INFLUENCE OF FOLIAR SULFUR, CHLORIDE AND NITROGEN ON WINTER WHEAT GRAIN YIELD AND TOTAL NITROGEN (*TRITICUM AESTIVUM L.*)

By

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Abstract: Optimum use of nitrogen (N) is a key component in improving wheat grain yield and quality. The combined effect of other nutrients with N can have a positive impact on crop production. Using sulfur (S) and chloride (Cl) in wheat and other cereals has received increased attention in recent years. Foliar S and Cl can assist in optimizing wheat yield and total N, especially in sandy soils with low organic matter where deficiencies are expected. Winter wheat studies were conducted for 3 site-years at Lake Carl Blackwell (LCB) and Lahoma (LAH) in the fall of 2011 and 2012 to evaluate the effect of flag leaf applied foliar N, S and Cl on winter wheat grain yield and grain N. Two N rates, 10 and 20 kg N ha^{-1}, as urea triazone (N-SURE, 28-0-0) and urea ammonium nitrate (UAN, 28-0-0) were foliar applied. Treatments included foliar application of gypsum (6 kg S ha^{-1}) and calcium chloride at a rate of 10 kg Cl ha^{-1}applied with the help of CO_2 backpack sprayer. Results showed total grain N increased with increasing preplant N rate at LCB and LAH. With increasing preplant N, a linear increase in yield was observed at LAH and a quadratic increase in yield at LCB. There was no response to foliar N, Cl and S at both locations. This study indicated that S and Cl fertilization did not increase yield and protein.

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CHAPTER I

INTRODUCTION

Worldwide, wheat growers are constantly making efforts to increase grain production and quality to meet the increasing food demand of a growing world population. The growth in global wheat production over the years has established wheat as the second largest staple food. In Oklahoma, hard red winter wheat is the dominant crop by value and area.

Nitrogen is an essential constituent of grain protein, the most mobile and most limiting nutrient in the soil. Improved management of N will be essential for wheat growing farmers in order to increase the nitrogen use efficiency (NUE). An adequate amount of soil N is necessary to increase grain yields and grain protein concentration. Halloran, 1981 and Pearman et al., 1978 suggested that higher grain yields may not give higher protein as yield and protein are inversely related due to energy constraints and dilution effects within the plant. Maximum N response can only be obtained when S is sufficient and vice versa (Hu, 1992). Wheat generally requires 1 kg of N to produce 27 kg of grain (Zhang et al., 2006). In regard to human nutrition, flour quality for making bread, pasta and other products, protein content of the wheat grain has an influential role. The level of protein is the main factor determining milling and baking quality. Desired protein ranges from 10 to 15 percent depending on the type for milling and baking quality.

Sulfur has received extensive attention in the past few years as the areas of S deficiency are becoming widespread throughout the world including the US (Scherer, 2001). Sulfur functions as a component of protein through sulfur containing amino acids cysteine, cystine and methionine; key component for the production of chlorophyll (Imsande, 1998). While the essential role of sulfur in plant growth and development has long been recognized, deficiencies in cereals were first reported in Scotland (Scott et al., 1984).

Chloride has been recognized as an essential plant nutrient since 1954 (Broyer et al., 1954). Because soil Chloride levels were high and inputs from rain were adequate to meet the crop requirement, until recently little attention was given to Cl as a fertilizer. Sulfur and Cl are mobile in the soil and can thus be easily lost from the soil system through leaching. Deficiencies are observed when high yields are produced in deep, sandy soils with low organic matter in high rainfall areas (LaRuffa, 1999). Chloride deficiencies are sometimes seen in soils with high levels of potassium (K). Most of the soils in western Oklahoma are high in K and farmers don't fertilize with potash (potassium chloride). Potassium chloride or potash is the most common Cl fertilizer.

Sulfur and Cl are essential nutrients for plant growth. Oklahoma soils receive around 22.4 kg ha^{-1} S (Johnson et al., 2003) and 4 kg ha^{-1} Cl through annual precipitation. Cereal crops require only a moderate amount of S, (15-20 kg ha^{-1}) for optimum growth (Shahsavani et al., 2008). For Oklahoma soils, the optimum soil chloride level is 39 kg ha^{-1} (depth = 0-60 cm). When soil Cl in the surface 15 cm is tested, the level of Cl at 30 and 45 cm depth can be obtained by multiplying the soil Cl at 15 cm by 2 and 3 respectively (Oklahoma State University, 2013).

Wheat has a relatively low S requirement of 20 kg ha^{-1}to obtain a grain yield 8 Mg ha^{-1} (McGrath et al., 1996). When the amount of S supplied from precipitation and other S containing fertilizers are lower, the crop requires additional supply of S. Sulfur response has been observed on winter wheat in Perkins and Carrier Oklahoma where the soil is sandy (LaRuffa, 1999). Therefore use of S and Cl in wheat can optimize yield in soil deficient conditions.

CHAPTER II

REVIEW OF LITERATURE

Higher wheat grain protein concentrations offer higher market values and in some parts of the US like Colorado (coloradowheat.org, 2012), Minnesota (minnesotafarmguide.com, 2011) premiums are paid for protein above baseline levels. Protein content for hard red winter wheat should be 11.5% or higher (Terman, 1979; Johnson et al., 1979). Anthony (2003) mentioned that in the upper Midwest of the USA, standard market GPC for spring wheat is 14%.

Dupont et al. (2003) mentioned that environmental variables such as temperature, water and fertilizer influence the rate and duration of wheat grain development, protein accumulation and starch deposition in unique ways, and by different mechanisms. The most important factors that affect protein content are N fertilization rate, time of application and residual soil N (Rao et al., 1993). Mary et al. (2001) suggested that moisture stress can influence both grain yield and the end use quality of wheat. Campbell (1981) noted that temperature is the most important factor affecting yield and protein, while moisture stress is the least important. Various studies have reported the influence of N fertilization on grain protein concentration (Goos et al., 1981; Somme, 2007). Foliar application of N may increase or decrease yield and application of foliar N before or immediately following flowering increases the grain protein content (Woolfolk et al., 2002). Increasing grain protein via foliar N is dependent on the growth stage of wheat. Woolfolk et al., (2002) showed that UAN applied post flowering was very effective in increasing grain protein. Arnall et al. (2012) found an inconsistent relationship between grain protein and foliar N application at flag leaf stage in wheat. Foliar application of urea is a practical method to increase grain N content and percent protein in winter wheat (David et al., 1989; Woolfolk et al., 2002). Engin et al. (2007) showed that foliar treatment of N, P, K and other micronutrients had a positive effect on grain yield, spikelet number per spike, number of grains per spike, 1000 grain weight, and harvest index. (Phillips et al., 1999)

It has been established that sulfur nutrition of wheat influences bread making quality of flour (Thomason et al., 2007). The disulfide bond in sulfur has a primary role in maintaining the gluten functionality which influences the bread making quality of flour (Zhao et al., 1998). Several factors are contributing to increasing soil S deficiency: a considerable decrease in inputs from atmospheric deposition caused by stricter emission regulations, high yielding varieties and intensive agriculture (Scherer, 2001), farmers shifting from using S-containing fertilizers to S-free fertilizers (Zhao et al., 1999a). A study conducted in Great Britain, showed that the dough extensibility could be limited by sulfur deficiency (Kettlewell et al., 1996).

Extensibility is the stretching property of the dough. Dough with good extensibility is easy to stretch which is a fairly important characteristic for manual shaping of bakery products. Wrigley (1983) found that sulfur deficient wheat showed an increase in toughness and increase in dough extensibility. Deficiency of sulfur results in lower protein levels without S which decreases the extensibility of dough. In severe cases the loaf volume also decreases. Sulfur is also useful in improving texture and flour color (Moss et al., 1983).

In Oklahoma, the current S recommendation for wheat and other non-legumes is based on a 20:1 N: S ratio (Zhang et al., 2006). Timms et al., (1981) suggested that large amounts of N applied to wheat at later growth stages causes an imbalance in N and S ratio in plant which deteriorates the protein quality. Numerous studies (Tea et al., 2004, 2007; Learner et al., 2005) have shown that optimum N and S nutrition at anthesis increased N and S assimilation in wheat grain. Salvagotti et al., (2009) reported that the interaction of N and S reflected higher nitrogen use efficiency in wheat crops. Therefore the interaction of N and S maximizes plant performance and grain quality.

Chloride maintains water regulation in plants. Chloride is also useful in suppressing take-all disease in wheat (Thomason et al., 2001; Christensen et al., 1985). Also, Cl has been found to act as a nitrification inhibitor which helps to prevent losses of N through nitrification and helps to preserve the favorable ammonium to nitrate ratio which is a critical management practice for take-all disease.

Richard (1984) claimed that Cl suppressed powdery mildew, leaf rust, and leaf spot in wheat. In addition, soil applied Cl fertilizer increased mature kernel weights up to 17% and yield by an average of 267 kg ha^{-1} in winter wheat cultivars (Richard et al., 1994). Fixen (1986) noted that potassium chloride (KCl) fertilization in the Northern plains increased wheat grain yield by 0.2 to 0.5 tons ha^{-1}. In higher plants Cl affects the uptake and utilization of macronutrients like N, K, S, Mg and micronutrients like Mn, Fe and Cu (Chen et al., 2010). Crops grown in sandy and sandy loam soils will benefit more from added Cl fertilizers (LaRuffa, 1999).

Although some experiments have shown responses to S and Cl fertilizers in Oklahoma, these nutrients are often promoted without incorporating actual soil test levels in the decision making process. The objective of this study was to evaluate the effect of foliar applications of N, S, and Cl applied at the flag leaf stage on winter wheat grain yield and protein.

CHAPTER III

MATERIALS AND METHODS

Winter wheat experiments were established for a total of 3 site-years in the fall of 2011 at Lake Carl Blackwell and Lahoma, OK and 2012 at Lahoma. The locations were at the North Central Research Station near Lahoma and near Lake Carl Blackwell, OK. The experimental site at Lake Carl Blackwell was located on a Port silt loam (fine-silty, mixed, thermic Cumulic Haplustolls) and Lahoma was located on a Grant silt loam (fine-silty, mixed, superactive, thermic Udic Argiustolls). Both sites were operated under rain fed conditions. These sites are further delineated in Table 1. Composite soil samples (0-15 cm) were collected before any treatments were applied. Soil samples were dried, ground and analyzed to determine pH, NH_4-N, NO_3-N, SO_4-S, Cl, total N, and organic C. Soil pH was determined using a calomel electrode and a 1:1 soil: water mix. Total N and organic C were determined using dry combustion (Schepers et al., 1989). Ammonium-N and NO_3-N were determined using a 2M KCl extraction followed by automated flow injection analysis. Sulfate-S was determined by extracting with calcium phosphate and measured on an inductively coupled argon plasma spectrophotometer. Chloride was also extracted with calcium phosphate and analyzed using mercuric thiocyanate methodology.

A randomized complete block experimental design was used with four replications and sixteen treatments (Figure 1). The plot size was 3x3 m. Wheat in the fall of 2011 and 2012 was planted in 15 cm wide rows at a seeding rate of 100 kg seed ha^{-1}. The wheat varieties ‘Billings’ and ‘Endurance’ were planted at LAH and LCB respectively. Preplant N in the form of urea ammonium nitrate (UAN) (28-0-0) at rates of 0, 40, and 80 kg N ha^{-1} was applied on September 27, 28 and October 4 for LAH (2011) and LCB (2011) and LAH (2012) respectively.

The products, N-SURE (28-0-0) and UAN (28-0-0) were used as the foliar N sources. N-SURE is N-fertilizer solution containing 20.2 % slow release N derived from urea triazone solution. Urea ammonium nitrate is a solution of urea and ammonium nitrate dissolved in water. Foliar applications of N were applied at flag leaf growth stage (Feekes 8.0, Large, 1954) at rates of 10 kg N ha^{-1} (treatments 3, 4, 5, 10, 11 and 12) and 20 kg N ha^{-1} (6, 7, 8, 13, 14, 15 and 16). Foliar S in the form of gypsum (17% S) was applied to plots (4, 7, 11, 14, and 16) at a rate of 6 kg S ha^{-1}. To analyze the effect of foliar Cl, half of each treatment in rep 4 and treatment number 16 in rep 4 received 10 kg Cl ha^{-1} in the form of calcium chloride (47% Cl). For each treatment, all foliar materials were dissolved in water to make a 1 liter solution and applied at the flag leaf growth stage and delivered with a CO_2 back-pack sprayer. The use of Tee Jet flat fan nozzles and an application pressure of 275.8 kPa yielded fine spray droplets. The treatment structure employed at both sites is reported in Table 2.

Foliar treated plot were visually monitored for variation in leaf burn to after the applications. The foliar burns were scored with 0-5 ratings, indicating 0 as no burn and 5 as maximum of 80 % burn.

Green Seeker™ normalized difference vegetation index (NDVI) sensor readings were collected at Feekes growth stages 4, 5, 6 and 7. All NDVI readings were collected 30 cm above the canopy from the center of each plot. The normalized difference vegetative index (NDVI) was calculated with the formula:

$$NDVI = (NIR_{ref} - Red_{ref}) / (NIR_{ref} + Red_{ref})$$

Red reflectance (Red_{ref}) is calculated by dividing red reflected light by red incident light and NIR reflectance (NIR_{ref}) is calculated by dividing NIR reflected light by NIR incident light.

At maturity, wheat was harvested using an experimental Massey Ferguson 8XP combine (AGCO Corp., Duluth GA) equipped with a Harvest Master (Juniper Systems Inc., Logan, UT) automated weighing system. Sub-samples of 400 grams were collected from each plot and adjusted to 12.5% moisture. Grain samples were dried for 48 hours at 70°C, and then ground and rolled to pass a 100 µm sieve. Total grain N content, and grain protein was analyzed with a LECO TruSpec (LECO Corp., St. Joseph, MI) dry combustion analyzer (Schepers et al., 1989). Grain protein was calculated by multiplying total N by 5.7 (Mosse, 1990). Treatment effects on grain yield, grain N were evaluated using single-degree-of-freedom, non-orthogonal contrasts SAS 9.2 (SAS Institute Inc., Cary, NC, 2004). The effect of chlorine was analyzed using a paired T-test for rep 4.

CHAPTER IV

RESULTS

Response of each dependent variable for this study was different by location and year. Independent location and year analysis was performed and results were reported. Means and single degree-of-freedom contrasts for grain yield and total grain N are reported in Table 3 and Table 4 for Lake Carl Blackwell (2011-12) and Lahoma (2011-12 and 2012-13). Average monthly air temperature and monthly rainfall data were obtained from nearest Mesonet weather station (www.mesonet.org). The data from replications 1, 2 and 3 were used to determine the response of foliar S and N. Response of chloride was obtained by comparing replication 4 with other replications.

Lake Carl Blackwell 2011-2012

Grain Yield

Grain yield ranged from 2025 to 3202 kg ha^{-1}, with an average of 2582 kg ha^{-1} (Table 3). The maximum yield was obtained at 80 kg preplant N and 10 kg foliar N (UAN). No response to foliar N applications was observed in grain yield. However, the grain yield was significant with preplant N at 10 percent level of significance.

The application of preplant N showed a quadratic yield increase (Figure 1). Treatments with sulfur did not increase yield.

Grain N

For Lake Carl Blackwell, total grain N percent ranged from 1.44 to 1.86 with an average of 1.69. The highest grain N percent 1.86 was obtained with 80 kg ha^{-1} preplant N, 20 kg ha^{-1} foliar N (UAN) and 6 kg ha^{-1} foliar S. Total grain N showed a linear response to preplant N. There was no relationship between total grain N and foliar N. Eighty percent of Sulfur treated plots gave total N higher than the average value (Table 3).

Feekes 4, Feekes 5 and Feekes 6 NDVI

Feekes 4 NDVI values ranged from 0.61 to 0.70 with an average of 0.66, F5 NDVI ranged from 0.65 to 0.72 and averaged 0.70 while F6 NDVI ranged from 0.64 to 0.74 with an average of 0.71 (Table 3). The average NDVI was highest at F6 and lowest at F4 because the N availability was higher at F5 and F6 growth stages.

Lahoma 2011-2012

Grain Yield

Grain yields ranged from 1752 to 2907 kg ha^{-1}, with an average of 2328 kg ha^{-1} at Lahoma for the 2011-2012 growing season (Table 4). The highest grain yield was observed with 80 kg ha^{-1} N preplant, 10 kg^{-1} ha foliar N (UAN) and 6 kg ha^{-1} S. Grain yield did not increase for any of the foliar applications but was significant with preplant N. The yield data showed a significant ($p<0.01$) linear increase with increasing preplant N (Figure 2). There was no significant response in yield to applied S at Lahoma, but some treatments tended to have higher yields.

Grain N

For Lahoma, total grain N ranged from 1.71 to 1.96 percent with an average of 1.84. Highest total grain N was obtained with 80 kg ha $^{-1}$ preplant N, 20 kg ha $^{-1}$ foliar N. The total grain N showed a linear response to preplant N. Grain N was not affected by foliar N applications. Three of the S receiving plots had total N values higher than the average.

Feekes 4, Feekes 5 and Feekes 7 NDVI

Feekes 4 NDVI values ranged from 0.30 to 0.49 with an average of 0.43, F5 NDVI ranged from 0.38 to 0.45 and averaged 0.42 while F7 NDVI ranged from 0.34 to 0.56 with an average of 0.49 (Table 4). The average NDVI was highest at F7 and lowest at F5 growth stages.

Lahoma 2012-2013

Grain Yield

Grain yields ranged from 692 to 1501 kg ha^{-1}, with an average of 1196 kg ha^{-1} at Lahoma for the 2011-2012 growing season (Table 5). The highest grain yield was observed with 80 kg ha^{-1} preplant N, 10 kg^{-1} ha foliar N (UAN) and 6 kg ha^{-1} S. Grain yield did not increase for any of the foliar applications but was significant with preplant N. The yield data showed a linear increase with increasing preplant N (Figure 3). There was no significant response in yield to applied S at Lahoma, but some plots yielded higher with S treatment. Grain yield was different with two different rates of UAN and N-SURE, which was quite obvious.

Grain N

The total grain N ranged from 1.91 to 2.32 percent with an average of 2.13. Highest total grain N was obtained with 80 kg ha $^{-1}$ preplant N, and 10 kg ha $^{-1}$ foliar N. The total grain N showed a linear response to preplant N. Plots receiving S had total grain N higher than the average. Total N was significantly higher with foliar N applications. Preplant N rate together with foliar N resulted in significant treatment differences. Also the total N showed differences with N sources.

Foliar Burn

Limited foliar burn was observed at all site years. For all site years, the range of temperature during the growing season was within 3-25 $^{\circ}$C. Foliar N application was accomplished in early morning when the temperatures were lower. Temperatures at the time of application for all sites years are reported in Figure 8 and 10.

CHAPTER V

DISCUSSION

Grain Yield

Grain yield was higher at Lake Carl Blackwell and lower at Lahoma for 2011-2012 (Tables 4 -5). On visual observation, Lake Carl Blackwell had more tillers and a better plant stand than at Lahoma. This was due to timely rainfall. For winter wheat in Oklahoma, the period from late March to mid-April is generally considered critical concerning water requirements. Stem elongation takes place around the fourth week of March whereas around the second week of May flowering begins (Figure7-8). Although the total rainfall was higher at Lahoma, Lake Carl Blackwell received more rain from late March to mid-April as compared to Lahoma. Also, NDVI values at Feekes 4, 5, and 7 were higher for Lake Carl Blackwell and lower for Lahoma.

The yield at Lahoma for 2012-2013 was very low as compare to LCB and LAH for 2011-2012.This was due to very dry fall and the poor plant conditions at the beginning. In addition, the late spring freezes in February and March (Table 6) induced extreme stress and poor root system development which further impaired grain yield.

Although higher yields were obtained with some foliar S treated plots, this was not significant at either site. This was in part due to sufficient amount of S in the soil at planting which is shown in Table.1. At Lahoma, N-SURE yielded higher than that of UAN while at Lake Carl Blackwell, both the sources showed similar effects on yield. This would suggest that at LCB there were no significant post application losses for both sources.

Grain N

The grain N was higher for Lahoma (Tables 4-5) than LCB giving a higher protein percentage. Protein formation is much less affected by water and temperature stress and protein level is typically greater in wheat grown under these conditions (Bhullar, 1986). For Lake Carl Blackwell, grain N was lower than at Lahoma and was negatively correlated with yield. The total N was highest for Lahoma (2012-2013) among all site-years (Table 5). Lahoma received higher rainfall from April to mid-May and where optimum conditions for plant N uptake occurred. Average monthly air temperature was almost the same for both locations for 2011-2012 (Figure 8). The average monthly air temperature for Lahoma 2012-2013 slightly dropped from December onwards (Figure 10).

Some treatments at LCB and LAH receiving foliar sulfur and 80 kg ha $^{-1}$ preplant N rate had higher grain N values (Table 3-4). However, this was not consistent and likely due to the sufficiency of sulfur in the soil.

The chloride response was similar to that of sulfur. The soil test data showed that the amount of sulfur in the upper 15 cm of soil was sufficient for winter wheat (Table 1). Soil Cl was also sufficient at both locations, thus differences due to Cl applications were not observed. The soil Cl value in the upper 15 cm of soil was 131.6 kg ha^{-1}for Lake Carl Blackwell, 51.8 and 57.5 kg ha^{-1} for Lahoma 2011 and 2012, respectively (Table 1).

There were no interactions between foliar applied N, S and Cl on grain yield and/or grain N.

CHAPTER VI

CONCLUSIONS

The main objective of the experiment was to evaluate the relationship between flag leaf foliar applied nitrogen (0, 10 and 20 kg ha^{-1}) sulfur (0 and 6 kg ha^{-1}) and chloride (0 and 10 kg ha $^{-1}$) and final grain yield and grain N. Over the growing season 2011-2012 and 2012-2013 it was observed that foliar application of nitrogen had no effect on grain yield and grain N when applied at the flag leaf stage. However, preplant N had a significant effect on grain yield and grain N.

Foliar S applied at the flag leaf stage did not result in increased yield and or grain N. Data from this study indicates that sulfur fertilization is not effective when the soil S is sufficient. Similarly, there was no response to foliar Cl at both locations.

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TABLES

Table1. Initial surface (0-15cm) soil test characteristics at Lake Carl Blackwell and Lahoma, OK, 2011 and 2012

Location	pH[a]	NH_4-N[b]	NO_3-N[b]	P[c]	K[c]	SO_4-S[d]	Cl[e]	Total N[f]	Organic C[f]	OM[f]
2011		kg ha^{-1}						g kg^{-1}		
LCB	7.7	11.4	11.7	32.4	289.7	126.6	131.6	0.1	0.8	1.8
LAH	5.7	24.6	15.0	26.3	467.0	29.1	51.8	0.1	0.8	1.8
2012										
LAH	5.7	12	9.5	31	672.5	19	57.5	0.1	0.8	1.8

a 1:1 soil water ratio
b 2M KCl extracting solution
c Melich □□□
f Dry combustion
d Inductively Coupled Argon Plasma Spectrophotometer (ICP)
e Mercuric thiocyanate

Table 2.Treatment structure employed including foliar N source, preplant N rate, foliar N, S, and Cl, Lake Carl Blackwell and Lahoma, OK (2011-2012 and 2012-2013)

Treatment	Foliar N Source	Preplant N rate	Foliar N Rate	Foliar S rate
			kg ha^{-1}	
1	Check	0	0	0
2	Check	40	0	0
3	UAN	40	10	0
4	UAN	40	10	6
5	N-SURE	40	10	0
6	UAN	40	20	0
7	UAN	40	20	6
8	N-SURE	40	20	0
9	Check	80	0	0
10	UAN	80	10	0
11	UAN	80	10	6
12	N-SURE	80	10	0
13	UAN	80	20	0
14	UAN	80	20	6
15	N-SURE	80	20	0
16	N-SURE	80	20	6+10 kg ha^{-1} $CaCl_2$

UAN, urea ammonium nitrate
N-SURE, nitrogen fertilizer containing urea triazone

Table 3.Treatment means for grain yield and grain N, Lake Carl Blackwell, OK, 2011- 2012.

Foliar N Source	Preplant N	Foliar N	Foliar S	Yield	Grain N	FK4	FK5	FK6
	kg ha^{-1}				%	NDVI		
Check	0	0	0	2025	1.44	0.61	0.67	0.67
Check	40	0	0	2603	1.54	0.66	0.71	0.73
UAN	40	10	0	2812	1.65	0.66	0.71	0.72
UAN	40	10	6	2411	1.66	0.67	0.70	0.71
N-SURE	40	10	0	2708	1.71	0.66	0.71	0.72
UAN	40	20	0	2851	1.74	0.66	0.72	0.72
UAN	40	20	6	2738	1.75	0.68	0.71	0.72
N-SURE	40	20	0	2520	1.66	0.70	0.72	0.71
Check	80	0	0	2758	1.82	0.63	0.68	0.71
UAN	80	10	0	2343	1.58	0.67	0.65	0.64
UAN	80	10	6	2588	1.74	0.65	0.73	0.74
N-SURE	80	10	0	2236	1.74	0.64	0.69	0.69
UAN	80	10	0	3202	1.71	0.68	0.69	0.70
UAN	80	20	6	2497	1.86	0.64	0.71	0.72
N-SURE	80	20	0	2411	1.69	0.64	0.69	0.70
N-SURE	80	20	6	2605	1.77	0.68	0.70	0.72
			Average	2582	1.69	0.66	0.7	0.71
			StDev	275	0	0.02	0.02	0.02
			CV, %	11	6	3	3	3
			SED	131	0	0.12	0.11	0.10
Contrasts								
All trt vs.Check				*	**			
Sulfur effect				NS	NS			
Preplant N linear				*	**			
Preplant N quadratic				*	NS			

*- Significant at the 0.05 probability level

**- Significant at 0.1 probability level

NS - not significant

UAN - urea ammonium nitrate

N-SURE - nitrogen fertilizer containing urea triazone

SED - standard error of difference between two equally replicated means

CV - coefficient of variance

Table 4.Treatment means for grain yield, grain N and grain protein, Lahoma, OK, 2011-2012.

Foliar N Source	Preplant N	Foliar N	Foliar S	Yield	Grain N	FK4	FK5	FK7
	kg ha^{-1}				%		NDVI	
Check	0	0	0	1752	1.71	0.30	0.38	0.34
Check	40	0	0	1851	1.77	0.40	0.41	0.46
UAN	40	10	0	2100	1.78	0.41	0.45	0.45
UAN	40	10	6	2190	1.73	0.45	0.43	0.48
N-SURE	40	10	0	2073	1.82	0.42	0.42	0.41
UAN	40	20	0	1926	1.78	0.39	0.42	0.47
UAN	40	20	6	2072	1.77	0.40	0.41	0.48
N-SURE	40	20	0	2489	1.81	0.45	0.41	0.48
Check	80	0	0	2604	1.90	0.46	0.45	0.52
UAN	80	10	0	2641	1.92	0.49	0.45	0.52
UAN	80	10	6	2907	1.87	0.46	0.43	0.52
N-SURE	80	10	0	2638	1.83	0.48	0.41	0.53
UAN	80	10	0	2292	1.93	0.40	0.39	0.47
UAN	80	20	6	2391	1.94	0.45	0.41	0.55
N-SURE	80	20	0	2701	1.96	0.44	0.43	0.52
N-SURE	80	20	6	2620	1.90	0.47	0.40	0.55
			Average	2328	1.84	0.43	0.42	0.48
			StDev	345	0.1	0.05	0.02	0.05
			CV, %	15	4	11	5	11
			SED	115	0	0.02	0.04	0.05
Contrasts								
All trt vs Check				*	*			
Sulfur effect				NS	NS			
Preplant N linear				**	**			

*Significant at the 0.05 probability level.

** Significant at the 0.01 probability level

NS - not significant

UAN - urea ammonium nitrate

N-SURE - nitrogen fertilizer containing urea triazone

SED - standard error of difference between two equally replicated means

CV - coefficient of variance

Table 5.Treatment means for grain yield, grain N and grain protein, Lahoma, OK, 2012-13.

Foliar N Source	Preplant N	Foliar N	Foliar S	Yield	Grain N
	kg ha^{-1}				%
Check	0	0	0	692	1.91
Check	40	0	0	1085	2.04
UAN	40	10	0	1147	2.06
UAN	40	10	6	1027	2.02
N-SURE	40	10	0	1144	1.98
UAN	40	20	0	1005	2.12
UAN	40	20	6	1070	2.20
N-SURE	40	20	0	1262	2.14
Check	80	0	0	1364	2.09
UAN	80	10	0	1445	2.08
UAN	80	10	6	1501	2.15
N-SURE	80	10	0	1416	2.16
UAN	80	10	0	1027	2.32
UAN	80	20	6	1359	2.29
N-SURE	80	20	0	1203	2.23
N-SURE	80	20	6	1383	2.22
			Average	1196	2.13
			StDev	345	0.1
			CV, %	18	5
			SED	72.83	0.20
Contrasts					
All trt vs. Check				**	***
Sulfur effect				NS	NS
Preplant N linear				***	***
Foliar linear				NS	**
Foliar Quadratic				NS	*
40Pre(10 vs. 20)				NS	**
80 Pre(10 vs. 20)				NS	**
UAN 10 vs. 20				*	**
N-SURE 10 vs. 20				*	*
Foliar Rate w/S				NS	**

*, **, *** Significant at 0.05, 0.01, and 0.001 probability level respectively.
NS - not significant, UAN - urea ammonium nitrate
N-SURE - nitrogen fertilizer containing urea triazone
SED - standard error of difference between two equally replicated means
CV - coefficient of variance

Table 6. Freezing Days in February and March with temperature lower or near to 0°C for wheat growing season, 2012-2013, Lahoma, OK (source:www.mesonet.org)

Month	Day	°C
Feb	21	-2.0
Feb	22	-7.1
Feb	23	-2.4
Feb	25	0.8
Feb	26	-0.9
Feb	27	-1.8
Feb	28	-1.1
Mar.	1	-1.6
Mar.	24	-0.5
Mar.	25	0.0

FIGURES

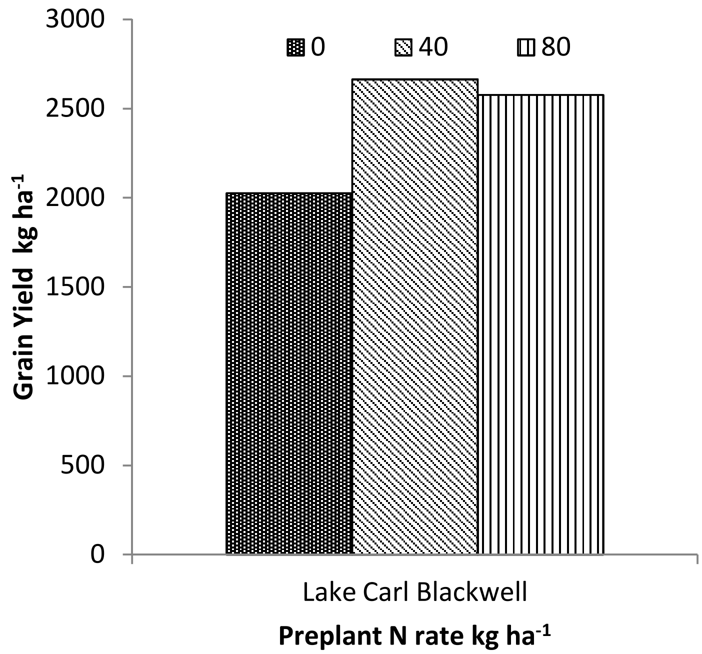

Figure 1: Relationship between grain yield and preplant N rate, Lake Carl Blackwell, OK (2011-2012), averaged over same N rate

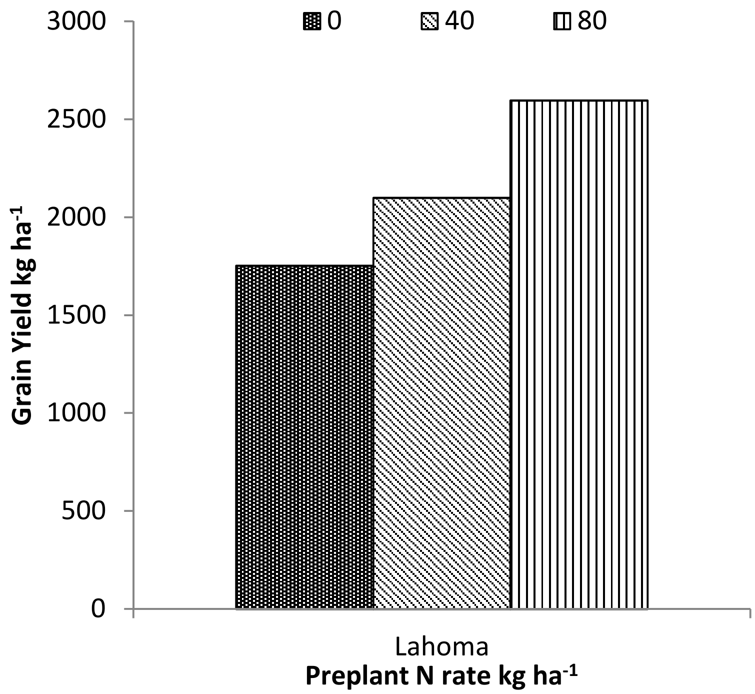

Figure 2: Relationship of grain yield and preplant N rate, Lahoma, OK (2011-2012) averaged over same N rate

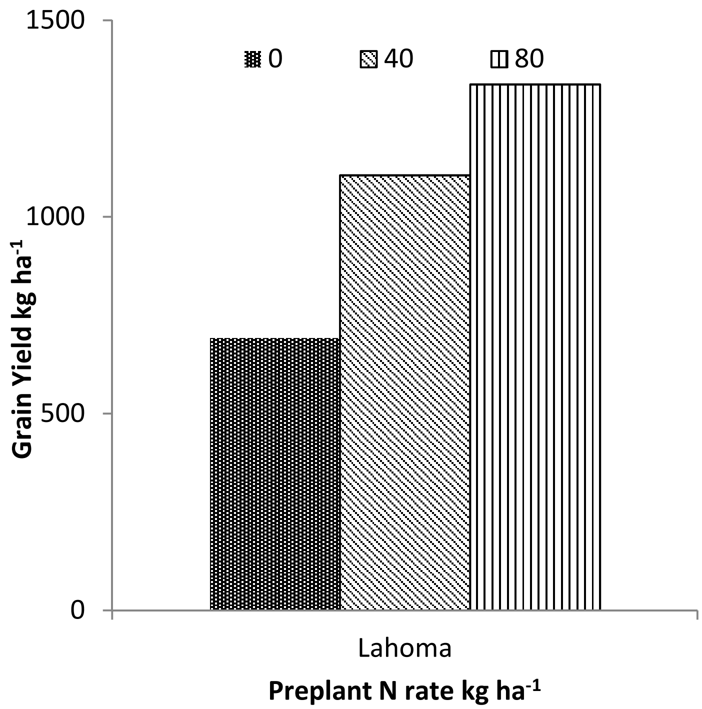

Figure 3: Relationship of grain yield and preplant N rate, Lahoma, OK (2012-2013) averaged over same N rate

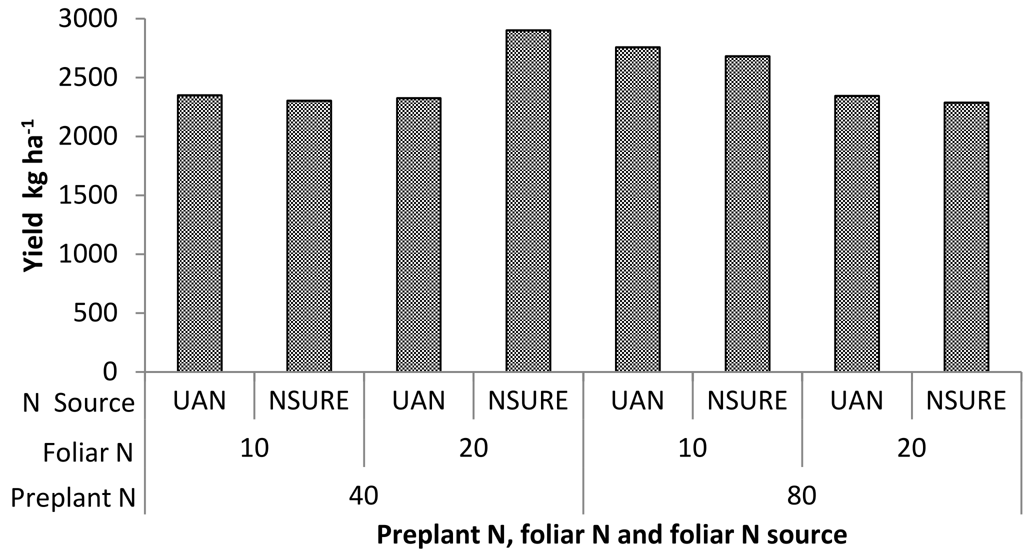

Figure 4: Treatment means for grain yield using two different foliar N sources, N-SURE and UAN 2011-2012, Lake Carl Blackwell, OK

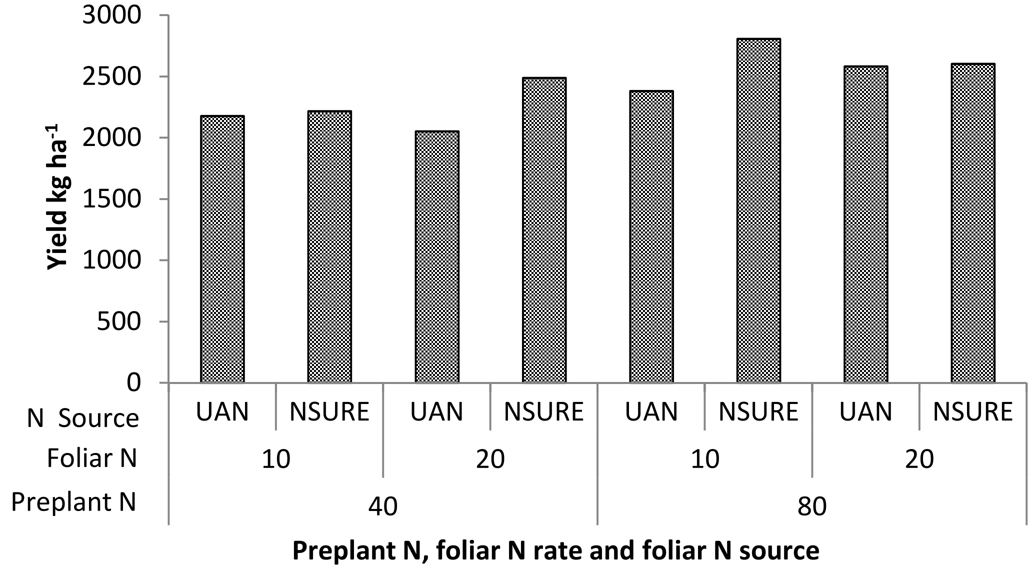

Figure 5: Treatment means for grain yield using two different foliar N sources, N-SURE and UAN 2011-2012, Lahoma, OK

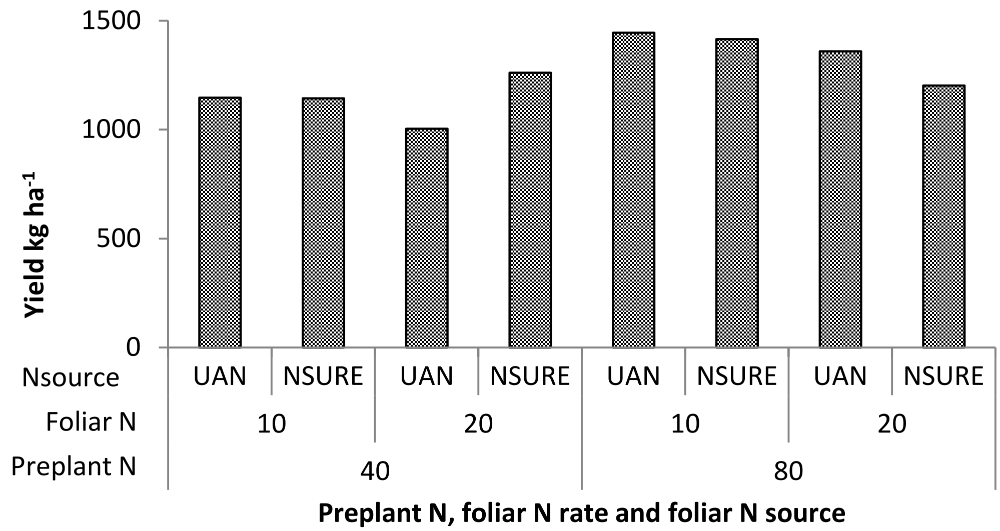

Figure 6: Treatment means for grain yield using two different foliar N sources, N-SURE and UAN 2012-2013, Lahoma, OK

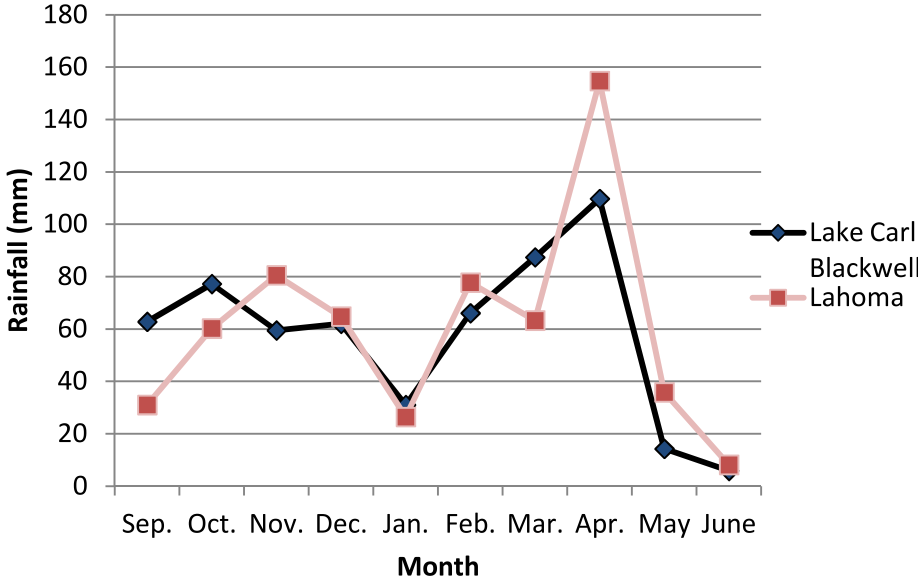

Figure 7: Total monthly rainfall during 2011-2012 winter wheat growing season at Lake Carl Blackwell and Lahoma, OK (source: www.mesonet.org)

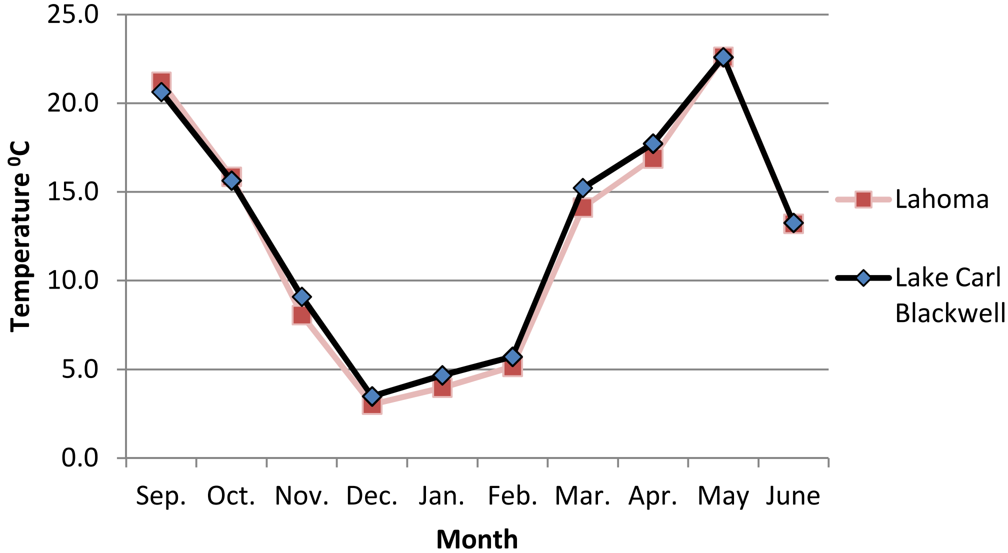

Figure 8: Average monthly air temperatures during 2011-2012 winter wheat growing season at Lake Carl Blackwell and Lahoma, Oklahoma (source:www.mesonet.org)

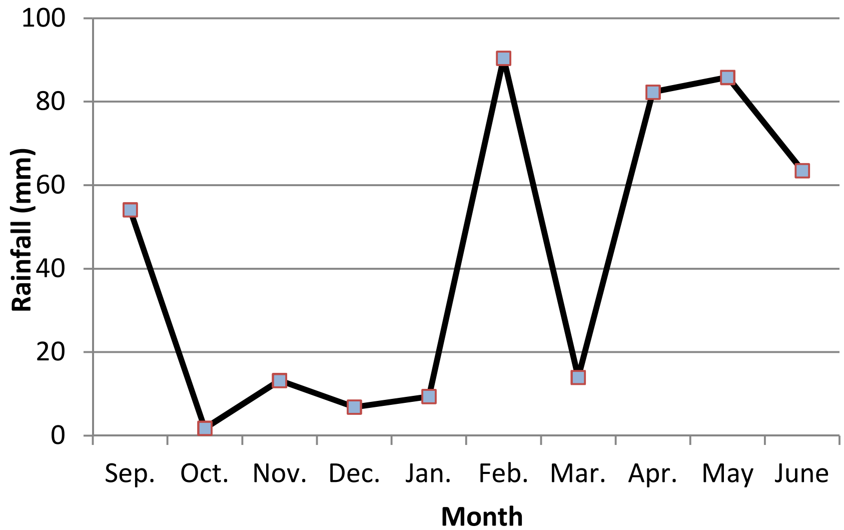

Figure 9: Average monthly rainfall during 2012-2013 winter wheat growing season at Lahoma, Oklahoma. (source:www.mesonet.org)

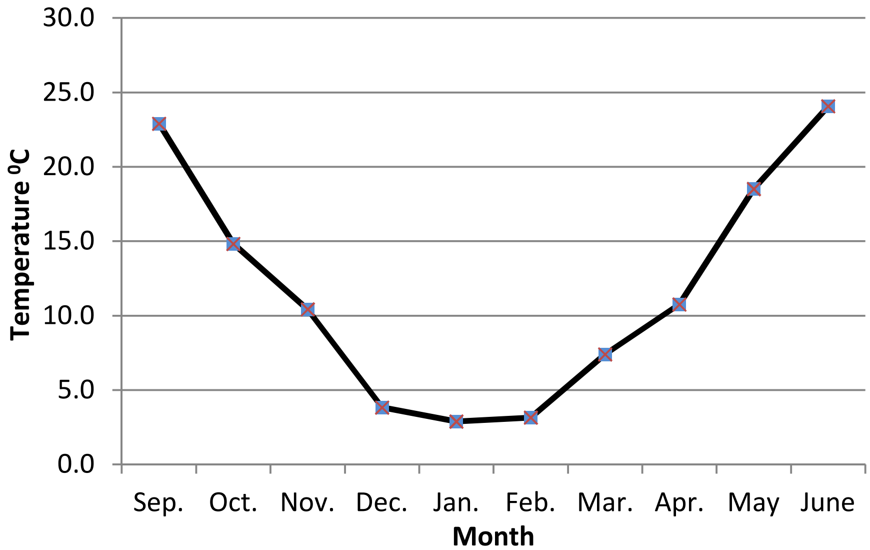

Figure 10: Average monthly air temperatures during 2012-2013 winter wheat growing season at Lahoma, Oklahoma. (source:www.mesonet.org)

VITA

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