ + 2H_2O \rightarrow 2NH_4^+ + HCO_3^- \tag{1}$$

This process is then followed by the conversion of NH_4^+ to NH_3, which is shown in equation 2. Once NH_3 is formed, volatilization can take place from the creation of NH_3 gas (Equation 3).

$$NH_4^+ \rightarrow NH_{3(d)} + H^+ \tag{2}$$

$$NH_{3(d)} \rightarrow NH_{3(gas)} + H^+ \tag{3}$$

Initial soil pH, soil buffering capacity, rate of N applied, and cation exchange capacity (CEC) can play a large role in the amount of NH_3 volatilization that can occur after an N application is made (Overrein and Moe, 1967; Hargrove, 1988; Whitehead and Raistrick, 1990; Roelcke et al., 1996). The effect of soil pH is displayed further in equation 4 below showing the equilibrium between NH_3 gas and NH_4^- ions (Nyle C. Brady, 2008).

$$H_2O + NH_3 \leftrightarrow NH_4^+ + OH^- \tag{4}$$

As is seen in equation 4, when there are more hydroxide (OH^-) ions in the soil solution (high pH soil), the reaction is driven to the right thus creating more ammonia. The opposite reaction occurs when NH_3^- producing fertilizers are applied, as they will drive the reaction to the left, thereby raising the pH of the soil surrounding the fertilizer granule. This reaction produces an environment that is favorable for the accumulation of NH_3, which in turn can lead to NH_3 volatilization (Gould et al., 1986). Unfavorable soil conditions such as soil moisture at the time of application and high temperatures further press volatilization upon the NH_3^- through evaporation, releasing NH_3 into the atmosphere (Malhi et al., 2001).

No-till production systems are becoming more common in the Southern Great Plains for their proven ability to increase soil water holding capacity, and potentially increase yields (Lal, 2007). Since rainfall can be sporadic and high in intensity, no-till production systems help to minimize the effects of runoff. In a study conducted in Oklahoma, Dao (1993) measured the effects on soil water storage in Bethany and Renfrow silt loam soils near El Reno, Oklahoma. The author found no-till soils consistently had higher volumetric water contents. The gain was found to be the result of increased water holding capacity and decreased soil bulk density, which led to lowering the seasonal variability of field water infiltration. As a result of the added water infiltration and holding capacity, crop production systems under no-till production can see alleviated effects of climate variability resulting in increased yields.

Fenn and Kissel (1976) conducted a study to evaluate the influence of CEC and shallow incorporation on NH_3 volatilization when applied to calcareous soils. It was found that as CEC was increased, NH_3 volatilization decreased by nearly half in a CEC range of 10- 40. Ammonia volatilization was also reduced with increasing depth of incorporation. The study revealed losses of nearly 50% when surface applied to a silty clay were reduced to less than 10% when incorporated to a depth of 7.5 cm. Losses were prevented, but to less of an effect, when tested in a sand. Losses in a sandy soil were reduced from 75% of applied N at the surface, to 50% when incorporated at a 7.5 cm depth. In a similar study, Fenn and Kissel (1975) studied the effects of calcium carbonate ($CaCO_3$) content and soil pH on NH_3 volatilization. Differing rates of $CaCO_3$ were added to soil to provide an increase in pH, and resulting $CaCO_3$ concentrations were 0.5, 1.3, 2.9, 6.1, 9.7, and 14.7% by weight. Losses were highest on soils with the highest pH, which was recorded at 7.6. While this study was focused on calcareous soils, it relates to implications involving acid soils that have had surface lime applied as well. Volk (1961) found that when applying 112 kg N ha^{-1} to soils that had 2,241 kg ha^{-1} of $CaCO_3$ applied four months previously and left unincorporated that the lime treated soil increased NH_3 volatilization from 29% to 39% when untreated urea was applied to the surface.

It would be hypothesized that by incorporating the urea in bands, below the soil surface, that urea volatilization could be reduced, or almost eliminated. However, Rochette et al. (2009) noted that by incorporating urea 5 cm deep in “v” shaped trenches using a hand hoe in a dry, acidic soil at a rate of 140 kg N ha^{-1} increased emissions from 9% to 27% over broadcasted urea. This was theorized to be due to a localized pH increase from 6.0 to 8.7. It should be noted that the broadcast incorporated treatment resulted in 16% losses, due to increased urea hydrolysis.

Environmental factors such as rain, wind, and temperature play almost as large of a role in the volatilization of urea as placement. Bouwmeester et al. (1985) suggested that precipitation can have a positive or negative effect on the rate of volatilization. Precipitation can add moisture to the soil, thus increasing urea hydrolysis, or carry it farther down into the soil increasing adsorption. It should also be noted that in the absence of moisture, no upward movement through evaporation can occur effectively leading to NH_3 volatilization. Lightner et al. (1990) noted that during the 1983 late summer portion of their study, soils and thatch were very dry, and no precipitation fell during the measurement portion of their volatilization study. The authors stated that volatilization from all treatments were the lowest during this period and ranged from 4-14% of applied N across treatments in comparison to the previous year, which had losses of 17-36% of applied N across treatments.

Gasser (1964) conducted a study evaluating losses of N from volatilization on two soils, a calcareous clay- loam and a calcareous sandy- loam. All treatments in the study received 112 kg N ha^{-1}. Treatments were maintained at 40, 50, and 60% of water holding capacity and incubated at 5° C or 25° C. Results from the study found that nitrate accumulation was favored by colder, wetter soils, and that higher losses favored higher temperatures and the sandy soil in the study.

Figure 2 displays the average statewide air temperature and plant available water in the top 100 mm of soil for Oklahoma from 2003- 2017. As is shown in the figure, average temperatures begin to rise during the typical period when Oklahoma wheat producers begin topdressing winter wheat. Water content in the top 100 mm of soil is also at one of the highest points during the year. Because of this, volatilization may be favored depending on the conditions at the time of application.

Broadcast vs. Banding

Surface applied urea can have losses of up to 50% or greater (Volk, 1959; Fowler and Brydon, 1989). Initial soil moisture content, post- application rainfall, soil pH, tillage system, and soil type can all have a markedly high effect on the amount of NH_3 volatilization from surface applied urea (Ernst and Massey, 1960; Rochette et al., 2009; Engel et al., 2011). Engel et al. (2011) found that in applications of urea followed by rainfall events of less than 8 mm, losses were reduced to 10 – 20% of applied N. It was also noted that applications made before a heavy rainfall event of over 18 mm further reduced losses to less than 10% of the applied N. The application of placing urea in bands below the soil surface, via drill or other applicator, has been well researched with sometimes conflicting results. The thought process behind placing N in the soil has good merit, because once hydrolysis has occurred, the ammonia has soil to bind to that could prevent it from being lost to the atmosphere through volatilization. Angus et al. (2014) found that placing the urea in bands below the soil surface can lead to gaseous losses near zero.

Along with placing the urea in the soil, depth can have differing effects on ammonia loss. Rochette et al. (2013a) looked at the effects of depth, and how increasing the depth of incorporation would effect gaseous losses of ammonia when banded urea was applied at 0, 2.5, 5, 7.5, and 10 cm banding depths. It was found that a surface application resulted in a 50% loss, while each cm of incorporation decreased emissions by an average of 7%. It was concluded that an incorporation depth of 7.5 cm resulted in maximum NH_3 retention and negligible losses.

Mengel et al. (1982), after observing increased N losses by surface application on no-till farmland, performed a study in Indiana to evaluate the differences between broadcasted AN, urea, and urea ammonium nitrate (UAN) to injection of NH_3 and UAN placed 20 cm below the soil surface in corn. Significantly higher grain yields and leaf N content were observed from the treatments that received subsurface applications of N, and an increase in NUE was attributed to decreased volatilization, which aligned with similar results found by Fox et al. (1986). In a similar study, Janzen et al. (1990) compared surface applied AN, urea, and UAN to point injected UAN at a depth of 30 cm. All N sources were labeled with ^{15}N to accurately check uptake. An increase in N uptake from the subsurface injected N was noted and suggested that an increase could be largely attributed to the direct placement of the N fertilizer into the active rooting zone of the growing crop. According to the authors, subsurface injected N is likely to be more pronounced when adequate precipitation is not achieved to bring N fertilizers into the soil after a surface application.

Urease and Nitrification Inhibitors

As described previously, urea when applied to bare soil, undergoes chemical changes once it is hydrolyzed by urease to NH_3 and CO_2, and is followed by a rise in the soil pH and an accumulation of NH_4^+ (Gioacchini et al., 2002). One of the most thoroughly scientifically evaluated urease inhibitors is N-(n-butyl)- thiophosphoric triamide (NBPT), which is effective throughout a large range of urea rates and can reduce losses across many different soils (Gezgin and Bayrakll, 1995; Grant et al., 1996; Gioacchini et al., 2002). Engel et al. (2011) stated that coating urea with an NBPT coating reduced cumulative NH_3 losses by 66% and that protection lasted for 2-3 weeks when applied to an acidic soil and over 7 weeks on an alkaline soil. By coating the urea in NPBT, it binds onto the urease binding sites which prevents the enzyme from reacting to the urease (Manunza et al., 1999). When urease inhibitors are used, an increase in soil pH is decreased, and nitrification is favored (Christianson et al., 1993). When NH_4 is nitrified to the soil mobile NO_3^-, it poses the risk that unused NO_3^- could be lost through leaching. Because of this, dicyandiamide (DCD) inhibitors are commonly used as they are effective at keeping applied N in the NH_4^+ form and very stable, which in turn can lead to reduced leaching (Serna et al., 1994).

Soares et al. (2012) conducted an experiment looking at the effect of urea coated with NBPT and DCD products. The trial consisted of five treatments; urea, urea + NBPT, urea + DCD 10%, urea + NBPT + DCD 5%, and urea + NBPT + DCD 10%. All treatments were surface applied to soil wetted at 60% of the maximum water retention and placed in control chambers to allow for NH_3 volatilized to be captured and measured. Soares found that the NBPT inhibitor decreased volatilization losses by 54 - 78% when compared to the unamended urea, which had losses of 28 - 37% of the total N applied. When DCD was added to the urea in combination with NBPT, volatilization losses were increased in comparison to the unamended urea and urea treated with NBPT only. The author suggests that DCD did not affect the function of the NBPT, instead, that DCD enhanced volatilization losses by keeping the N in the NH_4^+ form along with a higher pH for a longer amount of time. Similar results found by Prakasa Rao and Puttanna (1987), stated that DCD increased volatilization losses when surface applied, but they were minimized when placed at a 5 cm depth. This led the author to suggest that nitrification inhibitors be combined with a placement technique also intended to decrease losses from volatilization. Several commercial N fertilizers with each loss inhibitor are sold, but some, such as Super U, contain both a urease and nitrification (Jantalia et al., 2012). By adding urease and nitrification inhibitors, especially under no-till production, the risk of volatilization and leaching can be minimized when applied near the soil surface (Rao, 1996). Super U's effectiveness of reduced volatilization is well documented, and in some cases can be as low as 0.1% of the applied N (Jantalia et al., 2012). Price is a major determining factor when deciding if loss inhibitors should be used when applying urea. Super U, as it comes pre-mixed from the factory, is approximately $0.28 more per kg of N than bare urea. Possible loss determinations to determine if it is worth the investment should be done, and when there is no rain projected in the forecast it is more likely to be used (Rawluk et al., 2001).

The purpose of this study was to evaluate the impact on grain yield and protein concentration by utilizing two methods and applying different N sources to a growing no-till winter wheat crop in the Southern Great Plains at a yield limiting rate. It is hypothesized that AN will have the highest yields as it does not volatilize, drilled N and Super U will have equal yields and grain quality that are above broadcasted urea, and that drill opener type will have an effect on final grain yield and quality.

CHAPTER III

METHODOLOGY

The experiment was designed as a randomized complete block design (RCBD), with a total of 4 replications across 2 locations and 3 replications at 1 location during the 2016-17 and 2017-18 crop seasons. All plots measured 3.1 m by 6.1 m, and all locations were under no-till management. Best management practices for pests, disease, fertility, and general crop production recommended by Oklahoma State University were used. The effects of N source and application method (drilled urea, broadcasted urea, broadcasted ammonium nitrate, and broadcasted SuperU) as well as time of topdress application (January, February, and March) were compared against final yield and protein. All treatments were applied at a rate of 67.25 kg N ha^{-1}. This rate was chosen as it represented 50% of the expected N needs based upon the regional expected yield. A rate well below expected need was important as it should result in the crop being N deficient, and small differences in fertilizer efficiencies could be detected in the resulting grain yield and/or protein content. The locations utilized for the study were the Cimarron Valley Research Station near Perkins, the Raymond Sidwell Research Station near Lahoma, and the South Central Research Station near Chickasha. All locations are located within Oklahoma.

The soil at Perkins consists of Konowa and Teller Loamy fine sand and fine sandy loam, Lahoma consists of a Grant silt loam, and finally Chickasha is comprised of a Dale silt loam and Reinarch silt loam. Table 1 summarizes all soil types and the previous crop for each site- year. Weather data for all three locations was collected using the Oklahoma Mesonet (www.mesonet.org; Norman, OK), which has a sensor site at each of the locations used in this study. Temperature, wind, humidity, and precipitation were collected for each location for the length of the trial. Soil moisture was obtained from sensors using thermocouple induced heat resistance readings of temperature change at the 5 cm depth (Illston et al., 2008).

Before the trials were established, composite soil samples were taken in each of the trial locations to a depth of 15 cm, with each composite sample consisting of 15 cores. Each of the soil samples were submitted to the Soil, Water, and Forage Analytical Laboratory (SWAFL) in Stillwater, OK for analysis of N, phosphorus (P), potassium (K), and Soil pH. The pH analysis was done using a 1:1 soil to deionized water ratio. In cases where the soil pH was lower than 6.2, a Sikora buffer was added to determine the buffer index. For NO_3 -N, calcium sulfate was used as the extractor and analyzed on a flow injection analyzer using cadmium reduction. Mehlich 3 was used as the extraction method for P and K, and it was then analyzed with an inductively coupled plasma (ICP). Results for each site-year are listed in Table 2.

For both the 2016- 17 and 2017-18 crop seasons, multiple varieties and rates of starter fertilizers were used to best suit the location they were planted in. Perkins was planted with Doublestop at 84 kg ha^{-1} and due to acidic soil pH and low soil test P value, diammonium phosphate (DAP) was applied in furrow at the rate of 84 kg ha^{-1} for both crop seasons. At Chickasha, Ruby Lee was planted at 73 kg ha^{-1} for the 2016-17 season and at 84 kg ha^{-1} for the 2017-18 season and no starter fertilizer was used. The Lahoma location was planted with Bentley at 67.25 kg ha^{-1} for 2016-17 and at 84 kg ha^{-1} for the 2017-18 season and no starter fertilizer was used. All plant dates and summaries of varieties are listed in Table 3.

The effects of using a single disk opener vs a double disk opener were tested in both crop years. In the 2016-17 crop year, both a no-till single disk (John Deere 1590) and conventional tillage double disk drill (Kinkaid 2010) were used at the Chickasha location. In the 2017- 18 crop year, both Chickasha and Lahoma had both opener styles used, while the Perkins location compared two double disk drills, but with dissimilar fertilizer placements. A John Deere 450 double disk grain drill was used, and has a standard double disk opener and applied the fertilizer in the band. The other drill used in Perkins was a Great Plains 1006NT, which is also a double disk drill, but has a wavy opening coulter and does not apply the fertilizer directly into the furrow through the disks. Instead, it dribbles the fertilizer over the surface, but before the closing wheels. By doing this, it results in a partial cover of the fertilizer with soil (Figure 3). At the Lahoma location, a John Deere 1560 double disk and a TYE single disc drill were used. Both of these drills applied the fertilizer in the furrow band. All drills used across all locations were calibrated before each application to ensure accuracy of the rate being applied. Treatment structures for all site- years are detailed in Tables 4- 7.

A 1.5 m by 6 m strip was harvested through the center of each test plot with a Kinkaid 8XP plot combine (Kincaid Equipment Manufacturing; Haven, KS) which collects total plot grain weight, test weight, and moisture through the integrated Harvest Master Yield monitoring system (Juniper Systems; Logan, UT). Sub-samples from each plot were collected at the time of harvesting and labeled for further analysis. A Pertin DA 7200 near infrared spectroscopy Diode Array Analysis System (NIR) machine (Kungens Kurva, Sweden) was used for grain quality analysis. By-plot samples were analyzed for protein, starch, and moisture content. The moisture content collected through the Pertin NIR was used to correct the moisture of the samples to 12.5% thus normalizing the yield.

Data was analyzed using SAS 9.4 (SAS institute) and all comparisons were considered significant at alpha=0.05. Data was first tested through ANOVA methods to check for significance of location and year and location*year interaction. Once determining there was a site-year significance, the effect of the N application by location was evaluated to establish if there was a significant response to N fertilizer. Due to drought conditions and decreased yields it was hypothesized that not all locations would have a significant response. If there was no significant positive response to N, no further analysis would be conducted. Further analysis including testing main effects for time, method, and time by method. In this analysis each drill type and N source were evaluated as a method. Final analysis was done through individual contrasts statements. Contrasts comparing broadcasted urea against each drill by timing, broadcasted AN against each drill by timing, each drill against the other by timing, and finally all urea broadcast applications against each drilled application were tested. Soil moisture and rain data obtained through the Oklahoma Mesonet was used to for visual comparisons and justification of data results.

CHAPTER IV

RESULTS AND DISCUSSION

Result Procedures

This study was designed to evaluate the impact of N source and placement on final grain yield and protein concentration when compared to broadcasted AN, urea, and treated urea sources. Table 8 lists the fertilizer application dates for each location and year. Due to the size of the equipment used in the project, making applications during periods of high soil moisture had to be avoided. Due to an extended wet period only the first and second timings were applied at Perkins and Chickasha in the 2016-2017 growing season. Rainfall totals by month and days until cumulative precipitation was greater than 12.7 mm are displayed in Tables 9 and 10, respectively.

An ANOVA analysis was performed on the data set to determine contribution of location, year and year*location interaction (Table 11). The p-values were considered significant at the 95% confidence level. Location and year were significant with a p value of >0.0001, however there was no significant interaction of year*location. These significance levels indicate that the data should not be combined for analysis across locations, and that each site-year should be analyzed independently for accuracy of the results. Therefore the results will be presented by site-year.

Identifying whether a site-year had a significant response to N application was important, because if no treatment was significantly different than the check, no further analysis was needed. In order to verify that N application had a significant effect and further analysis should be tested, an ANOVA procedure was used on each site-year. Results from the ANOVA procedure can be found in Table 12. Once an N effect was identified, main effects were tested for each site year of interest by yield and protein for time, method, and for time by method. Results from the analysis are in Tables 13- 14. In order to further understand the relationships between treatments, multiple contrast tests were analyzed for each site-year for both grain yield and protein. Contrasts comparing broadcasted urea against each drill by timing, broadcasted AN against each drill by timing, each drill against the other drill by timing, and finally all urea broadcast applications against each drilled application. Each of these contrasts are detailed in Tables 16, 18, 20, 22, 24, and 26 by site- year. Of 134 total contrasts ran, 10 were significant for grain yield and 4 were significant for protein. To present the data, treatment means for both grain yield and protein are shown in Figures 4-9 for each site- year. Soil moisture data throughout the growing season for each site- year is shown in Figures 10-15.

Chickasha 2016-2017

At the Chickasha 2016-17 site year, the application of N had a significant positive effect on yield and protein. The grain yield of the check plot was 1,549 kg ha^{-1} with a protein concentration of 11.6%, while the fertilized plots averaged 3,087 kg ha^{-1} and 12.94% protein. When evaluating main effects, significance was found for time and method for both yield and protein. Timing 1 was found to be higher yielding than timing 2. Protein concentrations were significantly improved in all treatments made in the second application in comparison to the first application. Treatment means and Duncan LSD are displayed in Table 15.

Individual contrasts (Table 16) resulted in three comparisons that were significant in terms of grain yield however no contrasts evaluating treatment impact on protein content showed significance. The no-fertilizer check (1,549 kg ha^{-1}) yielded significantly lower than the rest of the treatments with the exception of the second urea broadcast application, while the highest treatment, the DD drill timing 1, yielded 3,653 kg ha^{-1}. The use of the SD drill significantly increased grain yield above the BC urea by nearly 2,000 kg ha^{-1}. The use of the SD drill also increased grain yield in the second timing over the BC urea by more than 1,100 kg ha^{-1}. The SD drill application yielded 3,572 and 3,343 kg ha^{-1} while BC urea yielded 3,294 and 2,163 kg ha^{-1} for timings 1 and 2, respectively. Unexpectedly, the SD drill application at the second timing was also significantly greater than the BC AN treatment which yielded 2,209 kg ha^{-1}. It is hypothesized that the significant increase due to the use of SD over BC urea and AN may be contributed to an extended dry period which occurred after the second application. This is shown in Figure 10, which displays the soil moisture data collected from the Chickasha mesonet location. The drill would have placed the urea into soil moisture allowing for plant uptake, while the lack of precipitation would be a delayed N incorporation into the rooting zone. The lack of difference between the SD drill and BC SuperU does challenge this hypothesis, as available N from this source should have been even further delayed. There may have been a significant amount of immobilization occurring on and near the soil surface of this no-till field. The urease inhibitor of the SuperU may have delayed urea hydrolysis to the point that N could be moved to the rooting zone. The DD drill which does not fully cover the urea with soil was not significantly different at the second timings when using at alpha=0.05. It should be noted that the DD drill resulted in a grain yield of 2,973 kg ha^{-1} and when contrasted with BC urea, the resulting p value was equal to 0.0793, which could be significant at a level of alpha=0.1.

Chickasha 2017-2018

At the Chickasha 2017-18 site- year, the ANOVA procedure did not indicate treatment had a significant impact on grain yield, however the impact on grain protein content was significant. When evaluating main effects for protein, a statistical impact was observed for grain protein concentration for Time and Method. Later applications resulted in higher protein concentrations.

At this location, the check yielded 3,215 kg ha^{-1} while the mean for fertilized treatments was 3,558 kg grain ha^{-1}. Treatment means and Duncan LSD are shown in Table 17. Analysis of treatments via the t Tests (LSD) for grain yield revealed that AN in timing 2 significantly increased yield above the fertilized check. In all timings AN did increase yield, however it was Super U, BC Urea, and DD Drill that increased yield in timing 1,2,3 respectively. The only other significance found in the LSD test was that the grain yield from the SD drill treatment (3,362 kg ha^{-1}) was significantly less than that of the AN treatment (3,901 kg ha^{-1}) at the second timing. Contrast also detected this difference in grain protein content as the AN resulted in protein values significantly greater than the SD Drill at the second timing of 14.9 and 14.1% respectfully.

All fertilized treatments were statistically higher than the check, which only contained 11.7% protein. This high response of protein and low response in yield relationship is most likely due to the lower rainfall amounts that occurred from mid to late in the growing season, effectively causing stress to the plant during the reproduction stages (Dupont et al., 2006). This scenario effectively lowered the starch accumulation throughout the treatments, and raised the protein accumulation in the grain.

While there were no significant responses of individual contrasts (Table 18) comparing urea to either of the drills used in this site- year, several observations can be made when comparing the two using the soil moisture data shown in Figure 11. Timings 1 and 3 were both applied when soil moisture was at its highest and followed by a period of no rainfall for 42 and 23 days, respectively. In these two timings, the drilled treatments yielded higher than the broadcasted urea treatments. In timing 2, the treatments were applied at a time of low soil moisture and received rain 13 days after application. Urea yielded higher than the double disc and single disc by 115 and 312 kg ha^{-1}, respectively. While only marginally higher than the drilled treatments, it does highlight a difference seen among the timings.

Lahoma 2016-2017

At the Lahoma 2016-17 location, the application of N had a statistical effect on final grain yield (Pr >F= 0.0114) and grain protein concentration (Pr>F= 0.0400). When evaluating main effects, a statistical impact was observed in grain yield for time and method. This was due to the non-fertilized check being included in the analysis. No main effect significance was observed for grain protein concentration. Treatment means and Duncan LSD is shown in Table 19.

No individual contrasts among treatments for grain yield and protein concentrations were found to be significant (Table 20). This location had a mean yield of 6,890 kg ha $^{-1}$ while the non-fertilized check harvested 6,111 kg ha^{-1} of grain. The highest yielding treatment was Super U at the third application timing, and this treatment averaged 7,209 kg ha^{-1}. This grain yield increase of 1,098 kg ha^{-1} would theoretically only need 35 kg ha^{-1} of additional N to meet the maximum yield in this site-year according to the standard 2.24 kg N of per 67.25 kg of grain. Based on this assumption, we can hypothesize that 67.25 kg ha^{-1} of N was not limiting in this particular site-year. Therefore, differences in NUE among treatments would have been masked by the over application of N beyond crop demand.

Lahoma 2017-2018

At the Lahoma 2017-18 site-year, the application of N had a significant effect on final grain yield and grain protein concentration. The non-fertilized check treatment resulted in a grain yield of 2,339 kh ha^{-1} with a grain protein concentration of 10.1%. The fertilized treatments had an average yield of 3,170.0 kg ha^{-1} with a grain protein content of 12.4%. When evaluating main effects, a statistical impact on time and method was seen for grain yield and grain protein concentration. Grain protein concentrations were increased in the last timing. The yield significance for time is due to the non- fertilized check being included in the analysis. Treatment means and Duncan LSD is shown in Table 21.

Testing individual contrasts (Table 22) revealed one grain yield comparison of significance, and one protein comparison of significance. Significance was found at the third timing for the SD drill vs DD drill. The DD drill yielded 3,281 kg ha^{-1} while the single disc yielded 2,856 kg ha^{-1}. At the second timing BC urea had a higher protein value than the SD drill, protein concentration of the two treatments was 12.3% and 11.3%, respectively. The grain yield of the DD drill was statistically better than the SD drill across all times with a yield of 3,311 kg ha^{-1} as opposed to the SD drill yield of 2,979 kg ha^{-1}. When comparing the two drills, the DD drill out yielded the SD drill in every timing. This could be attributed to a better closure that was achieved through the double disc drill. This poor closure may have also contributed to the BC urea treatment out yielding the SD drill when compared across all timings. It should also be noted that much like the Lahoma 2016-17 site-year, the response to N was low, and it is likely 67.25 kg ha^{-1} was greater than crop demand.

Perkins 2016-2017

At the Perkins 2016-17 site-year, the application of N had a significant effect on final grain yield, but not on grain protein concentration. The non-fertilized check harvested 1,373 kg ha^{-1} while the fertilized plots averaged 3,246 kg grain ha^{-1}. The grain protein concentration of the check and fertilized plots was 10% and 10.94% respectively. Evaluation of main effects revealed a statistical impact of time and method on grain yield due to the non-fertilized check being included in the analysis. Time did impact grain protein concentration, however method did not. See Table 23 for grain yield and grain protein treatment averages and Duncan LSD analysis.

Contrasts (Table 24) for timing 2 BC urea vs. AN and DD drill vs AN were both significant as AN out yielded both methods of urea application by 913 kg ha^{-1} and 950 kg ha^{-1} respectively. In the contrast of methods across the two timings, AN out yielded BC urea 3,841 to 3,436 kg ha^{-1} at the first timing and 3,566 kg ha^{-1} to 2,652 kg ha^{-1}at the second timing. As AN is not subject to volatilization, and was used as a check in this study because of this, it helps to explain the differences in yield between the BC urea and AN treatments.

Perkins 2017-2018

At the Perkins 2017-18 site-year, the application of N had a significant effect on final grain yield and grain protein concentration. The non-fertilized check harvested 2,187 kg grain ha^{-1} with a grain protein concentration of 10.5. The fertilized treatments average 3,602 kg grain ha^{-1} with a grain protein concentration of 13.3%. However , evaluating main effects, significance was found for both grain yield and grain protein concentration for both time and method due to the non-fertilized check being included in the analysis.

Duncan LSD (Table 25) and individual contrasts (Table 26) revealed no difference in grain yield among fertilized treatments, but there was one significant contrast for grain protein at the first timing. The BC urea treatment had a protein concentration of 12.2%, while the Super U treatment contained 13.2% protein. The contrast of BC urea and DDO drill for grain protein showed a positive impact of DDO drill. The DDO drill resulted in protein concentration of 12.9, 13.7, and 14.4% across the three timings while the BC urea treatment produced 12.2, 13.0, and 13.8% grain protein concentration across the three applications.

While not significantly different, a trend is seen when comparing the two drills against each other. DDI was consistently higher yielding than DDO. Complete cover of the fertilizer with soil was not achieved with the DDO drill, effectively leaving some of the urea vulnerable to volatilization on the surface. Because there was a decrease in grain yield, it effectively lowered the starch accumulation in the seed. When there is a decrease in starch, there is a possibility that protein concentration can be increased, which is what was observed between the two drills. Although there was a higher protein concentration, the total protein content was less, because there was less total grain harvested with the DDO drill. Much like both years at Lahoma, based upon the grain yield increase due to N application, 67.25 kg ha^{-1} was likely above crop demand and many of the potential differences in NUE would have been masked.

CHAPTER V

Conclusions

This study was initiated to evaluate the impact of fertilizer source and placement on winter wheat grain yield and protein concentration. It was hypothesized that placing urea below the soil surface in season with the use of a grain drill would increase both final grain yield and protein concentration when compared to broadcasted urea. It was also hypothesized that the use of a protected urea source would have a positive effect on grain yield and protein when compared to the broadcast urea check. There was concern that the grain drills could create enough disturbance and plant damage, that its implementation would significantly decrease yields. The results of this study suggested that using a grain drill during the growing season did not have a negative impact in any of the site-years for grain yield or grain protein content.

To compare methods and source of N application at each site-year, 113 contrasts were tested. Of these contrasts, six were found to be significant for treatment impact on grain yield and three significant contrasts were found for protein concentration. In 21 contrasts of drilled treatments by BC urea, only one was significant. However, the AN treatment was only statistically greater than BC urea in one comparison and SuperU was never statistically greater. These results were somewhat surprising as the BC urea out yielded (numerically) AN in three of the six site years, while SuperU out yielded BC urea in all but one location (Lahoma 2016-17).

When the average grain yields of each method were converted to percent of BC urea by location, the results showed that the use of a grain drill resulted in equivalent or better yields than

BC urea for six of the 10 comparisons. The SD drill had two locations with improved yield and two locations with grain yield less than BC urea, while the DD drill had four of six locations with yields greater then BC urea. Both drills combined averaged 5.5% higher grain yield than BC urea, comprising from the DD drill which had a 3.8% increase and the SD drill with an 8% increase. The study's average grain yield for the BC urea treatment was 3,848 kg ha^{-1}, which means the use of the SD drill on average increased yields by 308 kg ha^{-1}. It should be noted that AN increased yield by 3% and SuperU by 4%.

As was noted several drills were used across the locations, and as a result, several observations were made about the impact of soil environments on the placement and row closure of the drills that were used. Soil moisture and the ability of the grain drill to put sufficient down pressure on the openers were the two largest factors affecting complete cover of the urea with soil. This was best seen in the Kinkaid DD drill used at the Chickasha location, as it was attached to the tractor with a quick-hitch system and consequently lacked enough weight for proper down pressure in dry conditions to both create a furrow and then cover the furrows created. When there was sufficient soil moisture, the mechanical effects were alleviated in most cases and the drill was able to sufficiently cover the urea with soil. In the case of the Great Plains DDO drill used in Perkins 2017-18 an open furrow of the soil was achieved, but complete cover of the urea was not possible due to the drills design. Drills such as the John Deere 450 used at the Perkins location, rely on the closing wheel to control depth. Under certain cases of uneven terrain, there were times when the opener was not able to completely place the fertilizer beneath the soil surface because of this. The results of this study lead us to believe that the primary factor controlling the effectiveness of the drill to increase grain yield is not the necessarily the drill type that is used, but the rather the ability of the drill to properly place the N fertilizer beneath the soil surface with proper cover. Proper cover of the urea with soil has shown to have a positive benefit in this study, and when 100% of the urea is covered the results could potentially be higher for the drilled applications.

Considering in this experiment the rate of N applied was 67.25 kg N ha^{-1} which would have accounted for an increase of 1,607 kg grain per ha^{-1}, and only four locations had a response to N application of that level, the results for use of a grain drill are quite promising. At the one location (Chickasha 2016-17) with the environment most conducive to N loss and greatest response to N fertilizer, the SD drill increased grain yield by 41% or 729 kg ha^{-1}, while the DD drill increased yield by 21% or 585 kg ha^{-1}. Further research is needed however to better understand the impact of grain drill type and soil conditions of the probability of a positive response.

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TABLES

Table 1. Soil series classifications for each of the three experimental site locations (Chickasha, Lahoma, and Perkins) utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma over the 2016-2017 and 2017-2018 growing seasons. Soil Series and Description was obtained through the web soil survey (Soil survey staff, Natural Resource Conservation Service, United States Department of Ag).

Location/ Year	Soil Series and Description	Previous Crop
Perkins 2017	Teller; (fine-loamy, mixed, active, thermic Udic Agriustoll)	Wheat
Lahoma 2017 - 2018	Grant; (Fine-silty, mixed, superactive, thermic Udic Argiustolls)	Wheat
Chickasha 2017	McLain; (fine, mixed, superactive, thermic Pachic Argiustolls)	Wheat
Perkins 2018	Konawa; (fine-loamy, mixed, active, thermic Ultic Haplustalf) Teller; (fine-loamy, mixed, active, thermic Udic Agriustoll)	Wheat
Chickasha 2018	Dale; (fine- silty, mixed, superactive, thermic Pachic Haplustolls)	Wheat

Table 2. Soil test results for pH, buffer index, nitrogen, phosphorus, potassium, sulfate, calcium, magnesium, iron, boron, copper, and organic matter concentrations in the 0-15 cm zone for each of the three experimental site locations (Chickasha, Lahoma, and Perkins) utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma over the 2016-2017 and 2017-2018 growing seasons.

Location/Year	pH	BI	N	K	SO_4	Ca	Mg	P	Fe	Zn	B	Cu	OM
Unit			kg ha^{-1}					ppm					g kg^{-1}
Perkins 2017	5.6	6.6	31	193	14	667	178	18	27.6	0.4	0.1	1.1	11
Lahoma 2017	5.0	6.8	45	489	16	1828	571	34	na	na	na	na	na
Chickasha 2017	6.6	na	25	512	17	5322	1781	32	47.9	1.4	0.42	1.5	na
Perkins 2018	4.7	6.7	18	270	2	1180	267	34	na	na	na	na	na
Lahoma 2018	5.6	7.0	20	278	7	2424	390	25	na	na	na	na	na
Chickasha 2018	5.8	7	19	325	10	3148	989	22	na	na	na	na	na

Table 3. Planting dates, seeding rate, and seed variety for each of the three experimental site locations (Chickasha, Lahoma, and Perkins) utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma over the 2016-2017 and 2017-2018 growing seasons.

Trial/ year	Planting Date	Seeding Rate (kg ha-1)	Seed Variety
Perkins 2017	10/13/2016	84	Double Stop
Lahoma 2017	10/15/2016	67	Bentley
Chickasha 2017	10/10/2016	73	Ruby Lee
Perkins 2018	10/12/2017	84	Double Stop
Lahoma 2018	10/12/2017	84	Bentley
Chickasha 2018	10/13/2017	84	Ruby Lee

Table 4. Treatment structure utilized at the Lahoma location for the 2016-2017 growing season in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma over the 2016-2017 and 2017-2018 growing seasons.

trt	Source	Place	Time	Total N (kg ha^{-1})
1	Check			0
2	Urea	Single Disc	1	67.25
3	Urea	Broadcast	1	67.25
4	Super U	Broadcast	1	67.25
5	AN 34-0-0	Broadcast	1	67.25
6	Urea	Single Disc	2	67.25
7	Urea	Broadcast	2	67.25
8	Super U	Broadcast	2	67.25
9	AN 34-0-0	Broadcast	2	67.25
10	Urea	Single Disc	3	67.25
11	Urea	Broadcast	3	67.25
12	Super U	Broadcast	3	67.25
13	AN 34-0-0	Broadcast	3	67.25

Table 5. Treatment structure utilized at the Perkins locations for the 2016-2017 growing season in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma over the 2016-2017 and 2017-2018 growing seasons.

trt	Source	Place	Time	Total N (kg ha^{-1})
1	Check			0
2	Urea	Double Disc	1	67.25
3	Urea	Broadcast	1	67.25
4	Super U	Broadcast	1	67.25
5	AN 34-0-0	Broadcast	1	67.25
6	Urea	Double Disc	2	67.25
7	Urea	Broadcast	2	67.25
8	Super U	Broadcast	2	67.25
9	AN 34-0-0	Broadcast	2	67.25
10	Urea	Double Disc	3	67.25
11	Urea	Broadcast	3	67.25
12	Super U	Broadcast	3	67.25
13	AN 34-0-0	Broadcast	3	67.25

Table 6. Treatment structure utilized in the Chickasha 2016-2017 location as well as the Lahoma and Chickasha locations for the 2017-2018 growing season in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma over the 2016-2017 and 2017-2018 growing seasons.

trt	**Source**	**Place**	**Time**	**Total N (kg ha^{-1})**
1	Check			0
2	Urea	Single Disc	1	67.25
3	Urea	Double Disc	1	67.25
4	Urea	Broadcast	1	67.25
5	Super U	Broadcast	1	67.25
6	AN 34-0-0	Broadcast	1	67.25
7	Urea	Single Disc	2	67.25
8	Urea	Double Disc	2	67.25
9	Urea	Broadcast	2	67.25
10	Super U	Broadcast	2	67.25
11	AN 34-0-0	Broadcast	2	67.25
12	Urea	Single Disc	3	67.25
13	Urea	Double Disc	3	67.25
14	Urea	Broadcast	3	67.25
15	Super U	Broadcast	3	67.25
16	AN 34-0-0	Broadcast	3	67.25

Table 7. Treatment structure utilized at the Perkins location for the 2017-2018 growing season in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma over the 2016-2017 and 2017-2018 growing seasons.

Trt	Source	Place	Time	Total N
1	Check			0
2	Urea	Double Disc- in furrow	1	67.25
3	Urea	Double Disc- over furrow	1	67.25
4	Urea	Broadcast	1	67.25
5	Super U	Broadcast	1	67.25
6	AN 34-0-0	Broadcast	1	67.25
7	Urea	Double Disc- in furrow	2	67.25
8	Urea	Double Disc- over furrow	2	67.25
9	Urea	Broadcast	2	67.25
10	Super U	Broadcast	2	67.25
11	AN 34-0-0	Broadcast	2	67.25
12	Urea	Double Disc- in furrow	3	67.25
13	Urea	Double Disc- over furrow	3	67.25
14	Urea	Broadcast	3	67.25
15	Super U	Broadcast	3	67.25
16	AN 34-0-0	Broadcast	3	67.25

Table 8. Dates of nitrogen fertilizer application for each of the three experimental site locations (Chickasha, Lahoma, and Perkins) utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma over the 2016-2017 and 2017-2018 growing seasons

Site Year	**Timing 1**	**Timing 2**	**Timing 3**
Chickasha 2016-17	1/27/17	2/28/17	n/a
Chickasha 2017-18	1/9/18	2/8/18	3/6/18
Lahoma 2016-17	1/24/17	2/10/17	3/6/17
Lahoma 2017- 18	1/10/18	2/8/18	3/13/18
Perkins 2016-17	1/23/17	2/23/17	n/a
Perkins 2017-18	1/8/18	2/5/18	3/3/18

Table 9. Rainfall totals (mm) by month for each site-year for each of the three experimental site locations (Chickasha, Lahoma, and Perkins) utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma over the 2016-2017 and 2017-2018 growing seasons.

Site-Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	Total
Chickasha 2016-17	89	7	70	23	45	70	108	131	57	600
Chickasha 2017-18	152	88	3	28	4	75	14	43	164	571
Lahoma 2016-17	132	65	9	10	60	53	80	148	82	639
Lahoma 2017-18	54	58	4	2	0	34	24	0	80	253
Perkins 2016-17	60	54	55	12	67	50	60	230	101	690
Perkins 2017-18	69	144	7	16	4	83	20	66	100	507

Table 10. Days after application until cumulative precipitation greater than 12.7 mm after date of application for each of the three experimental site locations (Chickasha, Lahoma, and Perkins) utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma over the 2016-2017 and 2017-2018 growing seasons. Days until rain event was calculated using Mesonet (www.mesonet.org; Norman, OK) rain data.

Site-year	**Timing 1**	**Timing 2**	**Timing 3**
Chickasha 2016-17	17	29	n/a
Chickasha 2017-18	42	13	23
Lahoma 2016-17	20	5	22
Lahoma 2017-18	42	14	5
Perkins 2016-17	21	8	n/a
Perkins 2017-18	40	12	24

Table 11. ANOVA table produced by SAS 9.4 comparing all locations and years data for each of the three experimental site locations (Chickasha, Lahoma, and Perkins) utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma over the 2016-2017 and 2017-2018 growing seasons.

Source	**DF**	**ANOVA SS**	**Mean Square**	**F Value**	**Pr > F**
Location	2	156831020.5	78415510.3	70.19	<.0001*
Year	1	112655700.5	112656700.5	100.84	<.0001*

Table 12. Results of an ANOVA procedure of each site year testing N treatment effects for each of the three experimental site locations (Chickasha, Lahoma, and Perkins) utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma over the 2016-2017 and 2017-2018 growing seasons.

Site- Year	**Pr > F Yield**	**Pr > F Protein**
Chickasha 2016-17	<.0001	<.0001
Chickasha 2017- 18	0.1296	<.0001
Lahoma 2016- 17	0.0114	0.0400
Lahoma 2017- 18	0.0003	<.0001
Perkins 2016- 17	<.0001	0.1067
Perkins 2017- 18	0.0152	<.0001

Table 13. Main effects testing for yield for each of the three experimental site locations (Chickasha, Lahoma, and Perkins) utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma over the 2016-2017 and 2017-2018 growing seasons.

Site- Year	**Pr > F Time**	**Pr > F Method**	**Pr > F Time x Method**
Chickasha 2016-17	<.0001	<.0001	1.0000
Chickasha 2017-18	.1096	.0506	1.0000
Lahoma 2016-17	<.0001	<.0001	1.0000
Lahoma 2017-18	<.0001	<.0001	1.0000
Perkins 2016-17	<.0001	<.0001	1.0000
Perkins 2017-18	<.0001	<.0001	1.0000

Table 14. Main effects for protein for each of the three experimental site locations (Chickasha, Lahoma, and Perkins) utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma over the 2016-2017 and 2017-2018 growing seasons.

Site- Year	**Pr > F Time**	**Pr > F Method**	**Pr > F Time x Method**
Chickasha 2016-17	<.0001	<.0001	1.0000
Chickasha 2017-18	<.0001	<.0001	1.0000
Lahoma 2016-17	0.3348	0.6270	0.9958
Lahoma 2017-18	<.0001	<.0001	1.0000
Perkins 2016-17	0.0231	0.4788	0.5317
Perkins 2017-18	<.0001	<.0001	1.0000

Table 15. Treatment means and protein concentrations with Duncan Grouping for Chickasha 2016-17 utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma.

Treatment	**Description**	**Time**	**Yield Means (kg ha^{-1})**	**Duncan Grouping**	**Protein Means (%)**	**Duncan Grouping**
1	Check	0	1549.5	C	11.6	F
2	Single Disc	1	3572.5	A	11.9	EF
3	Double Disc	1	3653.5	A	12.3	DEF
4	Urea	1	3294.8	A	12.5	CDEF
5	Super U	1	3558.3	A	12.8	BCDE
6	AN	1	3307.3	A	12.5	CDEF
7	Single Disc	2	3343.5	A	13.9	A
8	Double Disc	2	2973.8	AB	13.5	ABC
9	Urea	2	2163.0	BC	13.3	ABCD
10	Super U	2	2792.8	AB	13.7	AB
11	AN	2	2209.3	BC	13.3	ABC

Table 16. Table of individual contrasts by treatment of final grain yield and protein concentration for Chickasha 2016-17 utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma. Significance at the p = 0.95 level indicated by *.

Trt Contrast	Description (Method, Time)	P Value Yield (kg ha^{-1})	P Value Protein (%)
4 vs 2	Urea vs SD 1	.5394	.1581
4 vs 3	Urea vs DD 1	.4288	.6066
4 vs 5	Urea vs Super U 1	.5603	.6066
4 vs 6	Urea vs AN 1	.9779	.9087
9 vs 7	Urea vs SD 2	.0127*	.1426
9 vs 8	Urea vs DD 2	.0793	.6470
9 vs 10	Urea vs Super U 2	.1690	.3621
9 vs 11	Urea vs AN 2	.9184	.9087
6 vs 2	AN vs SD 1	.5577	.1931
6 vs 3	AN vs DD 1	.4449	.6886
6 vs 5	AN vs Super U 1	.5789	.5295
11 vs 7	AN vs SD 2	.0162*	.1749
11 vs 8	AN vs DD 2	.0972	.7311
11 vs 10	AN vs Super U 2	.2016	.4245
2 vs 3	SD vs DD 1	.8576	.3621
7 vs 8	SD vs DD 2	.4149	.3060
2,7 vs 3,8	SD vs DD 1,2	.5514	.9354
4,9 vs 6,11	Urea vs AN 1,2	.9266	1.000
4,9 vs 2,7	Urea vs SD 1,2	.0277*	.9677
4,9 vs 3,8	Urea vs DD 1,2	.0738	.9677

Table 17. Treatment means and protein concentrations with Duncan Grouping for Chickasha 2017-18 utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma.

Treatment	Description	Time	Yield Means (kg ha^{-1})	Duncan Grouping	Protein Means (%)	Duncan Grouping
1	Check	0	3215.8	B	11.7	C
2	Single Disc	1	3491.5	AB	14.2	AB
3	Double Disc	1	3654.8	AB	14.8	AB
4	Urea	1	3586.5	AB	14.3	AB
5	Super U	1	3718.3	AB	15.0	A
6	AN	1	3679.8	AB	14.5	AB
7	Single Disc	2	3362.8	B	14.7	AB
8	Double Disc	2	3559.5	AB	15.2	A
9	Urea	2	3674.5	AB	14.2	AB
10	Super U	2	3472.3	AB	14.9	AB
11	AN	2	3901.0	A	14.0	AB
12	Single Disc	3	3473.3	AB	14.1	AB
13	Double Disc	3	3678.7	AB	13.5	B
14	Urea	3	3317.5	B	14.5	AB
15	Super U	3	3554.0	AB	15.1	A
16	AN	3	3706.5	AB	14.9	A

Table 18. Table of individual contrasts by treatment of final grain yield and protein concentration for Chickasha 2017-18 utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma. Significance at the p = 0.95 level indicated by *.

Trt Contrast	Description (Method, Time)	P Value Yield (kg ha^{-1})	P Value Protein (%)
4 vs 2	Urea vs SD 1	.6657	.9661
4 vs 3	Urea vs DD 1	.7562	.3309
4 vs 5	Urea vs Super U 1	.5495	.2064
4 vs 6	Urea vs AN 1	.6715	.6406
9 vs 7	Urea vs SD 2	.1604	.4458
9 vs 8	Urea vs DD 2	.6012	.1114
9 vs 10	Urea vs Super U 2	.3595	.2377
9 vs 11	Urea vs AN 2	.3422	.7234
14 vs 12	Urea vs SD 3	.4796	.4458
14 vs 13	Urea vs DD 3	.1328	.1117
14 vs 15	Urea vs Super U 3	.2847	.3521
14 vs 16	Urea vs AN 3	.0816	.4458
6 vs 2	AN vs SD 1	.3934	.6106
6 vs 3	AN vs DD 1	.9094	.6106
6 vs 5	AN vs Super U 1	.8609	.4211
11 vs 7	AN vs SD 2	.0272*	.2911
11 vs 8	AN vs DD 2	.1547	.0695
11 vs 10	AN vs Super U 2	.0758	.1502
16 vs 12	AN vs SD 3	.9066	.0241*
16 vs 13	AN vs DD 3	.0816	.4458
16 vs 15	AN vs Super U 3	.4887	.8650
2 vs 3	SD vs DD 1	.4588	.3105
7 vs 8	SD vs DD 2	.3726	.3972
12 vs 13	SD vs DD 3	.3886	.3677
2,7,12 vs 3,8,13	SD vs DD 1,2,3	.1527	.6165
4,9,14 vs 6,11,16	Urea vs AN 1,2,3	.0748	.6333
4,9,14 vs 2,7,12	Urea vs SD 1,2,3	.5105	.9804
4,9,14 vs 3,8,13	Urea vs DD 1,2,3	.4229	.6333

Table 19. Treatment means and protein concentrations with Duncan Grouping for Lahoma 2016-17 utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma.

Treatment	Description	Time	Yield Means (kg ha^{-1})	Duncan Grouping	Protein Means (%)	Duncan Grouping
1	Check	0	6111.8	B	9.2	A
2	Single Disc	1	7077.8	A	10.2	A
3	Urea	1	6776.5	A	9.8	A
4	Super U	1	6990.8	A	9.3	A
5	AN	1	6802.0	A	9.7	A
6	Single Disc	2	7137.5	A	10.2	A
7	Urea	2	6946.8	A	10.2	A
8	Super U	2	6694.5	A	10.6	A
9	AN	2	6749.3	A	9.9	A
10	Single Disc	3	7025.8	A	10.0	A
11	Urea	3	7007.0	A	9.6	A
12	Super U	3	7209.3	A	9.8	A
13	AN	3	7050.3	A	10.3	A

Table 20. Table of individual contrasts by treatment of final grain yield and protein concentration for Lahoma 2016-17 utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma. Significance at the p = 0.95 level indicated by *.

Trt Contrast	Description (Method, Time)	P Value Yield (kg ha^{-1})	P Value Protein (%)
3 vs 2	Urea vs SD 1	.2288	.5218
3 vs 4	Urea vs Super U 1	.3898	.5451
3 vs 5	Urea vs AN 1	.9181	.9715
7 vs 6	Urea vs SD 2	.4435	.9715
7 vs 8	Urea vs Super U 2	.3122	.5689
7 vs 9	Urea vs AN 2	.4276	.7214
11 vs 10	Urea vs SD 3	.9397	.5689
11 vs 12	Urea vs Super U 3	.4167	.7483
11 vs 13	Urea vs AN 3	.8616	.3382
5 vs 2	AN vs SD 1	.2699	.4990
5 vs 4	AN vs Super U 1	.4482	.5689
9 vs 6	AN vs SD 2	.1231	.6950
9 vs 8	AN vs Super U 2	.8253	.3562
11 vs 12	Urea vs Super U 3	.9213	.6950
11 vs 13	Urea vs AN 3	.5225	.5218
3,7,11 vs 5,9,13	Urea vs AN 1,2,3	.7645	.7419
3,7,11 vs 2,6,10	Urea vs SD 1,2,3	.2386	.4723

Table 21. Treatment means and protein concentrations with Duncan Grouping for Lahoma 2017-18 utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma.

Treatment	**Description**	**Time**	**Yield Means (kg ha^{-1})**	**Duncan Grouping**	**Protein Means (%)**	**Duncan Grouping**
1	Check	0	2339.0	C	10.1	E
2	Single Disc	1	3041.3	AB	12.2	ABCD
3	Double Disc	1	3297.8	AB	11.7	BCD
4	Urea	1	3270.0	AB	12.3	ABCD
5	Super U	1	3120.0	AB	12.1	ABCD
6	AN	1	3111.8	AB	12.1	ABCD
7	Single Disc	2	3039.5	AB	11.3	D
8	Double Disc	2	3354.8	AB	11.7	BCD
9	Urea	2	3354.3	AB	12.3	ABCD
10	Super U	2	2967.3	AB	11.5	CD
11	AN	2	3159.3	AB	11.9	BCD
12	Single Disc	3	2856.5	B	12.6	AB
13	Double Disc	3	3281.5	AB	13.0	A
14	Urea	3	3124.5	AB	12.3	ABCD
15	Super U	3	3400.3	A	12.5	ABC
16	AN	3	3169.3	AB	12.7	AB

Table 22. Table of individual contrasts by treatment of final grain yield and protein concentration for Lahoma 2017-18 utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma. Significance at the p = 0.95 level indicated by *.

Trt Contrast	**Description (Method, Time)**	**P Value Yield (kg ha^{-1})**	**P Value Protein (%)**
4 vs 2	Urea vs SD 1	.2742	.7835
4 vs 3	Urea vs DD 1	.8938	.1735
4 vs 5	Urea vs Super U 1	.4718	.6212
4 vs 6	Urea vs AN 1	.4479	.6604
9 vs 7	Urea vs SD 2	.1346	.0319*
9 vs 8	Urea vs DD 2	.9981	.2098
9 vs 10	Urea vs Super U 2	.0674	.0663
9 vs 11	Urea vs AN 2	.3504	.3809
14 vs 12	Urea vs SD 3	.2012	.4759
14 vs 13	Urea vs DD 3	.4515	.0931
14 vs 15	Urea vs Super U 3	.1887	.5461
14 vs 16	Urea vs AN 3	.8296	.3521
6 vs 2	AN vs SD 1	.7347	.8690
6 vs 3	AN vs DD 1	.3729	.3521
6 vs 5	AN vs Super U 1	.9683	.9562
11 vs 7	AN vs SD 2	.5653	.1910
11 vs 8	AN vs DD 2	.3492	.7006
11 vs 10	AN vs Super U 2	.3578	.3248
16 vs 12	AN vs SD 3	.5898	.4429
16 vs 13	AN vs DD 3	.8296	.3521
16 vs 15	AN vs Super U 3	.2696	.7416
2 vs 3	SD vs DD 1	.2209	.2745
7 vs 8	SD vs DD 2	.1340	.3521
12 vs 13	SD vs DD 3	.0453*	.3248
2,7,12 vs 3,8,13	SD vs DD 1,2,3	.0077*	.6344
4,9,14 vs 6,11,16	Urea vs AN 1,2,3	.3934	.8242
4,9,14 vs 2,7,12	Urea vs SD 1,2,3	.0280*	.3123
4,9,14 vs 3,8,13	Urea vs DD 1,2,3	.6074	.5900

Table 23. Treatment means and protein concentrations with Duncan Grouping for Perkins 2016-17 utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma.

Treatment	Description	Time	Yield Means (kg ha^{-1})	Duncan Grouping	Protein Means (%)	Duncan Grouping
1	Check	0	1373.3	D	10.5	A
2	Double Disc	1	3264.7	ABC	10.63	A
3	Urea	1	3436.3	AB	10.3	A
4	Super U	1	3373.7	ABC	10.3	A
5	AN	1	3841.0	A	10.9	A
6	Double Disc	2	2716.3	BC	10.87	A
7	Urea	2	2652.7	C	11.23	A
8	Super U	2	3113.3	ABC	11.7	A
9	AN	2	3566.3	A	11.6	A

Table 24. Table of individual contrasts by treatment of final grain yield and protein concentration for Perkins 2016-17 utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma. Significance at the p = 0.95 level indicated by *.

Trt Contrast	Description (Method, Time)	P Value Yield (kg ha^{-1})	P Value Protein (%)
3 vs 2	Urea vs DD 1	0.5981	0.6012
3 vs 4	Urea vs Super U 1	0.8469	1.0000
3 vs 5	Urea vs AN 1	0.2220	0.3510
7 vs 6	Urea vs DD 2	0.8445	0.5657
7 vs 8	Urea vs Super U 2	0.1670	0.4660
7 vs 9	Urea vs AN 2	0.0105*	0.5657
5 vs 2	AN vs DD 1	0.0883	0.6754
5 vs 4	AN vs Super U 1	0.1612	0.3510
9 vs 6	AN vs DD 2	0.0160*	0.2571
9 vs 8	AN vs Super U 2	0.1738	0.8750
3,7 vs 5,9	Urea vs AN 1,2	0.0093*	0.2897
3,7 vs 2,6	Urea vs DD 1,2	0.8140	0.9704

Table 25. Treatment means and protein concentrations with Duncan Grouping for Perkins 2017-18 utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma.

Treatment	**Description**	**Time**	**Yield Means (kg ha^{-1})**	**Duncan Grouping**	**Protein Means (%)**	**Duncan Grouping**
1	Check	0	2181.7	B	10.5	E
2	Double Disc-In Furrow	1	3705.3	A	12.7	DC
3	Double Disc-Over Furrow	1	3632.3	A	12.9	DC
4	Urea	1	3560.7	A	12.2	D
5	Super U	1	3663.3	A	13.2	BCD
6	AN	1	3446.7	A	12.9	DC
7	Double Disc-In Furrow	2	4021.7	A	13.2	BCD
8	Double Disc-Over Furrow	2	3441.7	A	13.7	ABC
9	Urea	2	3470.3	A	13.0	CD
10	Super U	2	4101.7	A	13.1	BCD
11	AN	2	3605.7	A	13.6	ABC
12	Double Disc-In Furrow	3	3358.0	A	13.6	ABC
13	Double Disc-Over Furrow	3	3300.3	A	14.4	A
14	Urea	3	3727.7	A	13.8	ABC
15	Super U	3	3436.3	A	13.4	ABCD
16	AN	3	3556.7	A	14.2	AB

Table 26. Table of individual contrasts by treatment of final grain yield and protein concentration for Perkins 2017-18 utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma. Significance at the p = 0.95 level indicated by *.

Trt Contrast	**Description (Method, Time)**	**P Value Yield (kg ha^{-1})**	**P Value Protein (%)**
4 vs 2	Urea vs DD-I 1	.6921	.3755
4 vs 3	Urea vs DD-O 1	.8443	.1764
4 vs 5	Urea vs Super U 1	.7786	.0462*
4 vs 6	Urea vs AN 1	.7549	.1563
9 vs 7	Urea vs DD-I 2	.1376	.7319
9 vs 8	Urea vs DD-O 2	.9374	.1764
9 vs 10	Urea vs Super U 2	.0908	.7839
9 vs 11	Urea vs AN 2	.7110	.1984
14 vs 12	Urea vs DD-I 3	.3149	.6317
14 vs 13	Urea vs DD-O 3	.2466	.2224
14 vs 15	Urea vs Super U 3	.4269	.3755
14 vs 16	Urea vs AN 3	.6399	.4526
6 vs 2	AN vs DD-I 1	.4801	.5841
6 vs 3	AN vs DD-O 1	.6116	.9453
6 vs 5	AN vs Super U 1	.5537	.5382
11 vs 7	AN vs DD-I 2	.2591	.3404
11 vs 8	AN vs DD-O 2	.6536	.9453
11 vs 10	AN vs Super U 2	.1802	.3075
16 vs 12	AN vs DD-I 3	.4841	.6317
16 vs 13	AN vs DD-O 3	.6399	.4526
16 vs 15	AN vs Super U 3	.7418	.1069
2 vs 3	DD-I vs DD-O 1	.8415	.6317
7 vs 8	DD-I vs DD-O 2	.1190	.3075
12 vs 13	DD-I vs DD-O 3	.8744	.0936
2,7,12 vs 3,8,13	DD-I vs DD-O 1,2,3	.2655	.0698
4,9,14 vs 6,11,16	Urea vs AN 1,2,3	.8129	.0501
4,9,14 vs 2,7,12	Urea vs DD-I 1,2,3	.6064	.6636
4,9,14 vs 3,8,13	Urea vs DD-O 1,2,3	.5443	.0272*

Figure 1. Nitrogen Cycle (Zhang and Raun 2006)

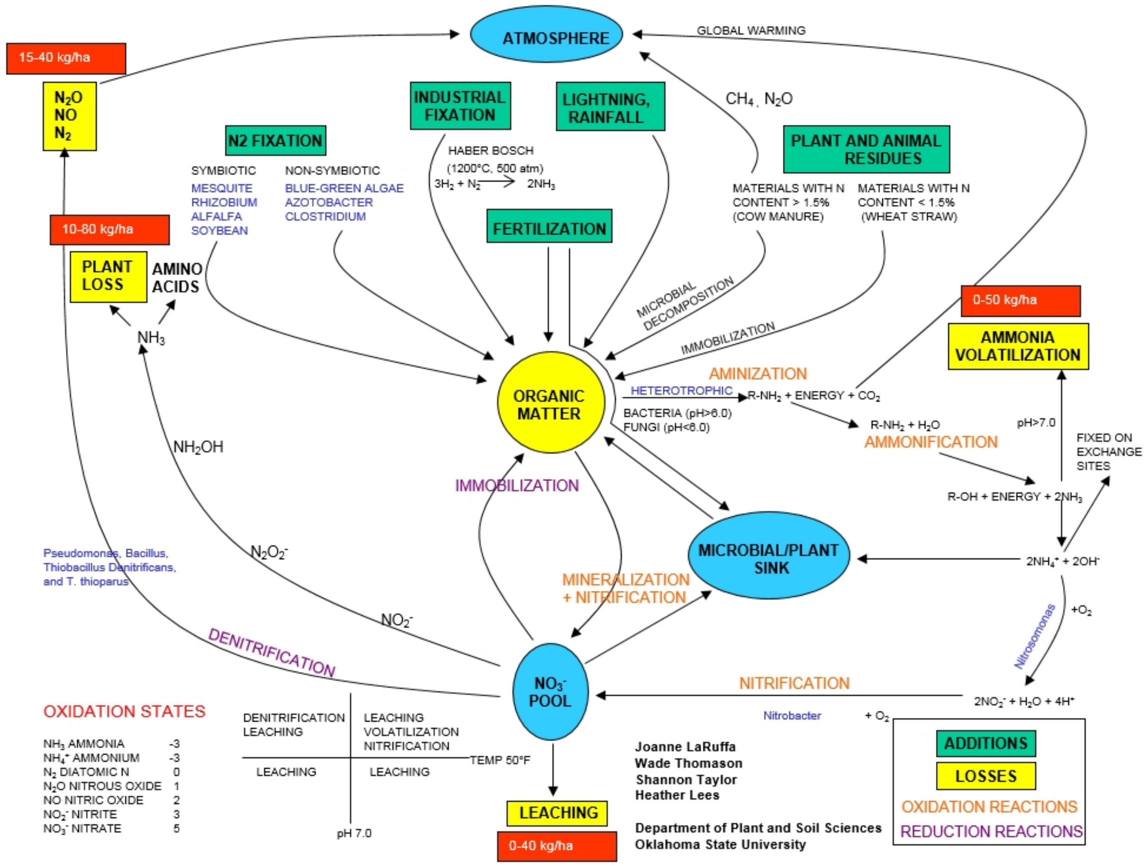

Figure 2. Average plant available water in top 100 mm and average air temperature for the state of Oklahoma from 2003- 2017.

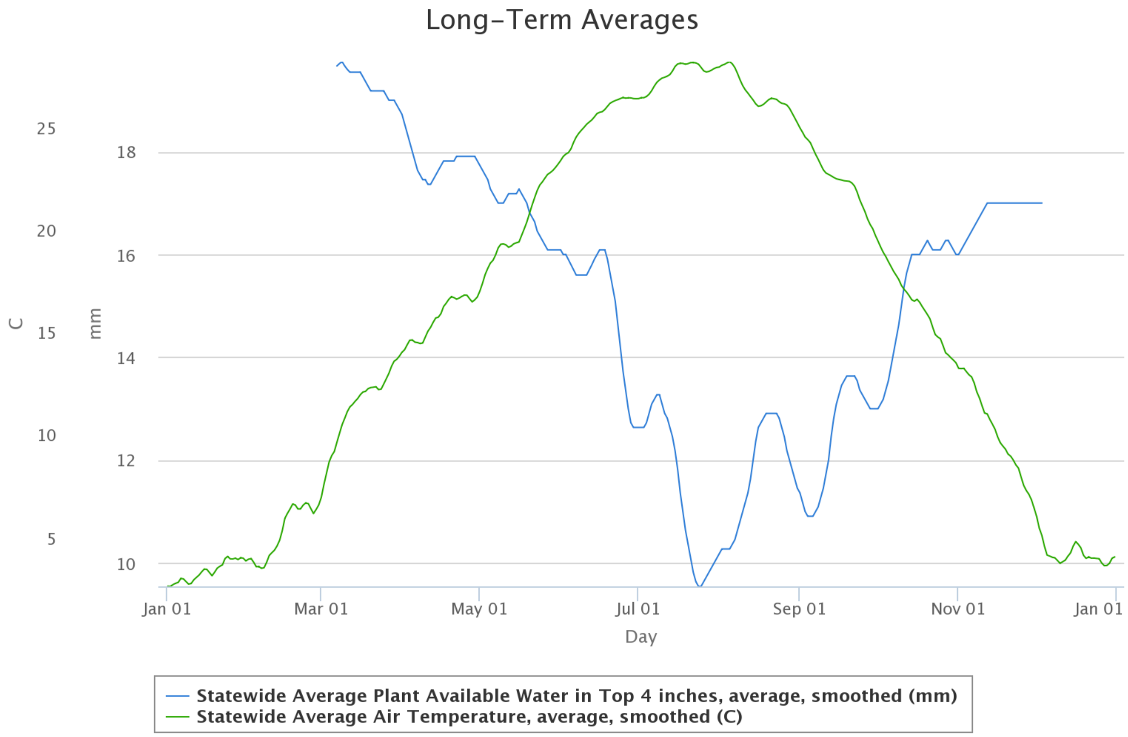

Figure 3. Photo displaying implications with closure at the Perkins 2017-18 location utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma. This photo highlights the partial cover of urea from the Great Plains 1006NT that applies the fertilizer above the furrow, but before the closing wheel.

Figure 4. Winter wheat grain yield and protein response to the application of 67.25 kg N ha^{-1} as affected by application method and timing at Chickasha in the 2016- 2017 growing season.

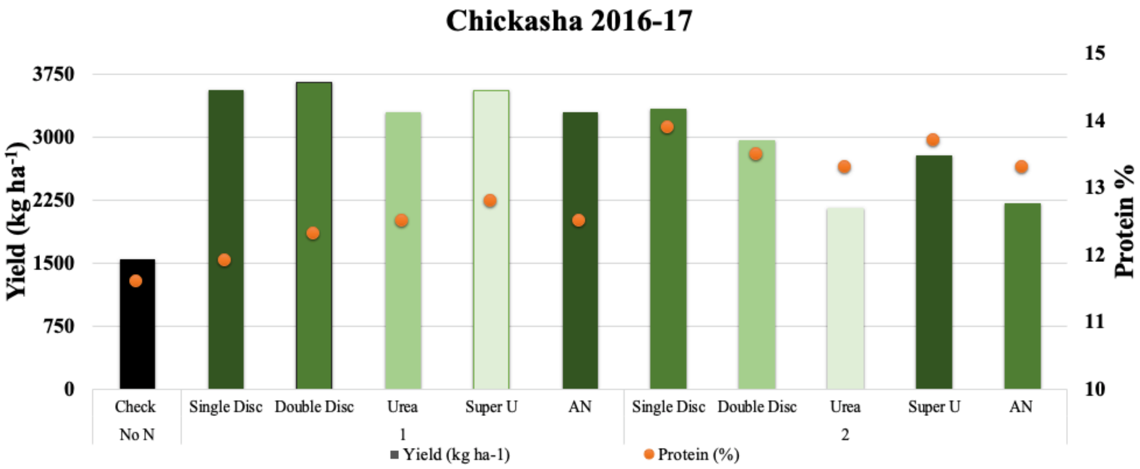

Figure 5. Winter wheat grain yield and protein response to the application of 67.25 kg N ha^{-1} as affected by application method and timing at Chickasha in the 2017- 2018 growing season.

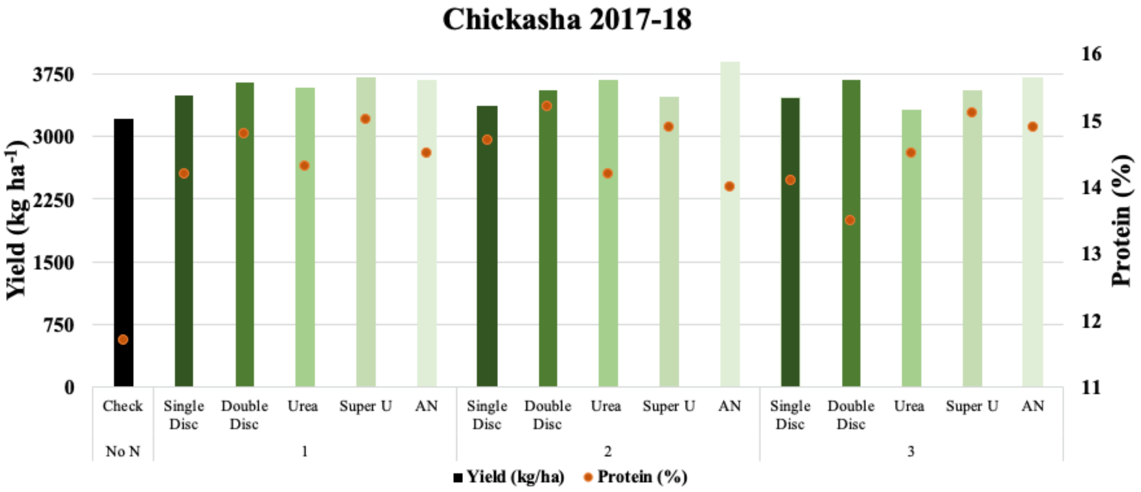

Figure 6. Winter wheat grain yield and protein response to the application of 67.25 kg N ha^{-1} as affected by application method and timing at Lahoma in the 2016- 2017 growing season.

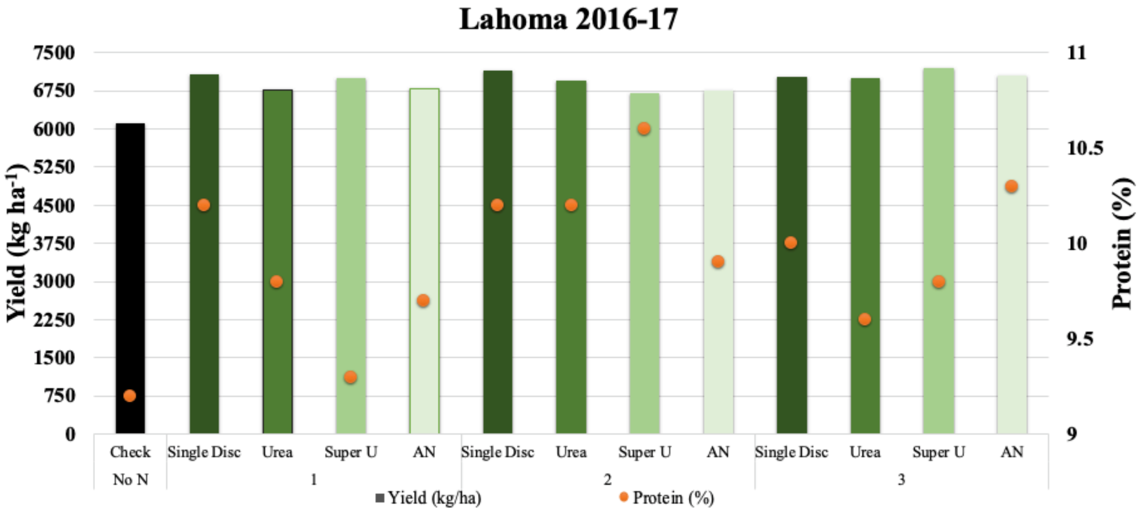

Figure 7. Winter wheat grain yield and protein response to the application of 67.25 kg N ha^{-1} as affected by application method and timing at Lahoma in the 2017- 2018 growing season.

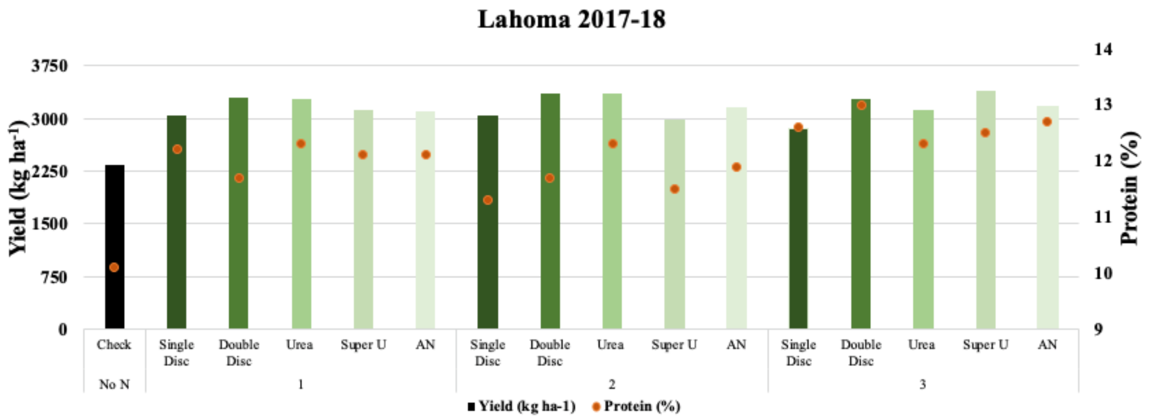

Figure 8. Winter wheat grain yield and protein response to the application of 67.25 kg N ha^{-1} as affected by application method and timing at Perkins in the 2016- 2017 growing season.

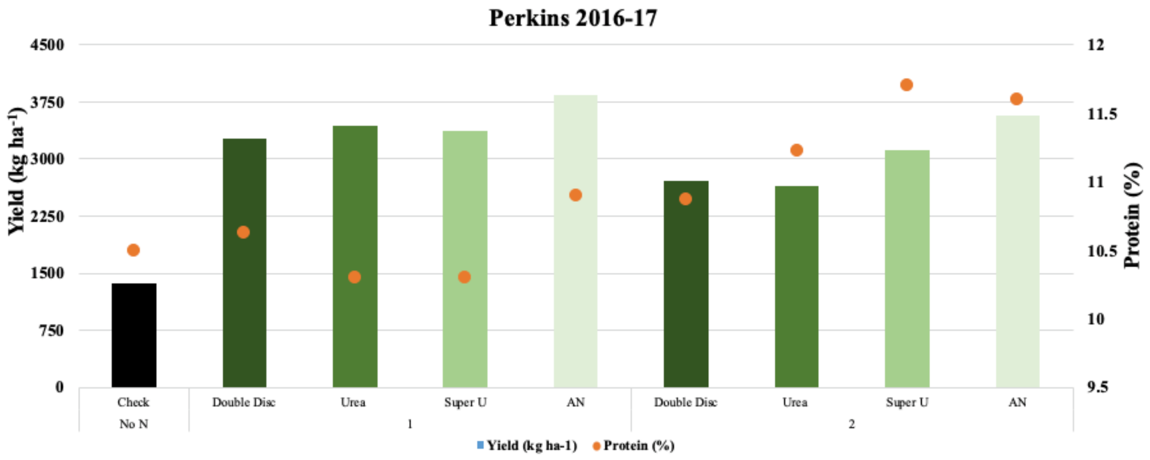

Figure 9. Winter wheat grain yield and protein response to the application of 67.25 kg N ha^{-1} as affected by application method and timing at Perkins in the 2017- 2018 growing season.

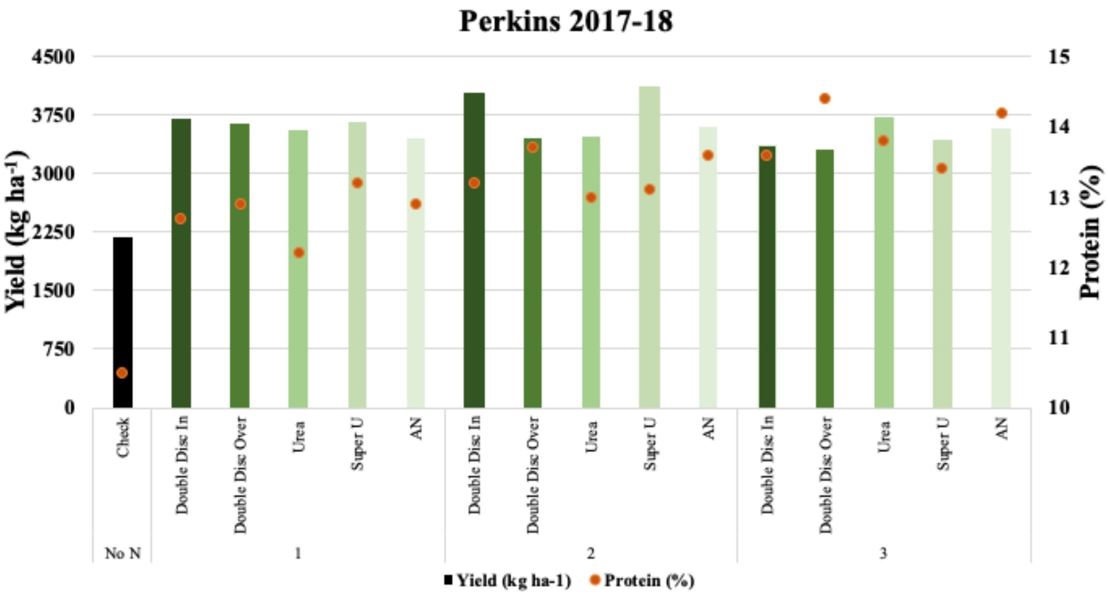

Figure 10. Soil moisture obtained through the Oklahoma Mesonet, using heat induced resistance readings at the 5 cm depth for the Chickasha 2016-2017 location. Each timed application utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma is designated by an arrow and the appropriate label.

Figure 11. Soil moisture obtained through the Oklahoma Mesonet, using heat induced resistance readings at the 5 cm depth for the Chickasha 2017-2018 location. Each timed application utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma is designated by an arrow and the appropriate label.

Figure 12. Soil moisture obtained through the Oklahoma Mesonet, using heat induced resistance readings at the 5 cm depth for the Lahoma 2016-2017 location. Each timed application utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma is designated by an arrow and the appropriate label.

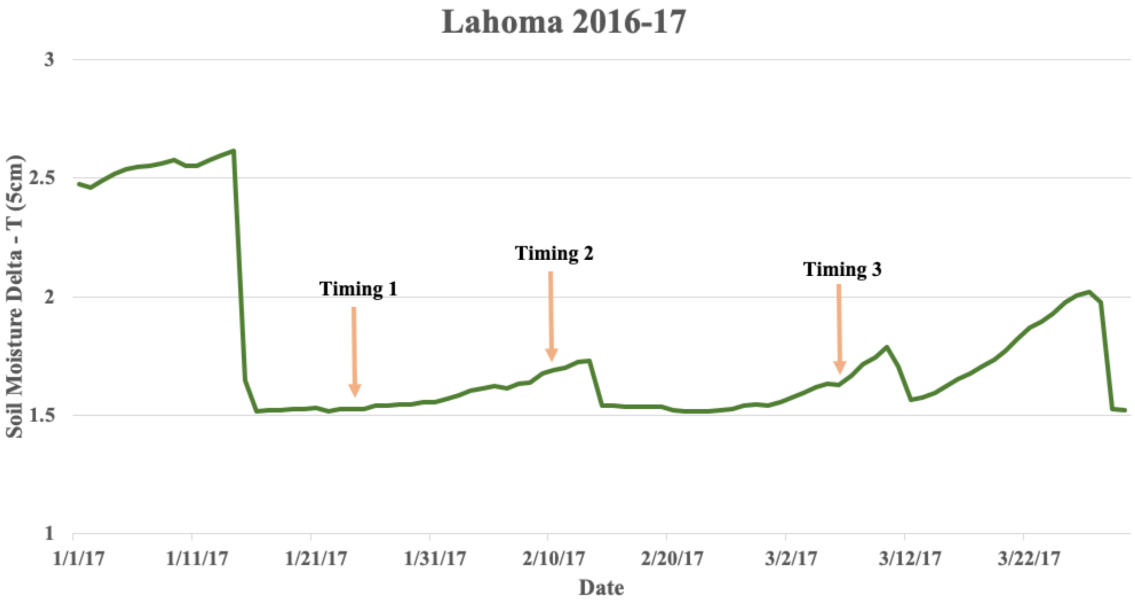

Figure 13. Soil moisture obtained through the Oklahoma Mesonet, using heat induced resistance readings at the 5 cm depth for the Lahoma 2017-2018 location. Each timed application utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma is designated by an arrow and the appropriate label.

Figure 14. Soil moisture obtained through the Oklahoma Mesonet, using heat induced resistance readings at the 5 cm depth for the Perkins 2016-2017 location. Each timed application utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma is designated by an arrow and the appropriate label.

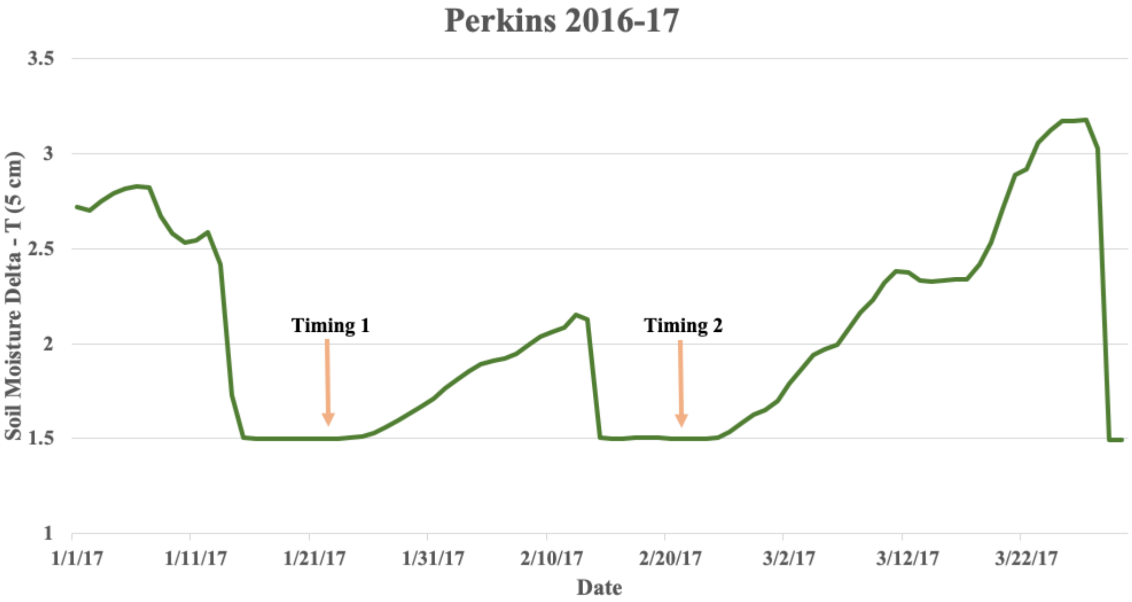

Figure 15. Soil moisture obtained through the Oklahoma Mesonet, using heat induced resistance readings at the 5 cm depth for the Perkins 2017-2018 location. Each timed application utilized in the study evaluating the impact of methods on nitrogen topdressing winter wheat in Oklahoma is designated by an arrow and the appropriate label.

VITA

Brent Arthur Ballagh

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