THE EFFECTS OF FOLIAR APPLIED NITROGEN ON HARD RED WINTER WHEAT PRIOR TO FEEKES 8

By

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Abstract: Recent drought and market instability has led farmers to reduce pre-plant and mid-season nitrogen (N) applications. The objective of this project was to determine the effects of a foliar N prior to Feekes 8 (F7) in hard red winter wheat (*Triticum aestivum L*.), and ensuing effects on grain yield and total grain N. Studies were conducted at three locations in 2012-2013 and 2013-2014. Two rates of foliar N, 17 kg ha^{-1} and 34 kg ha^{-1} were evaluated at four dilution ratios. Nitrogen dilution ratios consisted of 1:0, 1:1, 2:1 and 3:1 parts urea ammonium nitrate (UAN, 28-0-0) to water. Two rates of a low salt (LS) N source, 17 & 34 kg ha^{-1}, were also applied prior to Feekes 8. A pre-plant N rate was also evaluated (90 kg ha^{-1}) to determine maximum yield potential. Foliar applications consistently improved average yields above the 0-N plot. However, they did not always reach maximum yield potential. No trend was found across all site years for any single treatment. Foliar rates were significant at one location, while the dilution ratio was significant at 3 sites. Urea ammonium nitrate proved to be a practical N source for late season applications in N deficient wheat, and based on average yields it was concluded that F7 applications are beneficial regardless of dilution.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Introduction

The majority of nitrogen (N) fertilization in Oklahoma is made prior to stem elongation (F6), either as pre-plant or split applications, to insure adequate nutrients in the soil for vegetative growth (Morris et al. 2006). This growth is required for photosynthesis and to allow the crop to store carbohydrates for winter dormancy. The two most common methods of N fertilization are 100% pre-plant or split application, both of which are based on yield goal. During dormancy, N applied prior to planting can be lost through processes of the N cycle. Processes such as leaching or denitrification of greenhouse gases, and plant loss lead to N deficiency (Richter and Roelcke, 2000). A common form of loss is leaching where water moves nitrogen down through the soil profile. In a dormancy period certain water sources like rain or snow melt can move nitrate (NO_3^-) downward through the profile where it cannot be taken up by wheat roots, thereby rendering it useless when spring growth resumes. Depending on soil profile and the amount of water moved through the soil this will usually increase with higher amounts of pre-plant fertilization (Richter and Roelcke, 2000). In recent years the farm belt has been under drought conditions leading to minimal applications of fertilizer with little expectation of average yields due to lack of plant available water in the soil profile. With low residual N levels and no additional fertilizer, crops will likely express N deficiency when environmental conditions improve. Foliar applied N prior to hollow stem can be beneficial in correcting deficiencies. Under similar conditions, crops will respond with substantial N uptake and partitioning. The amount of uptake from a plant can also be affected by the stage of the plant's life cycle (Thomason et al. 2002). This project was established to see if yield recovery could be obtained in hard red winter wheat (*Triticum aestivum* L.) through F7 N applications. Apart from water, N is the most common limiting factor in Oklahoma wheat fields. If significantly higher yields are found this trial could prove the value and profitability of F7 applications. This could also lead to more feasible applications of N for producers while using the same equipment already needed to apply pesticides and other foliar products.

Nitrogen

Nitrogen is the second most abundant element in wheat, after carbon, and the most limiting nutrient required for essential plant growth in cereal crops. N is required for many essential plant components such as proteins, nucleic acids, chlorophyll, co-enzymes, phytohormones and secondary metabolites (Marschner, 2012).

Many forms of N fertilization are available for producer application and deficiency correction, but two forms of N dominate plant uptake. Nitrate and ammonium (NH_4^+) are the two most commonly utilized forms of N in plants (Marschner, 2012). Ammonium may be more abundant in unfertilized agricultural soils, but NO_3^- is the more mobile form of N and more readily available in soils (Miller and Cramer, 2004; Marschner, 2012). Whether NO_3^- or NH_4^+ is actually more beneficial for plant growth and productivity is dependent on many other factors (Marschner, 2012). Gazzarrini (1999) stated that NH_4^+ will be taken up in higher quantities when supplied in equimolar concentration with NO_3^-. However N supply and demand can control the expression of NH_4^+ and NO_3^- transport genes in a plant (Marschner, 2012). No matter the form of N, the plant takes up NO_3^- and it is either stored in the vacuole or reduced to NH_4^+ to form organic molecules (Gojon et al. 2011). Nitrate storage in the vacuole is a key component to maintaining cytosolic NO_3^- concentrations (Dechorgnat et al. 2010). Both NH_4^+ and NO_3^- rely on ion transport to move across cell membranes (Marschner, 2012). This transportation relies on the cellular conditions and the electrochemical gradient. Depending on the external concentrations NH_4^+ may use active or passive transport while NO_3^- is dependent on proton symport for active transportation (Williams and Miller, 2001). Plants may also take up urea through the use of the enzyme urease, but urea is usually converted into NH_4^+ in the soil (Witte, 2011). Proper growth and development in a plant depends on N being taken up in vast possibilities of environmental conditions (Williams and Miller, 2001). There are many factors that control the availability of N in the soil such as soil texture, structure, pH, microbial activity, moisture and organic material (Robinson, 1994). As Clarke *et al* (1990) stated, plant uptake of N is directly proportional to available water and associated with dry matter accumulation. Halverson and Reule (1994) stated that any field planted into wheat that was left fallow over a summer will respond to N fertilization, even given the many factors involved in the soil. In turn the application of foliar N is to correct any deficiencies in the plant after an initial fertilization in the fall or to increase grain protein to meet required levels (Harder et al. 1982). Delayed applications until Feekes 5 could still result in maximum to near maximum yields with 0 pre-plant N applied (Morris et al. 2006).

Nitrogen is one of the most beneficial elements to plants and therefore, it is called a macro nutrient. In order for a plant to complete its life cycle without major interruption or disturbance a plant needs adequate but not excessive amounts of N. The most noticeable form of N deficiency is chlorosis or yellowing of the leaves. This will occur in older leaves because nitrogen is a mobile nutrient and therefore it will move from source to sink, or an area of higher concentration to lower concentration within a plant (Marschner, 2012). In leaf senescence the plant will break down proteins and nucleic acids during N deficiency (Hortensteiner and Feller, 2002).

Foliar Nutrient Application

Providing N directly to sink locations on the plant or increasing uptake is vital to preventing over application of N and increasing nitrogen use efficiency (NUE), and with precision agriculture practices, in-season N can be more accurately and precisely applied to increase NUE (Thomason et al. 2002). Nitrogen use efficency in general is the ratio between N input and output and then divided into two categories, uptake efficiency and utilization efficiency (Marschner, 2012). In cereal grains the high amounts of N fertilizer required to obtain higher yields result in large losses and reduced NUE. Nitrogen use efficiency is estimated to be below 50% in cereal grains (Raun and Johnson, 1999). While high amounts of N loss are caused by leaching, denitrification and volatilization, these losses may be reduced by enhancing genetic capability for uptake and storage during times of high soil concentration (Marschner, 2012). Application methods will also help to reduce N loss and increase NUE.

Ammonium application is preferred over NO_3^- during in-season application for protein production because it requires less energy to utilize (Cox and Reisenauer, 1973). Nitrogen itself is found in every organ of the plant in multiple organic and inorganic forms. Nitrate can be reduced to NH_4^+ via nitrate reductase and utilized in leaf cells to form amino acids and proteins. Source cells can also remobilize organic compounds such as amino acids in plant seeds in order to form proteins (Williams and Miller, 2001). Prior to senescence leaves act as a sink for N concentrations. Improving sink concentrations can increase both yields and protein content, though grain yields and protein content are often inversely related (Xu et al. 2012). Protein content in wheat is a central aspect for milling and baking quality. Protein content is subject to consumer use for each variety but a higher content is favored in hard red winter wheat (HRWW) (Woolfolk, 2002).

Pre-plant soil testing is not sufficienly accurate in predicting late season deficiencies in wheat and does not take into account losses during the season (Woolfolk, 2002). Urea being a common and inexpensive fertilizer makes it a popular choice with producers; however it is susceptible to volatilization. Volatilization is affected by many environmental factors such as pH, cation exchange capacity, urease activity and soil moisture (Siva et al. 1999). Understanding the N loss in the field as related to each pathway such as leaching and volatilization will greatly help to understand the effects on NUE (Cossey et al. 2002). Field studies have shown that N applied late in the growing season can increase protein and N content in cereal grains. Point injection and topdressing are better methods of N application to improve NUE (Woolfolk, 2002). Even later application of N near anthesis can increase grain protein content while doing nothing for yields or vegetative state (Dampney and Salmon, 1990; Marschner, 2012). This mostly relies on the plants ability to remobilize nutrients within a plant, and the time lapse between application and utilization. Signs of deficiency in younger leaves are a common signal of a plant’s inability to remobilize nutrients. Foliar application of the deficient nutrient can bypass the plant’s remobilization period by applying directly to the desired areas (Marschner, 2012). When N is taken up through the roots long distance transportation moves it up through the plant via the xylem to mature leaves where it can be stored, assimilated or redistributed through the phloem to N sinks (Williams and Miller, 2001).

Alcoz et al (1993) found that when split applying N at Feekes growth stage 4 or 6, significant yield increases were achieved compared to all pre-plant or post anthesis applications. It was also observed that increasing the number of split applications with a decreased rate of N succeeded in increasing yields. However, N applied late in the growing season near plant heading resulted in considerably smaller yields than that applied at tillering (Woolfolk et al. 2002). Woolfolk et al (2002) also stated that no consistent increases or decreases were observed in grain yields from foliar applications made pre-or post flowering. Conversely, Mallory and Darby (2013) found that among their application timings, a 7% yield increase was produced with flagleaf treatments over tillering treatments. Mahler et al (1994) stated that winter wheat will require less than 30% of its nitrogen by Feekes 3. Their results indicated that 75% spring broadcast application was favorable over 50% spring and 100% fall applications and generated a higher NUE and grain yields. However, Vaughan et al (1990) stated that spring applications increased grain yields more than fall and split applications, while fall applications required 18-20% more N than in the spring to make comparable yields, or that 1lb/ac of N applied in the spring would yield the same results as 1.28lb/ac applied prior to planting. However, Guy et al (1995) found that a 25% increase in N split applied at planting and flag leaf emergence only produced a 6.4 bu/acre increase over the standard yield goal.

Nitrogen recovery can reach 41.6% when applied at stem elongation compared to 12.7% when applied at planting (Lopez-Bellido et al. 2006). Wuest and Cassman (1992) stated that accumulation of N applied at planting ranged from 30 to 55%, while N applied at anthesis ranged from 55 to 80%. Woolfolk et al (2002) also stated that 65-80% of grain N is acquired from vegetative growth and the remainder attained from root uptake after anthesis. Barbottin et al (2005) indicated that remobilization of N in vegetative growth may rely on the plants efficiency of N uptake after anthesis. Delaying applications until later in the growth cycle will maximize efficiency and evade excessive vegetative growth and plant lodging (Alcoz et al. 1993). Morris et al (2006) concluded in a study conducted from 2002-2004 that four of six locations resulted in maximum yields when topdress N was applied in 0 N pre-plant plots, which resulted in increasing NUE. Applications of N made after Feekes growth stage 9 commonly produced fewer grain heads, but improved grain weight (Ellen and Spiertz, 1980). Beuerlein et al (1989) also documented that delaying application will decrease the number of seed heads but increase the number of grains per head and kernel weight. N response to delayed application is dependent on genotypic traits of the plant; environmental pressures and remobilization during times of stress are also affected by genotype (Barbottin et al. 2005). A common cause for delayed application is absence of soil moisture leading to no visible indicator of fertilization or crop deficiency. Considerable portions of N are applied to winter wheat in late winter or early spring after producers evaluate crop survival and economic returns (Knowles et al. 1994). Kelly (1995) stated that in areas of high precipitation spring applied N is beneficial over fall applications, and spring applications are also more efficient in semiarid environments. In a region of 480 to 650mm of precipitation, a 75% spring application of N led to maximum yields and NUE while in higher precipitation areas of > 650 mm less than 30% of total N should be applied prior to planting (Mahler et al. 1994). Late season applications allow producers to modify rates to crop growth and reduce potential losses (Woolfolk et al. 2002).

CHAPTER II

OBJECTIVES

- Determine if wheat can recover from N deficiency if application is delayed to F7-8
- Compare and contrast results of different dilution ratios, rates and fertilizers
- Establish economic benefits of late season (F7-8) N application to N deficient wheat

CHAPTER III

METHODOLOGY

Trials were established at four separate locations in Oklahoma. Trial sites one and two were planted at the Lake Carl Blackwell Research Station near Stillwater on a Udic Ustifluvent (Table 4), and the third location was planted at the Agronomic Research Station located in Lahoma, Oklahoma on an Udic Argiustoll (Table 4). Treatments were repeated on the same plots for both study years, 2012-2013 and 2013-2014. In 2013-2014 an additional location was established in Chickasha, Oklahoma at the agronomic research station on a Pachic Haplustolls (Table 4). Results from soil samples collected prior to planting are recorded in Table 1. Hard red winter wheat was planted at a rate of 166 kg/ha with 19.05 centimeters between rows for all locations. Plots measured 3m by 6m arranged in a randomized complete block design with three replications. Each replication consisted of twelve treatments starting with a 0-N check plot (Table 2). Eight foliar treatments at 17 kg ha^{-1} and 34 kg ha^{-1}, each with four urea ammonium nitrate (UAN 28-0-0) dilution ratios were applied after hollow stem. Dilution ratios consisted of 1:0, 1:1, 2:1 and 3:1 parts UAN to water. Different dilution ratios were implemented to determine if concentration effected yield or protein. Two applications of a low salt (LS) foliar fertilizer N source of CoRoN, Helena chemical company, were applied to two treatments with a

25-0-0 NPK analysis, 18.8% urea nitrogen and 6.2% water soluble nitrogen. These treatments were also applied at 17 and 34 kg ha^{-1} of N. The LS treatments were added to compare applications to a safened industry standard, and to determine if leaf burn was an influence in grain yield production. A 90 kg ha^{-1} pre-plant treatment (PP90) was also established to determine a yield potential for the trial. Ammonium nitrate (34-0-0) was broadcast as a N source to establish the PP90 plot. All foliar applications were made prior to Feekes 8 using a backpack sprayer with a CO_2 propulsion source and a handheld boom. Solutions for each treatment were prepared and stored in two liter bottles. These solutions were applied foliarly using a CO_2 power source to propel spray through TeeJet fan spray flat tip nozzles, except for the 0-N plot which received no additional nitrogen and the PP90 plot which received only pre-plant applied nitrogen. Applications were made by walking between plots and applying to one side of the plot at a time with two passes. Speed was maintained by walking in step with a metronome to keep a pace of 3.2 and 4.8Km/hr.

Grain was harvested with a Massey Ferguson experimental plot combine from the center 1.82m of each plot; each plot had a small subsample captured in envelopes for processing. After harvest grain was pulled from each plot to be dried, milled and rolled in glass bottles with four steel pins for 48 hours before being submitted for total nitrogen and carbon testing. Samples from each plot were submitted to Oklahoma State University Soil, Water, and Forage Laboratory for Carbon and Nitrogen analysis. Total N and C were analyzed using the combustion method where 0.15g of grain was placed into the LECO TruSpec 628. Grain protein was determined by multiplying total grain N by 6.25. Statistical analysis software (SAS) was used with various scripts to determine any data trends or significant differences in collected data for each treatment. The use of single degree of freedom, non-orthogonal contrast statements were used to determine differences between rate, source and dilution.

CHAPTER IV

RESULTS

The analysis of grain yield and protein content for Lake Carl Blackwell (LCB), Lahoma (LAH) and Chickasha (CHK) is reported in Tables 1-26. Data were collected from five site years, LCB location one was lost due to environmental pressure in 2012-13 and was replaced by the Chickasha location in 2013-14.

Lake Carl Blackwell, 2012-13

Yield

Two sites were located on the LCB Research Farm in 2012-13. LCB location one was abandoned prior to harvest. Pressure from weeds caused a 50% or more loss of stand. The second location also exhibited pressure from a nearby tree line creating a shading effect that was taken into account during analysis. The three plots closest to the tree line were removed prior to data analysis due to evident yield decreases. Application prior to Feekes 8 (F7) had a positive influence on grain yield at LCB, ranging from 100-500 kg/ha^{-1} yield increase above the 0-N plot at 3370 kg ha^{-1}, LS34 with 3462 kg ha^{-1}, and 34,1:0 with 3836 kg ha^{-1}(Table5). Plot PP90 resulted in a yield of 4002 kg ha^{-1} which was significantly higher than the 0N plot as well as LS34 with yields of 3370 kg ha $^{-1}$ and

3462 kg ha $^{-1}$(Table 7). Yields were numerically increased across all F7 N applications (Table 5). On average foliar applications increased yield by 289 kg ha^{-1} above the 0-N plot (Table 5). However, there was no significant difference between rates, source or dilution ratio as a treatment collection (Table 8).

Protein

t-Grouping (Table 9) for treatment means indicates that PP90 was significantly higher than the six other treatments including the 0-N, 17, 3:1, 2:1, 1:1, LS and 34,1:1. Analysis did indicate that F7 applications had an impact on grain protein content, treatments 17,1:1 and 17,3:1 through 34LS contained on average 117 g kg^{-1} more protein than the 0-N plot. There was a significant difference between LS N rates (Table 10), with treatments receiving 34 kg ha^{-1} producing higher grain protein content than treatments only receiving 17 kg ha^{-1} (Tables 5). There were also significant differences between dilution ratios for UAN treatments (Table 10). While a difference was evident for both UAN and LS N rates, there was no significant difference between the foliar N sources (Table 10).

Lahoma, OK, 2012-13

Yield

On average there was no significant difference between the PP90 and 0-N yields. Treatment 17,3:1 produced the only yields significantly higher than the average at 4739kg ha^{-1}. Treatment 17,3:1 was significantly higher than the 0-N plot as well as 17, 1:1, 1:0, LS and 34,2:1 (Table 11). On average F7 applications out produced the 0-N plot by 477 kg ha^{-1}(Table5). The means showed no trend with the exception of an increase in yields from 0-N through 17,3:1, which was the only treatment to show significant differences (Table 11.), offering no evidence of direct influence from F7 N rate. Along with N rate there was no significant differences between sources or dilution ratio (Table 12.). Lahoma was 16 cm below the 13 year average for total rainfall in 2012 (Table 3). It is probable that lack of rainfall was the cause of non-significant yield differences.

Protein

At 137 g kg^{-1} PP90 was significantly higher than 0-N & LS17 plots at 122 g kg^{-1} & 119 g kg^{-1} protein content (Table 13). In addition to grain yield 17,3:1 produced the highest mean protein content at 139 g kg^{-1}. There were however no significant differences between rate, source or dilution ratio (Table 14). However UAN applications that received 17 kg N ha^{-1} produced higher protein levels than treatments receiving 34 kg N ha^{-1} (Table 5). Based on protein content F7 application impacted protein for the site year, increasing protein content by an average of 10 g kg^{-1} above the 0-N plot.

Lake Carl Blackwell, 2013-14

Yield

As in 2012-13 yields in replication three were adjusted to account for the shading effect. There were no significant differences among treatment yields for LCB, 2013-14 (Table 15). Yields for 0-N and treatments that received 17kg ha-1 of UAN numerically increased from 1752kg ha^{-1} to 2246kg ha^{-1} across treatments, then declined for 34,2:1 to 1705 kg ha^{-1}(Table 6). This decline in yield occured in both years, only more drastically in 2013-14. There were also no significant differences between rate, source or dilution ratio (Table 16).

Protein

The 0-N treatment produced the lowest average grain content with 115 g kg^{-1}, and was significantly lower than PP90 with 158 g kg^{-1} (Table 17). Treatments 34,2:1, 34,1:1 and 17,1:0

were the only F7 applications to produce significantly higher protein contents than 0-N (Table 17). The only significant trend for the site was among dilution ratios (Table 18).

Lahoma, OK, 2013-14

Yield

There was no significant difference between PP90 and 0-N for the site year. The 0-N plot produced higher yields in two of the three replications with an average of 2125 kg ha^{-1}, suggesting that environmental factors had more effect than N (Table 6). Treatments LS17 and 17,1:0 yielded the two highest averages in the second year at 3033 kg ha^{-1} & 3025 kg ha^{-1} (Table 6), but neither were significantly higher than the 0-N (Table 19). The only significant trend occurred in application rate, with 17kg ha^{-1} out yielding 34 kg ha^{-1} in both foliar sources. There was no significant difference in dilution rate or source (Table 20).

Protein

There was no significant difference between PP90 and 0-N (Table 21). On average PP90 only produced 3 g kg^{-1} higher grain protein content than the 0-N plot at 155 g kg^{-1} (Table 6). There were also no significant differences among foliar N source, however, the LS treatments yielded two of the lowest protein contents at 149 g kg^{-1} and 142 g kg^{-1} (Table 21). There was also no significant difference among foliar N rate however there was between dilution ratios and rate by dilution (Table 22).

Chickasha, OK, 2013-14

Yield

There was no significant difference between PP90 and 0-N treatments (Table 23); there was only 134 kg ha^{-1} between the treatment average yields (Table 6). Treatments 17,1:0 and 34,1:1 yielded 1830 kg ha^{-1} and 1846 kg ha^{-1} respectively, and both were significantly higher than 17,2:1 at 1488 kg ha^{-1}(Table 23). There were no significant differences between rate, source or dilution ratio (Table 24).

Protein

Treatment PP90 produced 174 g kg^{-1} protein and was significantly higher than the 0-N plot at 142 g kg^{-1} (Table 25). In parallel PP90 contained the highest protein content for the site year; the 0-N plot also produced the least amount of protein (Table 25). There was no significant difference between N rates; however, there was a positive linear relationship (Figure 1). The only significant contrast was an interaction between rate and dilution ratio (Table 25).

CHAPTER V

DISCUSSION and CONCLUSION

Effects of foliar N applications were more apparent in 2013 with higher grain yields at both LCB and LAH. Lake Carl Blackwell produced 1,557 kg ha^{-1} more grain for treatments receiving F7 applications in 2013 (Tables 5 and 6). Lahoma also produced 1,624 kg ha^{-1} more grain in 2012-13. Environmental impacts are the most probable cause of the yield decline. The total rainfall for the LAH 2013-14 growing season was 9.93 cm less than 2012-13. However, the LCB 2013-14 growing season received 31cm less than in 2012-13 (Figure 2).

Using the 5 site years it was determined that foliar treatments are beneficial enough to cover material cost. Feasibility was determined for the two foliar sources at a cost of $6.60/kg N for LS and $1.12 /kg N for UAN. A market price of $0.22/kg was determined by averaging prices for the Kansas City Board of Trade price of HRWW over five years for the month of June. Combining both N rates for UAN, 75% of the treatments produced enough yield to cover material costs. However, the LS treatments only met cost 10% of the time. When separated by rate the LS treatments met cost 20% of the time for LS17, and never reached a high enough yield for LS34 to be justified. Urea ammonium nitrate proved to be a practical N source for late season applications in

N deficient wheat, and based on average yields it was concluded that F7 applications are beneficial regardless of dilution.

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TABLES AND FIGURES

Table 1. Initial surface (0-15 cm) soil test characteristics for Chickasha (CHK), OK, Lahoma (LAH), OK, and Lake Carl Blackwell (LCB) research farm near Stillwater, OK.

Loc	Year	Depth	pH[p]	BI	NO_3^{-} [a]	P[b]	K[b]
		cm				ppm	
LCB[RF]	2012	0-15	5	6.9	10.50	39.00	118.75
LAH[RS]	2012	0-15	5.2	6.8	16.00	34.50	201.50
CHK[RS]	2013	0-15	5.6	6.9	8.50	18.00	138.00

[p] 1:1 soil/water

[a] 2 *M* KCL extraction

[b] Mehlich 3.

[RF] Research farm used for location of trial

[RS] Research station used for location of trial

Table2. Treatment structure employed including treatment, Nitrogen rate, source and time of application during the plants growth cycle .

Treatment	N rate	Parts UAN/H2O by vol	N source[a]	Timing[b]
	kg ha^{-1}			
0-N	0	-	-	-
17,1:1	17	1:1	UAN	Foliar
17,2:1	17	2:1	UAN	Foliar
17,3:1	17	3:1	UAN	Foliar
17,1:0	17	No Dilution	UAN	Foliar
34,1:1	34	1:1	UAN	Foliar
34,2:1	34	2:1	UAN	Foliar
34,3:1	34	3:1	UAN	Foliar
34,1:0	34	No Dilution	UAN	Foliar
LS17[c]	17	-	CoRoN	Foliar
LS34[c]	34	-	CoRoN	Foliar
PP90[d]	90	-	$NH_4^+NO_3^-$	Pre-plant

[a] UAN, urea ammonium nitrate(28-0-0); CoRoN (25-0-0); $NH_4^+NO_3^-$(34-0-0)
[b] Foliar nitrogen was applied prior to Feekes growth stage 8
[c] LS indicates a low salt fertilizer was used instead of dilution
[d] PP indicates a pre-plant application was used instead of foliar application

Table3. Total rainfall in cm for Lake Carl Blackwell and Lahoma research station by month, by year, and 13 year average. Data obtained from the Mesonet website at Mesonet.org.

		Month													
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**	**13yr avg**
Location	**Year**	----- cm -----													
LCB	**2012**	3.10	6.60	8.74	10.97	1.42	8.51	0.20	6.12	3.05	1.17	1.40	1.12	52.40	86.36
	2013	2.64	8.48	1.37	15.37	24.13	14.12	19.81	9.09	5.97	5.26	2.67	1.52	110.44	
	2014	0.25	1.19	3.15	4.32	2.67									
	2012	2.64	7.77	6.32	15.47	3.58	5.94	0.99	4.72	5.41	0.18	1.32	0.69	55.04	71.12
LAH	**2013**	0.94	9.04	1.40	8.23	9.17	10.06	18.92	9.22	7.06	6.05	3.35	1.55	84.99	
	2014	0.08	1.09	1.07	0.53	5.66									

Table 4. Descriptive soils data for dominate soil series at each location obtained from Web Soil Survey.

Location	**Payne County, Oklahoma**[a]	**Major County, Oklahoma**[b]	**Grady County, Oklahoma**[c]
	43—Pulaski fine sandy loam, 0 to 1 percent slopes, occasionally flooded	**GrB—Grant silt loam, 1 to 3 percent slopes**	**43—Reinach silt loam, 0 to 1 percent slopes, rarely flooded**
	Map Unit Setting	**Map Unit Setting**	**Map Unit Setting**
National map unit symbol:	2s7g6	2td5w	dv60
Elevation:	700 to 1,300 feet	1,100 to 1,500 feet	1,070 to 1,460 feet
Mean annual precipitation:	30 to 40 inches	29 to 37 inches	26 to 40 inches
Mean annual air temperature:	59 to 63 degrees F	59 to 61 degrees F	57 to 64 degrees F
Frost-free period:	200 to 220 days	190 to 220 days	200 to 220 days
Farmland classification:	All areas are prime farmland	All areas are prime farmland	All areas are prime farmland
	Map Unit Composition	**Map Unit Composition**	**Map Unit Composition**
	Ap - 0 to 19 inches: fine sandy loam	Ap - 0 to 12 inches: silt loam	A - 0 to 30 inches: silt loam
	C1 - 19 to 40 inches: fine sandy loam	BA - 12 to 16 inches: silt loam	C - 30 to 84 inches: silt loam
	C2 - 40 to 80 inches: stratified loamy fine sand to fine sandy loam to loam	Bt - 16 to 32 inches: silty clay loam	
		BC - 32 to 47 inches: silt loam	
		C - 47 to 59 inches: silt loam	
		Cr - 59 to 72 inches: bedrock	
	Properties and qualities	**Properties and qualities**	**Properties and qualities**
Slope:	0 to 1 percent	1 to 3 percent	0 to 1 percent
Depth to restrictive feature:	More than 80 inches	53 to 60 inches to paralithic bedrock	More than 80 inches
Natural drainage class:	Well drained	Well drained	Well drained
Runoff class:	Negligible	Low	Negligible

[a] Soil series for Lake Carl Blackwell research farm
[b] Soil Series For Lahoma agronomic research station
[c] Soil series for Chickasha agronomic research station

Table 5. Treatment means for grain yield and protein content, Lake Carl Blackwell research farm (LCB) near Stillwater, OK, 2012-2013 and Lahoma (LAH), OK, 2012-2013.

Location		LAH[RS]		LCB[RF]	
		Yield	Protein	Yield	Protein
kg N ha^{-1}	Dilution[a]	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}
0	N/A[b]	3585	122	3371	113
17	1:1	3915	136	3616	121
17	2:1	4198	133	3540	111
17	3:1	4739	139	3686	122
17	1:0	3905	134	3733	126
34	1:1	3990	129	3763	121
34	2:1	3624	130	3679	128
34	3:1	4148	132	3650	129
34	1:0	3918	131	3836	128
17	LS[c]	3932	120	3645	119
34	LS[c]	4255	125	3462	130
90	PP[d]	4119	137	4002	134

[a] dilution ratio for the treatments indicating parts urea ammonium nitrate: parts water
[b] N/A states that this was the check plot and no dilution or nitrogen was applied
[c] LS signifies that a low salt fertilizer was used instead of dilution ratio
[d] Signifies that a pre-plant treatment was used instead of foliar applied nitrogen
[RS] Research station used for trial location
[RF] Research farm used for trial location

Table6. Treatment means for grain yield and protein content for Lake Carl Blackwell research farm (LCB) near Stillwater, OK, 2012-2013, Lahoma (LAH), OK, 2012-2013, and Chickasha (CHK), OK, 2012-2013.

Location		LAH[RS]		LCB[RF]		CHK[RS]	
		Yield	Protein	Yield	Protein	Yield	Protein
kg N ha^{-1}	Dilution[a]	kg ha-1	g kg^{-1}	kg ha-1	g kg^{-1}	kg ha-1	g kg^{-1}
0	N/A[b]	2125	155	1753	115	1561	142
17	1:1	2691	149	2053	128	1596	154
17	2:1	2237	149	2173	124	1488	157
17	3:1	2810	152	2154	127	1682	157
17	1:0	3025	145	2246	145	1830	150
34	1:1	1813	167	2165	143	1846	165
34	2:1	2439	159	1706	158	1679	160
34	3:1	2191	143	2574	134	1572	163
34	1:0	2157	152	2154	123	1705	165
17	LS[c]	3033	142	2125	121	1709	155
34	LS[c]	1984	149	1691	141	1577	159
90	PP[d]	1977	158	2283	158	1695	174

[a] dilution ratio for the treatments indicating parts urea ammonium nitrate: parts water
[b] N/A states that this was the check plot and no dilution or nitrogen was applied
[c] LS signifies that a low salt fertilizer was used instead of dilution ratio
[d] Signifies that a pre-plant treatment was used instead of foliar applied nitrogen
[RS] Research station used for trial location
[RF] Research farm used for trial location

Table 7. Significant differences among means for grain yield at Lake Carl Blackwell research farm near Stillwater, OK, 2012-2013.

Treatment[a]	0-N	17,1:1	17,2:1	17,3:1	17,1:0	34,1:1	34,2:1	34,3:1	34,1:0	LS17	LS34	PP90
0-N	-	-	-	-	-	-	-	-	-	-	-	-
17,1:1		-	-	-	-	-	-	-	-	-	-	-
17,2:1			-	-	-	-	-	-	-	-	-	-
17,3:1				-	-	-	-	-	-	-	-	-
17,1:0					-	-	-	-	-	-	-	-
34,1:1						-	-	-	-	-	-	-
34,2:1							-	-	-	-	-	-
34,3:1	***							-	-	-	-	-
34,1:0	***								-	-	-	-
LS17										-	-	-
LS34											-	-
PP90	***										***	-

*** indicates significant difference at 0.05 probability level.

[a] indicates kg ha^{-1} of nitrogen that were used as well dilution ratio, LS is to indicate a low salt fertilizer was used instead of dilution and PP indicates a pre-plant fertilizer was used instead of a foliar application

Table 8. Contrasts statements for grain yield at Lake Carl Blackwell research farm near Stillwater, OK, 2012-2013.

Contrast[a]	DF	Contrast SS	Mean Square	F Value	Pr > F
Check vs N	1	366245	366245	2.71	0.11
PP90 vs foliar	1	227862	227862	1.68	0.21
17 vs 34	1	54616	54616	0.40	0.53
dilution linear	1	2772	2772	0.02	0.89
dilution quadratic	1	42758	42758	0.32	0.58
dilution cubic	1	1660	1660	0.01	0.91
(17 vs 34)(dilution linear)	1	2214	2214	0.02	0.90
(17 vs 34)(dilution quadratic)	1	27697	27697	0.20	0.66
(17 vs 34)(dilution cubic)	1	47706	47706	0.35	0.56
UAN vs LS	1	142088	142088	1.05	0.32
LS17 vs LS34	1	39977	39977	0.30	0.59

*indicates significant difference at 0.05 probability level.

[a] numbers indicate kg ha^{-1} of nitrogen that were applied foliarly, LS is to indicate a low salt fertilizer was used instead of dilution, UAN is urea ammonium nitrate 28-0-0.

Table 9. t-Grouping (LSD) for grain protein content at Lake Carl Blackwell research farm near Stillwater, OK, 2012-2013.

t Grouping[a]			Mean	N	trt[b]
			g kg^{-1}		
	A		134	3	PP90
	A				
B	A		130	3	LS34
B	A				
B	A		129	3	34,3:1
B	A				
B	A	C	128	3	34,2:1
B	A	C			
B	A	C	128	3	34,1:0
B	A	C			
B	A	C	126	3	17,1:0
B		C			
B		C	122	3	17,3:1
B		C			
B	D	C	121	3	17,1:1
B	D	C			
B	D	C	121	3	34,1:1
	D	C			
E	D	C	119	3	LS17
E	D				
E	D		113	3	0-N
E					
E			111	3	17,2:1

[a] Means with the same are letter are not significantly different at 0.05 probability level.
[b] indicates kg ha^{-1} of nitrogen that were used as well dilution ratio, LS is to indicate a low salt fertilizer was used instead of dilution and PP indicates a pre-plant fertilizer was used instead of a foliar application

Table 10. Contrasts statements for grain protein content at Lake Carl Blackwell research farm near Stillwater, OK, 2012-2013.

Contrast[a]	DF	Contrast SS	Mean Square	F Value	Pr > F
Check vs N	1	3.93	3.93	11.02	0.003*
90PP vs foliar	1	2.87	2.87	8.05	0.009*
17 vs 34	1	2.68	2.68	7.50	0.012
dilution linear	1	0.08	0.08	0.21	0.650
dilution quadratic	1	2.10	2.10	5.88	0.023*
dilution cubic	1	0.04	0.04	0.11	0.745
(17 vs 34)(dilution linear)	1	0.69	0.69	1.92	0.178
(17 vs 34)(dilution quadratic)	1	0.25	0.25	0.70	0.411
(17 vs 34)(dilution cubic)	1	1.74	1.74	4.87	0.037*
UAN vs LS	1	0.20	0.20	0.55	0.464
LS17 vs LS34	1	1.88	1.88	5.26	0.031*

*indicates significant difference at 0.05 probability level.

[a] numbers indicate kg ha^{-1} of nitrogen that were applied foliarly, LS is to indicate a low salt fertilizer was used instead of dilution, UAN is urea ammonium nitrate 28-0-0.

Table 11. Significant differences among means for grain yield at Lahoma, OK, 2012-2013.

Treatment[a]	0-N	17,1:1	17,2:1	17,3:1	17,1:0	34,1:1	34,2:1	34,3:1	34,1:0	LS17	LS34	PP90
0-N	-	-	-	-	-	-	-	-	-	-	-	-
17,1:1		-	-	-	-	-	-	-	-	-	-	-
17,2:1			-	-	-	-	-	-	-	-	-	-
17,3:1	***	***		-	-	-	-	-	-	-	-	-
17,1:0				***	-	-	-	-	-	-	-	-
34,1:1						-	-	-	-	-	-	-
34,2:1				***			-	-	-	-	-	-
34,3:1								-	-	-	-	-
34,1:0									-	-	-	-
LS17				***						-	-	-
LS34											-	-
PP90												-

*** indicates significant difference at 0.05 probability level.

[a] indicates kg ha-1 of nitrogen that were used as well dilution ratio, LS is to indicate a low salt fertilizer was used instead of dilution and PP indicates a pre-plant fertilizer was used instead of a foliar application

Table 12. Contrasts statements for grain yield at Lahoma, OK, 2012-2013.

Contrast[a]	DF	Contrast SS	Mean Square	F Value	Pr > F
Check vs N	1	625246	625246	2.96	0.103
PP90 vs foliar	1	5972	5972	0.03	0.869
17 vs 34	1	348108	348108	1.65	0.216
dilution linear	1	579412	579412	2.74	0.115
dilution quadratic	1	290141	290141	1.37	0.257
dilution cubic	1	103597	103597	0.49	0.493
(17 vs 34)(dilution linear)	1	363106	363106	1.72	0.207
(17 vs 34)(dilution quadratic)	1	1850	1850	0.01	0.927
(17 vs 34)(dilution cubic)	1	108719	108719	0.51	0.483
UAN vs LS	1	79214	79214	0.37	0.548
LS17 vs LS34	1	125301	125301	0.59	0.452

*indicates significant difference at 0.05 probability level.

[a] numbers indicate kg ha^{-1} of nitrogen that were applied foliarly, LS is to indicate a low salt fertilizer was used instead of dilution, UAN is urea ammonium nitrate 28-0-0.

Table 13. t-Grouping (LSD) for grain protein content at Lahoma, OK, 2012-2013.

t Grouping[a]			Mean	N	Trt[b]
			g kg^{-1}		
	A		139	3	17,3:1
	A				
	A		137	3	PP90
	A				
B	A		136	3	17,1:1
B	A				
B	A	C	134	3	17,1:0
B	A	C			
B	A	C	133	3	17,2:1
B	A	C			
B	A	C	132	3	34,3:1
B	A	C			
B	A	C	131	3	34,1:0
B	A	C			
B	A	C	130	3	34,2:1
B	A	C			
B	A	C	129	3	34,1:1
B	A	C			
B	A	C	125	3	LS34
B		C			
B		C	122	3	0-N
		C			
		C	120	3	LS17

[a] Means with the same are letter are not significantly different at 0.05 probability level.

[b] indicates kg ha^{-1} of nitrogen that were used as well dilution ratio, LS is to indicate a low salt fertilizer was used instead of dilution and PP indicates a pre-plant fertilizer was used instead of a foliar application

Table 14. Contrasts statements for grain protein content at Lahoma, OK, 2012-2013.

Contrast[a]	DF	Contrast SS	Mean Square	F Value	Pr > F
Check vs N	1	2.63	2.63	1.95	0.175
PP90 vs foliar	1	0.97	0.97	0.72	0.404
17 vs 34	1	1.51	1.51	1.12	0.301
dilution linear	1	0.21	0.21	0.16	0.694
dilution quadratic	1	0.29	0.29	0.22	0.646
dilution cubic	1	0.12	0.12	0.09	0.772
(17 vs 34)(dilution linear)	1	0.03	0.03	0.02	0.887
(17 vs 34)(dilution quadratic)	1	0.00	0.00	0.00	0.969
(17 vs 34)(dilution cubic)	1	0.20	0.20	0.15	0.705
UAN vs LS	1	3.17	3.17	2.35	0.139
LS17 vs LS34	1	0.33	0.33	0.25	0.624

*indicates significant difference at 0.05 probability level.

[a] numbers indicate kg ha^{-1} of nitrogen that were applied foliarly, LS is to indicate a low salt fertilizer was used instead of dilution, UAN is urea ammonium nitrate 28-0-0.

Tabel 15. Significant differences among means for grain yield at Lake Carl Blackwell research farm near Stillwater, OK, 2013-2014.

Treatment[a]	0-N	17,1:1	17,2:1	17,3:1	17,1:0	34,1:1	34,2:1	34,3:1	34,1:0	LS17	LS34	PP90
0-N	-	-	-	-	-	-	-	-	-	-	-	-
17,1:1		-	-	-	-	-	-	-	-	-	-	-
17,2:1			-	-	-	-	-	-	-	-	-	-
17,3:1				-	-	-	-	-	-	-	-	-
17,1:0					-	-	-	-	-	-	-	-
34,1:1						-	-	-	-	-	-	-
34,2:1							-	-	-	-	-	-
34,3:1								-	-	-	-	-
34,1:0									-	-	-	-
LS17										-	-	-
LS34											-	-
PP90												-

*** indicates significant difference at 0.05 probability level.

[a] indicates kg ha-1 of nitrogen that were used as well dilution ratio, LS is to indicate a low salt fertilizer was used instead of dilution and PP indicates a pre-plant fertilizer was used instead of a foliar application

Table 16. Contrasts statements for grain yield at Lake Carl Blackwell research farm near Stillwater, OK, 2013-2014.

Contrast[a]	DF	Contrast SS	Mean Square	F Value	Pr > F
Check vs N	1	367091	367091	1.42	0.246
PP90 vs foliar	1	86160	86160	0.33	0.570
17 vs 34	1	237	237	0.00	0.976
dilution linear	1	27735	27735	0.11	0.746
dilution quadratic	1	354550	354550	1.37	0.254
dilution cubic	1	120864	120864	0.47	0.501
(17 vs 34)(dilution linear)	1	60946	60946	0.24	0.632
(17 vs 34)(dilution quadratic)	1	154909	154909	0.60	0.447
(17 vs 34)(dilution cubic)	1	337663	337663	1.31	0.266
UAN vs LS	1	227023	227023	0.88	0.359
LS17 vs LS34	1	225503	225503	0.87	0.361

*indicates significant difference at 0.05 probability level.

[a] numbers indicate kg ha^{-1} of nitrogen that were applied foliarly, LS is to indicate a low salt fertilizer was used instead of dilution, UAN is urea ammonium nitrate 28-0-0.

Table 17. t-Grouping (LSD) for grain protein content at Lake Carl Blackwell research farm near Stillwater, OK, 2013-2014.

t Grouping[a]			**Mean**	**N**	**Trt**[b]
			g kg^{-1}		
	A		159	3	34,2:1
	A				
	A		158	3	PP90
	A				
B	A		145	3	17,1:0
B	A				
B	A		143	3	34,1:1
B	A				
B	A	C	141	3	LS34
B	A	C			
B	A	C	134	3	34,3:1
B		C			
B		C	128	3	17,1:1
B		C			
B		C	127	3	17,3:1
B		C			
B		C	124	3	17,2:1
B		C			
B		C	123	3	34,1:0
B		C			
B		C	121	3	LS17
		C			
		C	115	3	0-N

[a] Means with the same are letter are not significantly different at 0.05 probability level.
[b] indicates kg ha^{-1} of nitrogen that were used as well dilution ratio, LS is to indicate a low salt fertilizer was used instead of dilution and PP indicates a pre-plant fertilizer was used instead of a foliar application

Table 18. Contrasts statements for grain protein content at Lake Carl Blackwell research farm near Stillwater, OK, 2013-2014.

Contrast[a]	DF	Contrast SS	Mean Square	F Value	Pr > F
Check vs N	1	12.52	12.52	5.29	0.030*
PP90 vs foliar	1	5.81	5.81	2.46	0.130
17 vs 34	1	0.42	0.42	0.18	0.678
dilution linear	1	10.51	10.51	4.44	0.046*
dilution quadratic	1	13.91	13.91	5.88	0.023*
dilution cubic	1	1.25	1.25	0.53	0.475
(17 vs 34)(dilution linear)	1	7.71	7.71	3.26	0.084
(17 vs 34)(dilution quadratic)	1	0.56	0.56	0.24	0.631
(17 vs 34)(dilution cubic)	1	0.38	0.38	0.16	0.693
UAN vs LS	1	3.37	3.37	1.42	0.244
LS17 vs LS34	1	8.86	8.86	3.74	0.065

*indicates significant difference at 0.05 probability level.

[a] numbers indicate kg ha^{-1} of nitrogen that were applied foliarly, LS is to indicate a low salt fertilizer was used instead of dilution, UAN is urea ammonium nitrate 28-0-0.

Table 19. Significant differences among means for grain yield at Lahoma, OK, 2013-2014.

Treatment[a]	0-N	17,1:1	17,2:1	17,3:1	17,1:0	34,1:1	34,2:1	34,3:1	34,1:0	LS17	LS34	PP90
0-N	-	-	-	-	-	-	-	-	-	-	-	-
17,1:1		-	-	-	-	-	-	-	-	-	-	-
17,2:1			-	-	-	-	-	-	-	-	-	-
17,3:1				-	-	-	-	-	-	-	-	-
17,1:0					-	-	-	-	-	-	-	-
34,1:1					***	-	-	-	-	-	-	-
34,2:1							-	-	-	-	-	-
34,3:1								-	-	-	-	-
34,1:0									-	-	-	-
LS17						***				-	-	-
LS34					***					***	-	-
PP90					***					***		-

*** indicates significant difference at 0.05 probability level.

[a] indicates kg ha-1 of nitrogen that were used as well dilution ratio, LS is to indicate a low salt fertilizer was used instead of dilution and PP indicates a pre-plant fertilizer was used instead of a foliar application

Table20. Contrasts statements for grain yield at Lahoma, OK, 2013-2014.

Contrast[a]	DF	Contrast SS	Mean Square	F Value	Pr > F
Check vs N	1	201105	201105	0.54	0.469
PP90 vs foliar	1	576938	576938	1.55	0.225
17 vs 34	1	1650276	1650276	4.44	0.046*
dilution linear	1	10253	10253	0.03	0.870
dilution quadratic	1	354890	354890	0.96	0.339
dilution cubic	1	32709	32709	0.09	0.769
(17 vs 34)(dilution linear)	1	246672	246672	0.66	0.424
(17 vs 34)(dilution quadratic)	1	232222	232222	0.63	0.437
(17 vs 34)(dilution cubic)	1	603959	603959	1.63	0.215
UAN vs LS	1	20430	20430	0.05	0.817
LS17 vs LS34	1	1650500	1650500	4.44	0.046*

*indicates significant difference at 0.05 probability level.

[a] numbers indicate kg ha^{-1} of nitrogen that were applied foliarly, LS is to indicate a low salt fertilizer was used instead of dilution, UAN is urea ammonium nitrate 28-0-0.

Table 21. t-Grouping (LSD) for grain protein content at Lahoma, OK, 2013-2014.

t Grouping[a]			**Mean**	**N**	**Trt**[b]
			g kg^{-1}		
	A		167	3	34,1:1
	A				
B	A		159	3	34,3:1
B	A				
B	A		159	3	34,2:1
B	A				
B	A		158	3	PP90
B	A				
B	A	C	155	3	0-N
B		C			
B	D	C	152	3	17,3:1
B	D	C			
B	D	C	152	3	34,1:0
B	D	C			
B	D	C	149	3	17,1:1
B	D	C			
B	D	C	149	3	17,2:1
B	D	C			
B	D	C	149	3	LS34
	D	C			
	D	C	145	3	17,1:0
	D				
	D		142	3	LS17

[a] Means with the same are letter are not significantly different at 0.05 probability level.
[b] indicates kg ha^{-1} of nitrogen that were used as well dilution ratio, LS is to indicate a low salt fertilizer was used instead of dilution and PP indicates a pre-plant fertilizer was used instead of a foliar application

Table 22. Contrasts statements for grain protein content at Lahoma, OK, 2013-2014.

Contrast[a]	DF	Contrast SS	Mean Square	F Value	Pr > F
Check vs N	1	0.12	0.12	0.23	0.639
PP90 vs foliar	1	0.05	0.05	0.09	0.768
17 vs 34	1	0.89	0.89	1.71	0.205
dilution linear	1	0.70	0.70	1.35	0.258
dilution quadratic	1	2.80	2.80	5.38	0.030*
dilution cubic	1	1.51	1.51	2.90	0.103
(17 vs 34)(dilution linear)	1	6.91	6.91	13.28	0.001*
(17 vs 34)(dilution quadratic)	1	0.14	0.14	0.28	0.604
(17 vs 34)(dilution cubic)	1	0.26	0.26	0.50	0.486
UAN vs LS	1	0.03	0.03	0.06	0.811
LS17 vs LS34	1	0.00	0.00	0.00	0.995

*indicates significant difference at 0.05 probability level.

[a] numbers indicate kg ha^{-1} of nitrogen that were applied foliarly, LS is to indicate a low salt fertilizer was used instead of dilution, UAN is urea ammonium nitrate 28-0-0.

Table 23. Significant differences among means for grain yield at Chickasha, OK, 2013-2014.

Treatment[a]	0-N	17,1:1	17,2:1	17,3:1	17,1:0	34,1:1	34,2:1	34,3:1	34,1:0	LS17	LS34	PP90
0-N	-	-	-	-	-	-	-	-	-	-	-	-
17,1:1		-	-	-	-	-	-	-	-	-	-	-
17,2:1			-	-	-	-	-	-	-	-	-	-
17,3:1				-	-	-	-	-	-	-	-	-
17,1:0			***		-	-	-	-	-	-	-	-
34,1:1			***			-	-	-	-	-	-	-
34,2:1							-	-	-	-	-	-
34,3:1								-	-	-	-	-
34,1:0									-	-	-	-
LS17										-	-	-
LS34											-	-
PP90												-

*** indicates significant difference at 0.05 probability level.

[a] indicates kg ha-1 of nitrogen that were used as well dilution ratio, LS is to indicate a low salt fertilizer was used instead of dilution and PP indicates a pre-plant fertilizer was used instead of a foliar application

Table24. Contrasts statements for grain yield at Chickasha, OK, 2013-2014.

Contrast[a]	DF	Contrast SS	Mean Square	F Value	Pr > F
Check vs N	1	33382	33382	0.69	0.416
PP90 vs foliar	1	1982	1982	0.04	0.842
17 vs 34	1	16025	16025	0.33	0.572
dilution linear	1	93709	93709	1.92	0.178
dilution quadratic	1	12126	12126	0.25	0.622
dilution cubic	1	22033	22033	0.45	0.508
(17 vs 34)(dilution linear)	1	10	10	0.00	0.989
(17 vs 34)(dilution quadratic)	1	171410	171410	3.52	0.073
(17 vs 34)(dilution cubic)	1	2827	2827	0.06	0.812
UAN vs LS	1	46557	46557	0.96	0.338
LS17 vs LS34	1	25841	25841	0.53	0.473

*indicates significant difference at 0.05 probability level.

[a] numbers indicate kg ha^{-1} of nitrogen that were applied foliarly, LS is to indicate a low salt fertilizer was used instead of dilution, UAN is urea ammonium nitrate 28-0-0.

Table 25. t-Grouping (LSD) for grain protein content at Chickasha, OK, 2013-2014.

t Grouping[a]			**Mean**	**N**	**Trt**[b]
			g kg^{-1}		
	A		174	3	PP90
	A				
B	A		165	3	34,1:0
B	A				
B	A		165	3	34,1:1
B	A				
B	A	C	163	3	34,3:1
B	A	C			
B	A	C	160	3	34,2:1
B		C			
B		C	159	3	LS34
B		C			
B		C	157	3	17,3:1
B		C			
B		C	157	3	17,2:1
B		C			
B	D	C	155	3	LS17
B	D	C			
B	D	C	154	3	17,1:1
	D	C			
	D	C	150	3	17,1:0
	D				
	D		142	3	0-N

[a] Means with the same are letter are not significantly different at 0.05 probability level.
[b] indicates kg ha^{-1} of nitrogen that were used as well dilution ratio, LS is to indicate a low salt fertilizer was used instead of dilution and PP indicates a pre-plant fertilizer was used instead of a foliar application

Table 26. Contrasts statements for grain protein content at Chickasha, OK, 2013-2014.

Contrast[a]	DF	Contrast SS	Mean Square	F Value	Pr > F
Check vs N	1	8.66	8.66	10.92	0.003*
PP90 vs foliar	1	0.76	0.76	0.96	0.338
17 vs 34	1	0.73	0.73	0.92	0.346
dilution linear	1	0.20	0.20	0.25	0.619
dilution quadratic	1	0.77	0.77	0.98	0.333
dilution cubic	1	0.03	0.03	0.04	0.853
(17 vs 34)(dilution linear)	1	8.42	8.42	10.62	0.003*
(17 vs 34)(dilution quadratic)	1	0.70	0.70	0.89	0.355
(17 vs 34)(dilution cubic)	1	0.45	0.45	0.56	0.460
UAN vs LS	1	0.15	0.15	0.18	0.673
LS17 vs LS34	1	0.14	0.14	0.18	0.677

*indicates significant difference at 0.05 probability level.

[a] numbers indicate kg ha^{-1} of nitrogen that were applied foliarly, LS is to indicate a low salt fertilizer was used instead of dilution, UAN is urea ammonium nitrate 28-0-0.

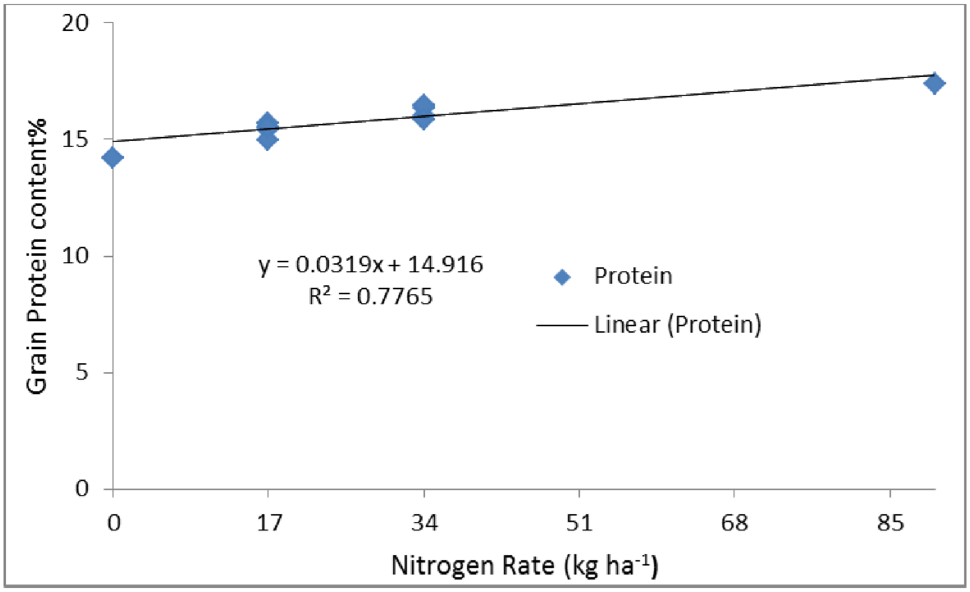

Figure 1. Linear regression displaying relationship between nitrogen rate and grain protein content for Chickasha, OK, 2013-2014.

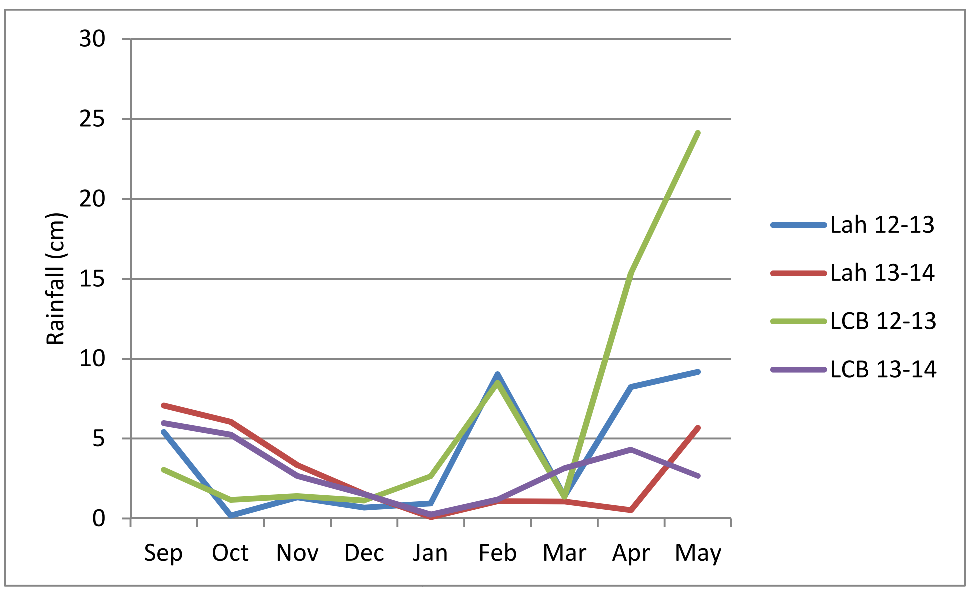

Figure 2. Total rainfall per month in cm for Lahoma (LAH), OK, 2012-2013 and 2013-2014, and Lake Carl Blackwell (LCB) research farm near Stillwater, OK, 2012-2013 and 2013-2014.

APPENDICES

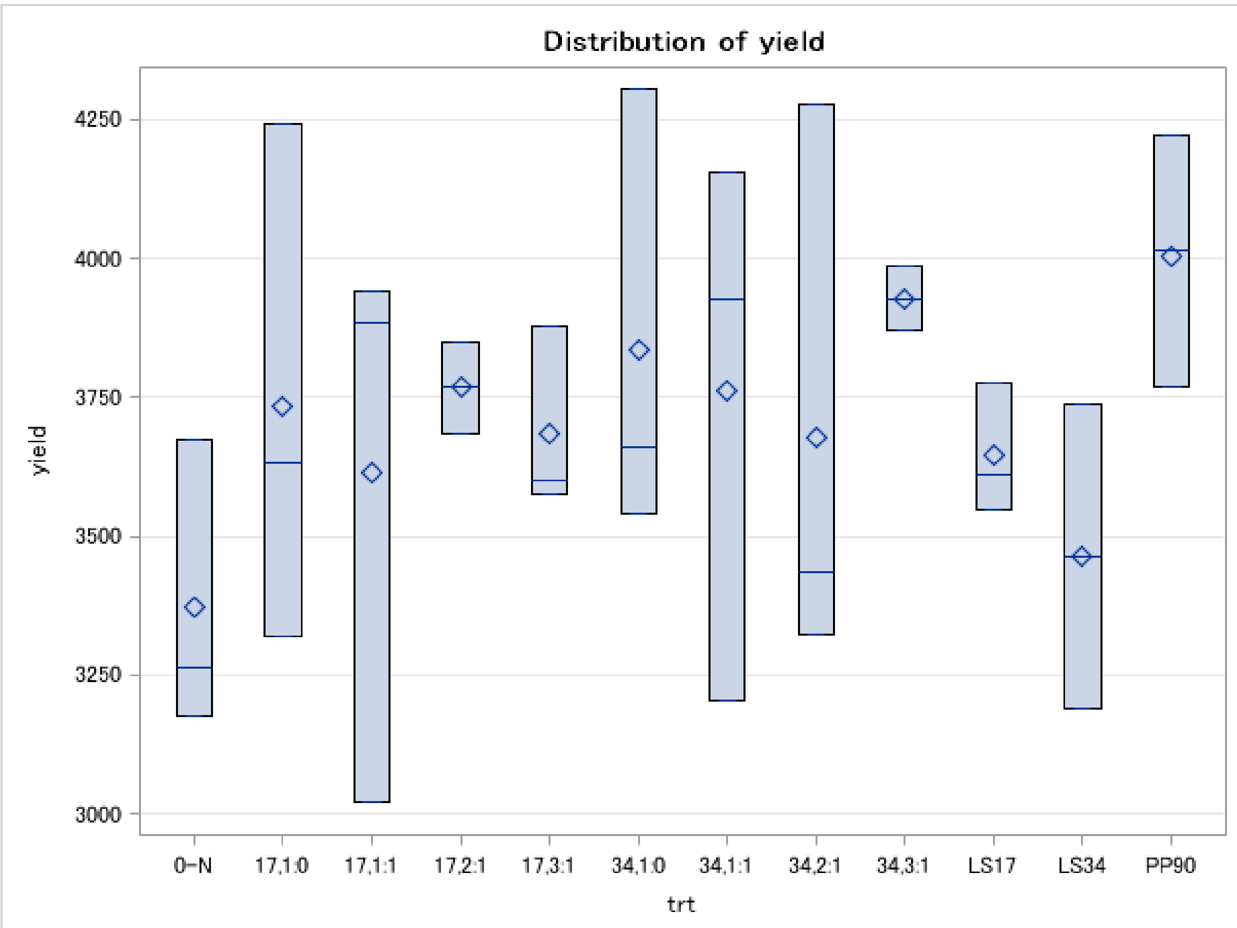

Figure 3. Boxplot graphing grain yield, Lake Carl Blackwell research farm near Stillwater, OK, 2012-13.

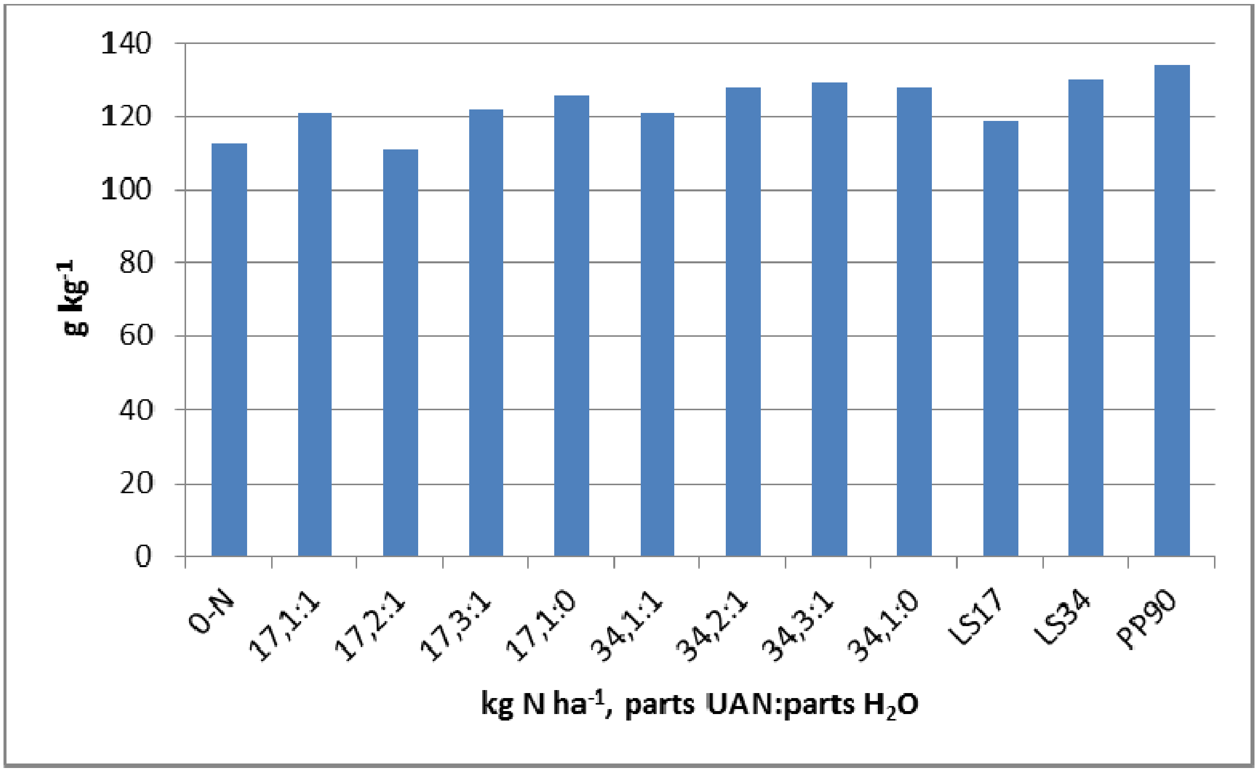

Figure 4. Histogram graphing grain protein content, Lake Carl Blackwell research farm near Stillwater, OK, 2012-13.

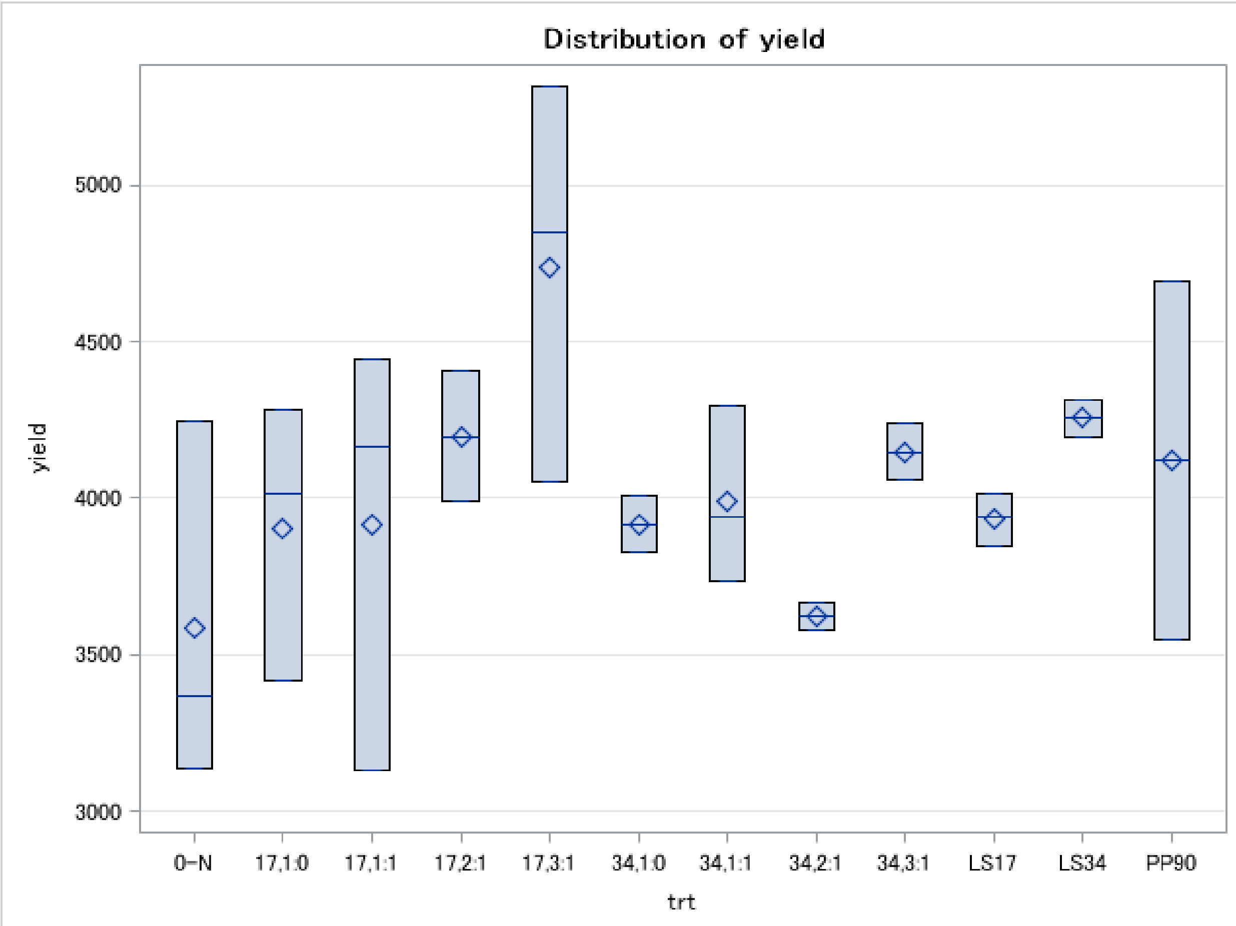

Figure 5. Boxplot graphing grain yield, Lahoma, OK, 2012-13.

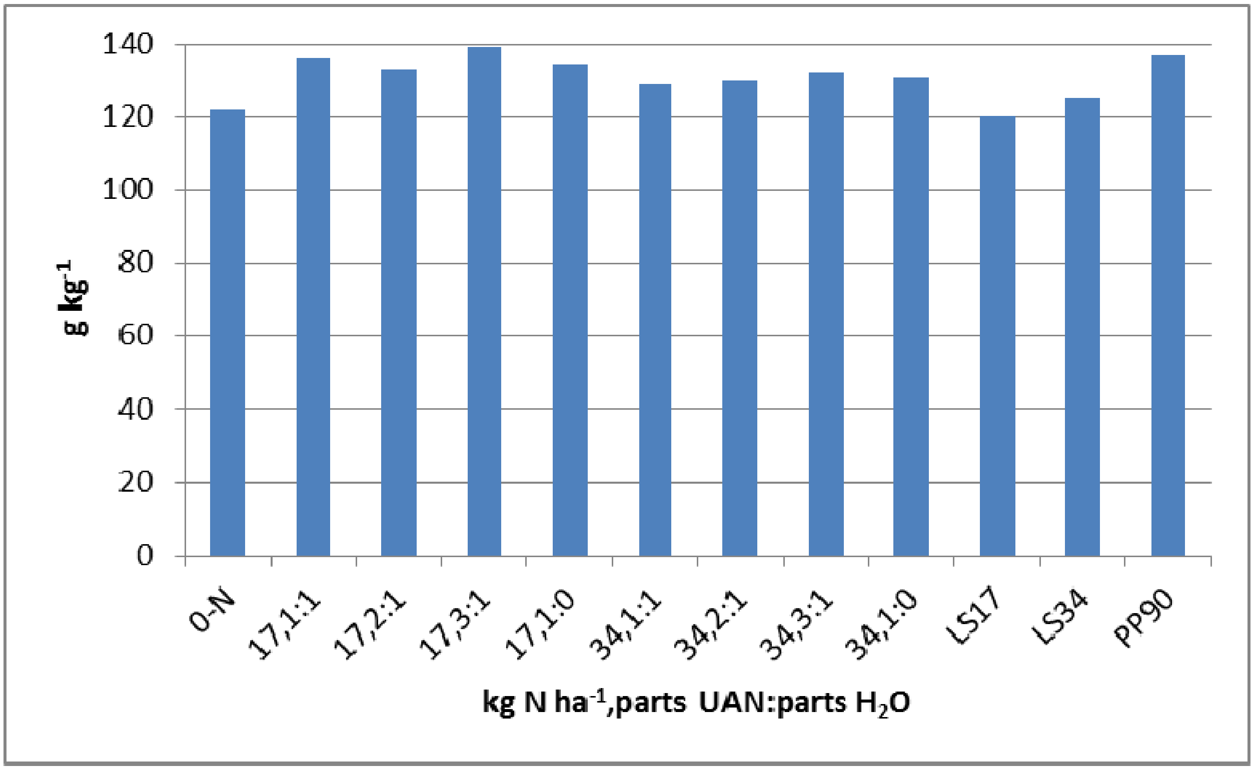

Figure 6. Boxplot graphing grain protein content, Lahoma, OK, 2012-13.

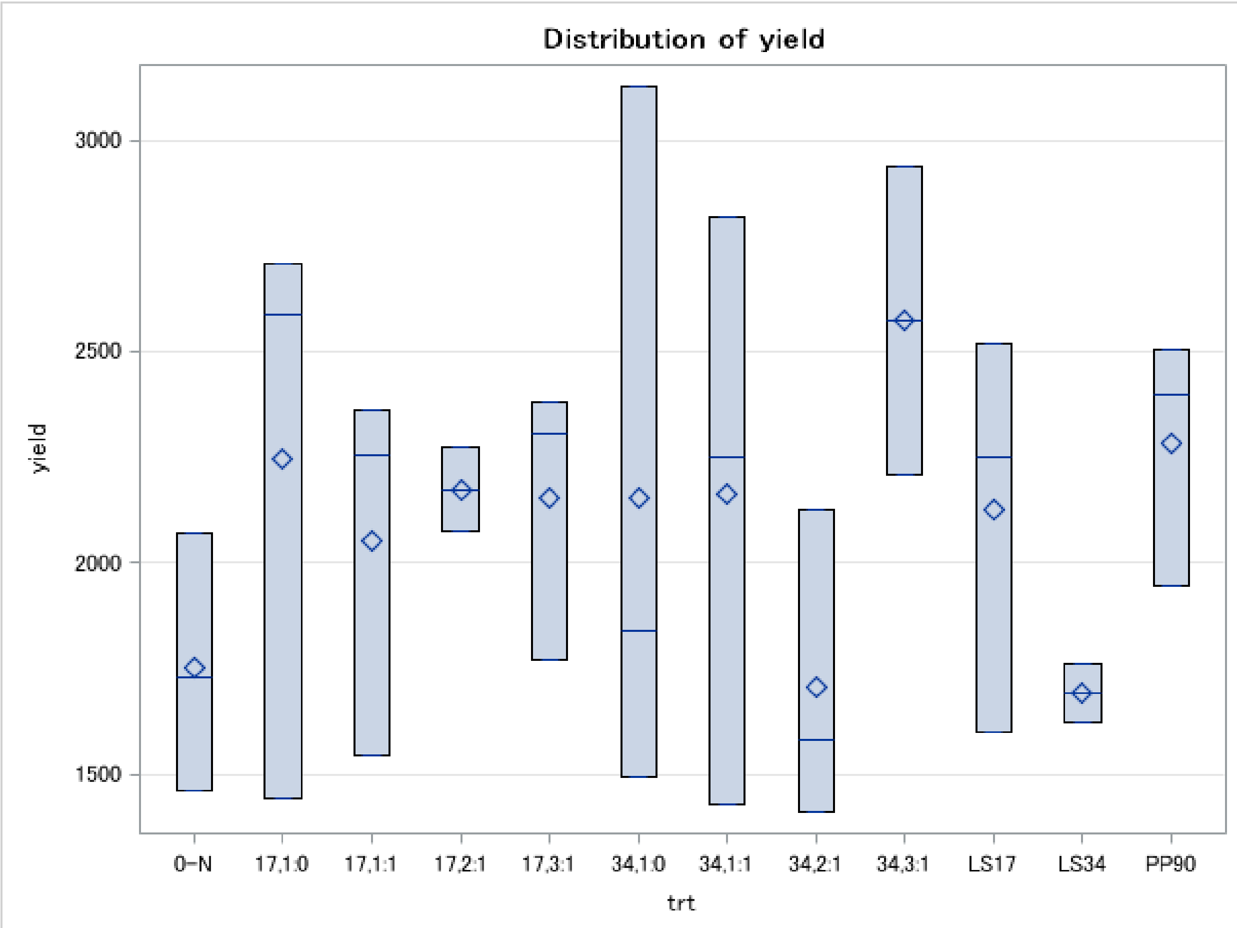

Figure 7. Boxplot graphing grain yield, Lake Carl Blackwell research farm near Stillwater, OK, 2013-14.

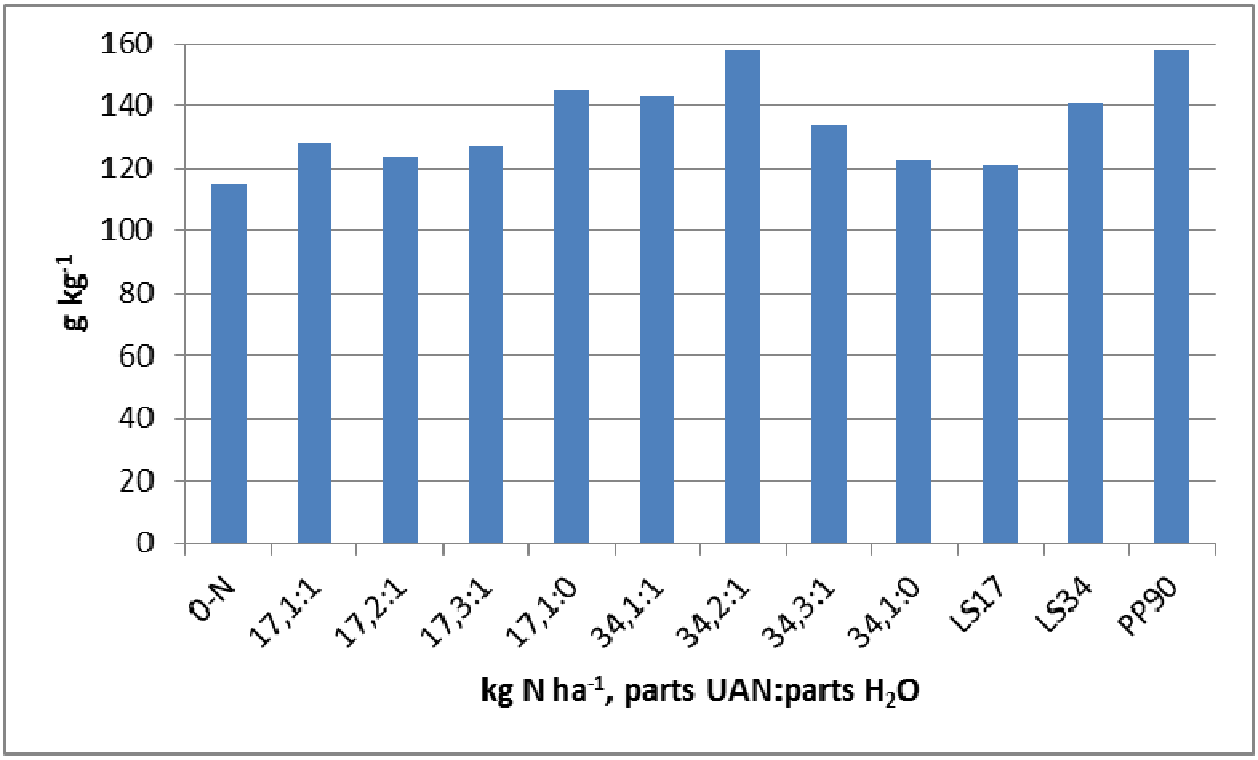

Figure 8. Histogram graphing grain protein content, Lake Carl Blackwell research farm near Stillwater, OK, 2013-14.

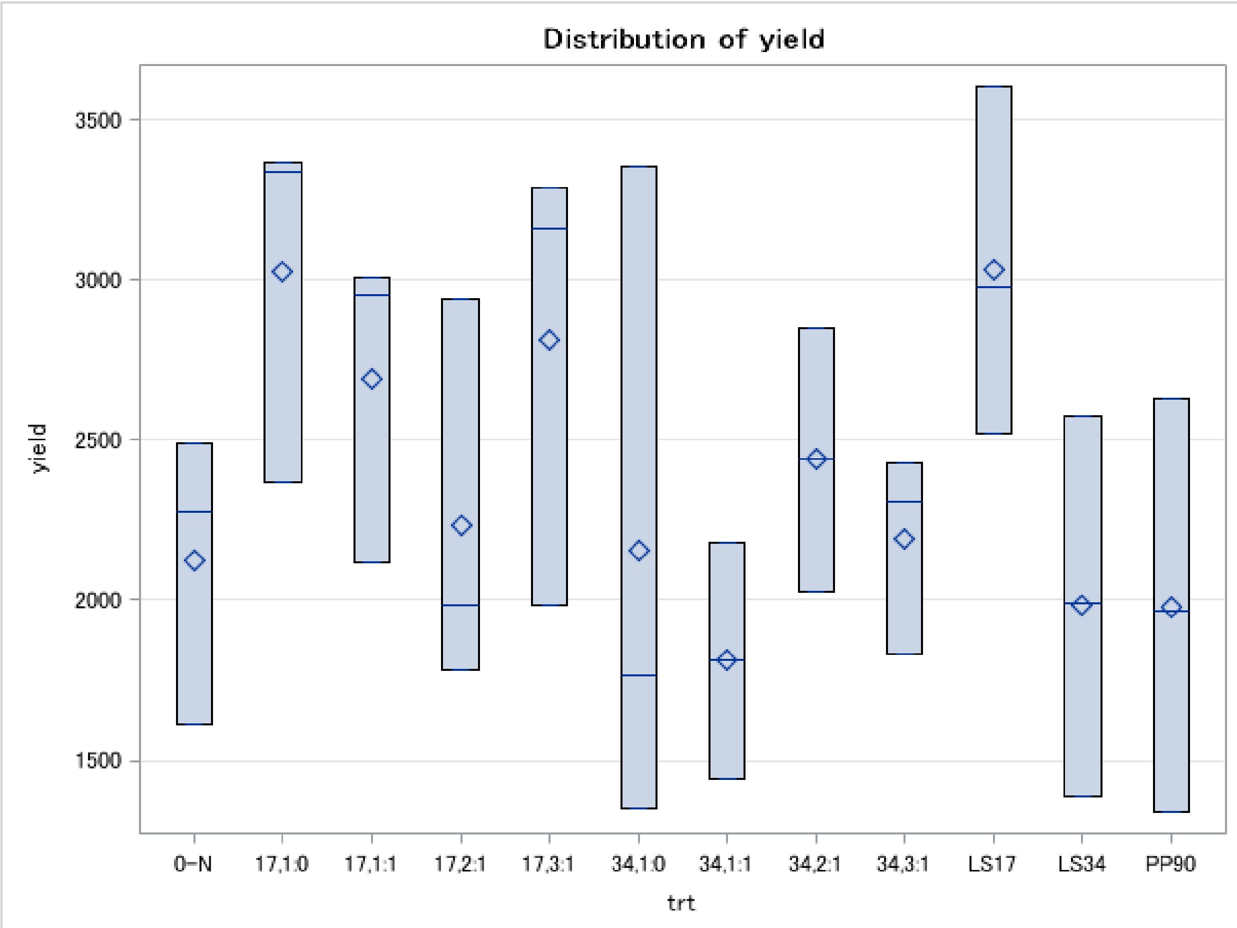

Figure 9. Boxplot graphing grain yield, Lahoma, OK, 2013-14.

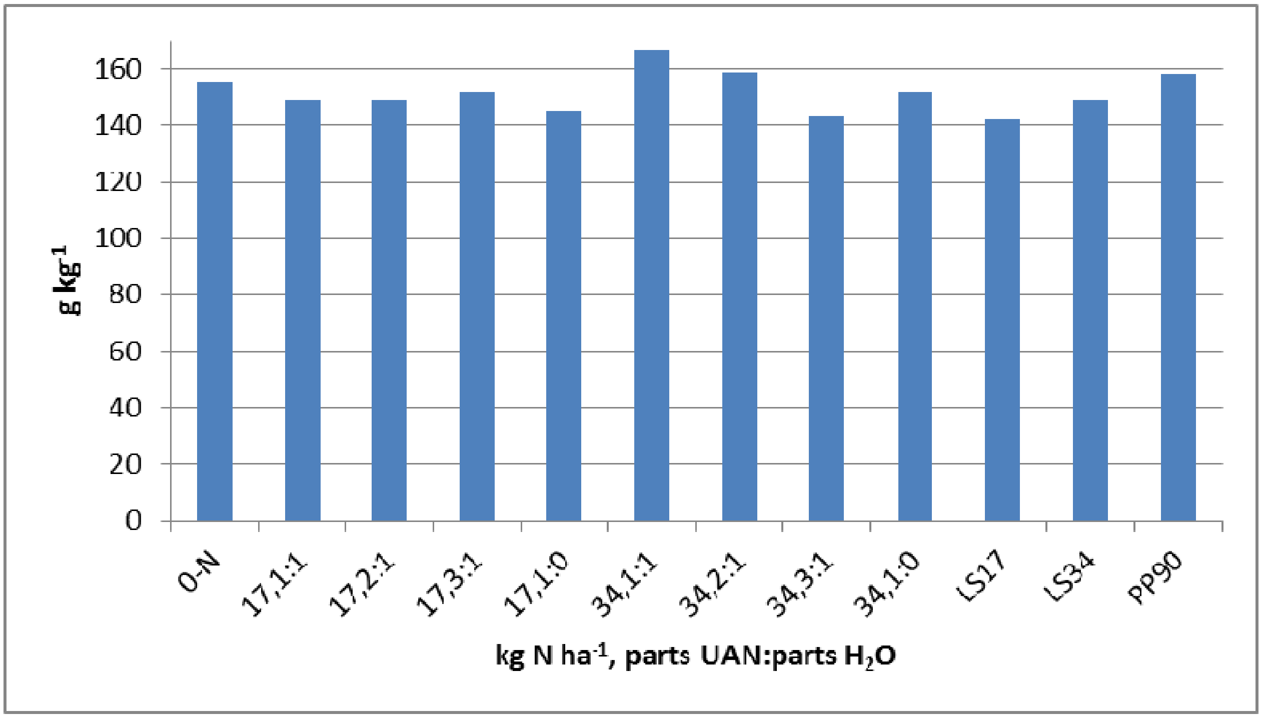

Figure 10. Histogram graphing grain protein content, Lahoma, OK, 2013-14.

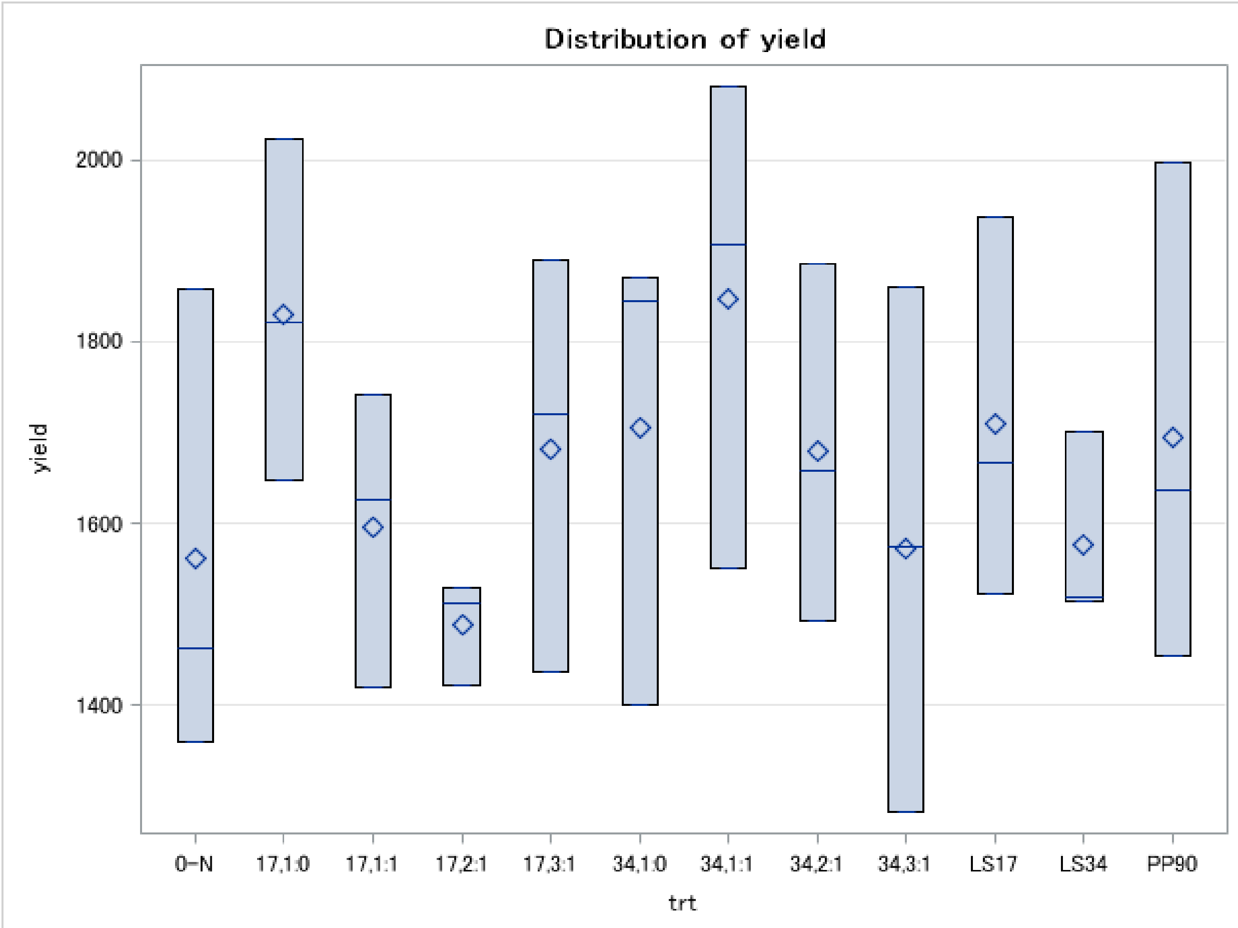

Figure 11. Boxplot graphing grain yield, Chickasha, OK, 2013-14.

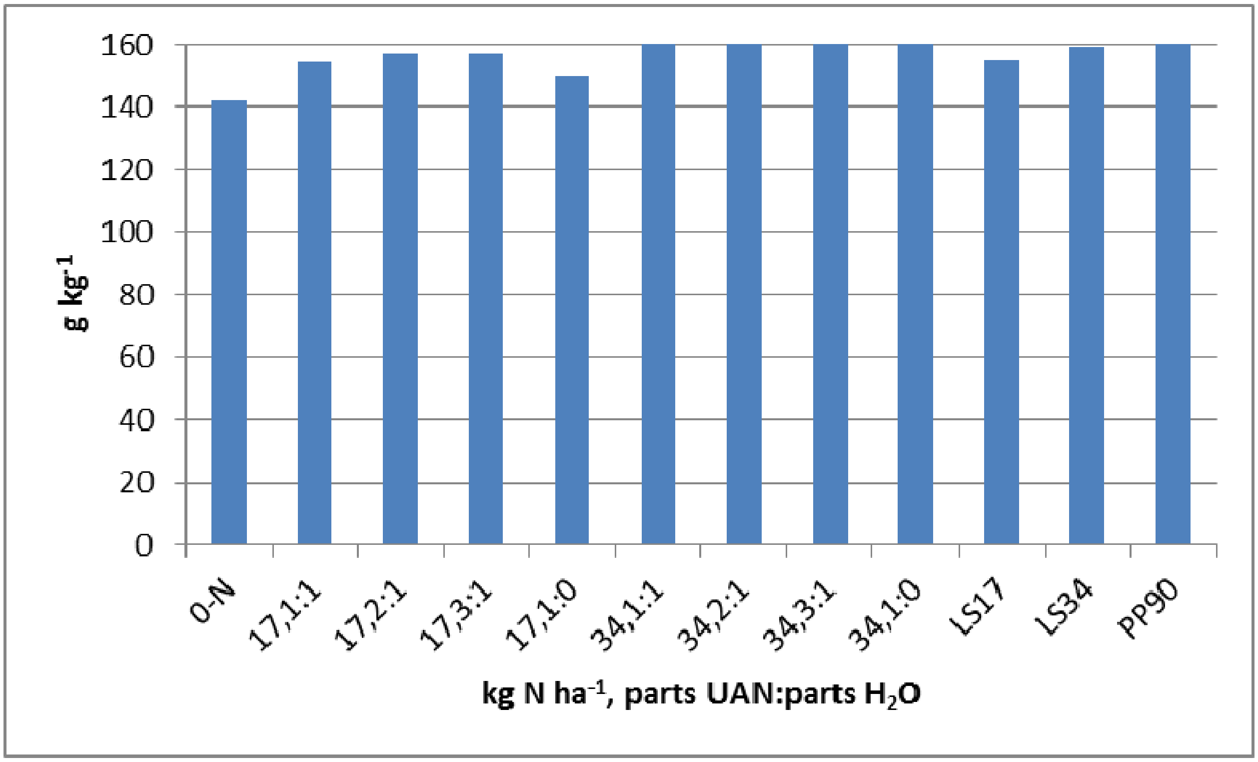

Figure 12. Histogram graphing grain protein content, Chickasha, OK, 2013-14.

VITA

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