EFFECT OF DROPLET SIZE AND NITROGEN RATE ON PROTEIN CONTENT OF HARD RED WINTER WHEAT (*TRITICUM AESTIVUM L.)*

By

ETHAN WYATT

Bachelor of Science in Plant and Soil Sciences

Oklahoma State University

Stillwater, OK

2012

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2013

EFFECT OF DROPLET SIZE AND NITROGEN RATE

ON PROTEIN CONTENT OF HARD RED WINTER

WHEAT (*TRITICUM AESTIVUM L.)*

Thesis Approved:

Dr. William R. Raun

Thesis Adviser

Dr. Brian Arnall

Dr. Randy Taylor

.

ACKNOWLEDGEMENTS

I would like to express my gratitude to Oklahoma State University, the Department of Plant and Soil Sciences, and my major advisor Dr. William R. Raun for allowing me the opportunity to pursue my degree. Dr. Raun's leadership, motivation, and expertise for soil nutrient management were invaluable. I would also like to express thanks to my committee members, Dr. Brian Arnall and Dr. Randy Taylor, for their assistance, wisdom, and guidance during my project. I would like to thank the entire Soil Fertility group for the assistance with my project and a special thanks to Jeremiah Mullock, Jake Bushong, and Eric Miller for their technical and editorial contributions to my project. I would like to extend a big thank you to Gary James at HYPRO for providing the nozzles and technical support for the droplet sizes in my project. To conclude I would like to thank Trevan, Mom, Dad and all of the rest of my family and friends for providing the support while completing my degree.

Name: Ethan Cord Wyatt

Date of Degree: DECEMBER, 2013

Title of Study: EFFECT OF DROPLET SIZE AND NITROGEN RATE ON PROTEIN CONTENT OF HARD RED WINTER WHEAT (*TRITICUM AESTIVUM L.)*

Major Field: Plant and Soil Sciences

Abstract: In past years, grain protein concentration (GPC) has been highly variable from one location to the next. Many factors, environmental and genetic, contribute to the percent protein levels in the grain (Kramer, 1978). Along with increasing prices of inputs (land prices, machinery, fertilizer, and seed) producers continually need to adopt more efficient practices to ensure that GPC is at adequate levels so as to avoid potential dockage and/ or realize potential premiums. This study was conducted to determine the effect of droplet size and late-season nitrogen application on grain protein concentration. The effects of late season foliar N applications (post-anthesis) and droplet size on protein concentration were investigated on hard red winter wheat (*Triticum aestivum L.)* at three winter wheat sites in Oklahoma, Efaw (Stillwater), Lake Carl Blackwell, and Perkins. Foliar N was applied at two rates 11.2 and 22.4 kg ha^{-1} with three different droplet sizes per N rate; the 11.2 kg ha^{-1} N rate consisting of an adjuvant tank-mixed treatment and a non-adjuvant treatment. For most locations and years grain protein concentration was increased linearly with higher rates of foliar N applied. Use of the fine droplet size with a foliar N rate of 11.2 kg N ha^{-1} applied post anthesis and with the addition of an adjuvant resulted in the highest grain protein concentration.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table Page

Chapter Page

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

Wheat production in the United States plays a major role in cereal production in the world. Although wheat production in the United States has declined since peaking in the early 1980s, the United States still ranks as one of the top producing countries in the world with more than 21 million hectares. Hard red winter (HRW) wheat, grown extensively in the Great Plains, accounts for 40 percent of the total wheat grown in the United States and is primarily used for bread flour (USDA-ERS, 2012). In past years, grain protein content has been highly variable from one location to the next. Many factors, environmental and genetic, contribute to protein levels in the grain (Kramer, 1978).

Grain protein concentration (GPC) levels of HRW wheat determine the degree of milling and baking quality of processed wheat products and price. Hard red winter wheat is considered a high protein wheat when analyzed against other classes of wheat excluding hard red spring wheat (Bale and Ryan, 1977). Woolfolk et al., (2002) explained that GPC market requirements have been established worldwide, with higher protein wheat receiving a higher price most commonly noted as a “protein premium”.

As of November 30, 2010, deliverable grades of HRW wheat must contain a protein concentration of at least 11% or a 10 cent discount to the contract price with a protein concentration of 10.5% (Kansas City Board of Trade, 2010). The new guideline set by the Kansas City Board of Trade has imposed a stricter policy for managing and producing HRW wheat. Along with increasing prices of inputs (land prices, machinery, fertilizer, and seed) producers continually need to adopt more efficient practices to ensure that GPC is at adequate levels so they can increase their profit margins on their wheat operations.

This study was conducted to determine the effect of droplet size and late-season nitrogen application on grain protein concentration.

CHAPTER II

REVIEW OF LITERATURE

Factors Affecting Grain Protein Concentration

Rao et al., (1993) reported that GPC is not controlled by one factor but rather by many different aspects such as: environment, cultivar selection, nitrogen fertilizer rate, and timing. Grain protein concentration of wheat grain is highly variable with an averaging between 8 and 20%, with the majority of this variation coming from environmental influences (Kramer, 1978). The remaining differences can be attributed to genetic variation. Year to year GPC levels at the same location can vary tremendously due to climatic conditions during growth and grain filling. Differentiating climatic conditions can affect physiological changes in the plant which affects grain quantity and quality (Garrido-Lestache et al.,2004; Stone and Savin, 2000). Soil nitrogen availability and soil water stress are major factors affecting GPC and in most cases GPC increases with higher temperatures and reduced rainfall events (Garrido-Lestache et al., 2004; Debaeke et al., 1996; Gooding and Davies, 1997; Daniel and Triboi, 2000; Stone and Savin, 2000; Rao et al., 1993).

Late Season N Applications

Soil nitrogen availability plays a critical role in determining GPC of the grain. In most cases, nitrogen is the most limiting nutrient in the production of winter wheat. Variability in nitrogen levels during the crop growing season can have tremendous influences on biomass, yield, and GPC of winter wheat. Grain protein concentration levels will not increase until N requirements for potential yield of the crop are met. When N levels are low, additional applications of N will increase crop yield until the yield curve starts to level off, indicating less grain is being produced per unit of N applied (Kramer, 1978). When the yield curve reaches its plateau, nitrogen is no longer the most limiting factor to yield and GPC will increase with additional N applications (Gauer et al., 1992). Research conducted on late-season top-dress N as either dry or liquid material has shown an increase in GPC (Woodward and Bly, 2003; Fowler, 1989; Woolfolk et al., 2002). Application of late foliar N conserves NUE and promotes an increase in GPC compared to excess N being applied preplant (Raun and Johnson, 1999; Wuest and Cassman, 1992). According to Woodward and Bly, (2003), GPC was increased 70% of the time when potential yield was exceeded and 23% when it was not with a post-pollination foliar N application. Woolfolk et al., (2002) reports GPC was increased with late season foliar N applications before and immediately following flowering. Although some leaf burn and awn burn has been reported with late foliar N applications, Woodward and Bly, (1998) concluded that GPC was increased up to 1.6% when compared to a check with no foliar N application.

Importance of Droplet Size

When applying liquid products through commercial sprayers, the main objective is to get an effective layer on to the crop's leaf surface. Lake (1977) describes an effective product application on the leaf surface to be one that achieves acceptable control while still maintaining an economic application rate. Factors that affect whether the application was retained on the leaf's surface depends on: droplet size, velocity of the droplet, trajectory from the sprayer, and also the physical properties of the spray liquid and leaf surface (Lake, 1977). Holloway et al., (2000) explained that adjuvants can also affect the physicochemical properties of spray droplets in terms of their size and velocity, which ultimately governs the reaction the droplet has with the leaf surface. According to Mercer (2007), decreasing the size of the droplet leads to an increase in uptake of active ingredient and increasing the spread area of the droplet is found to increase the uptake of active ingredient with the greatest effect in larger droplets. Both of these processes are due to the diffusion mechanism through the leaf's cuticle, which is the most limiting process in the uptake of active ingredient (Mercer, 2007). Research conducted on agricultural sprays agrees that many environmental and physical factors (evaporation, wind, temperature, humidity, leaf surface, liquid products, and surfactants) contribute to retain the droplet on the leaf's surface and diffusion through the plant leaf's cuticle.

Adjuvants in N Fertilizer Mixtures

In some agriculture sprays, especially foliar herbicide applications, an adjuvant is tank-mixed with the liquid product that is being applied. Adjuvants are useful in enhancing biological performance in two ways: increasing the amount of active ingredient retained by the target plant and increasing active ingredient uptake (Holloway et al., (2000). Mercer (2007) explains that an addition of an adjuvant spreads the droplet so that larger contact area is exposed to the leaf’s surface area resulting in less active ingredient diffusing through any one location increasing the diffusion process through the leaf’s cuticle. However, these processes mentioned above are highly dependent on adjuvant composition, how it is formulated with the liquid product, and the adjuvant amount that is present with the liquid product being applied (Holloway et al., 2000).

CHAPTER III

OBJECTIVE

The objective of this study was to evaluate the effects of adjuvant, droplet size, and foliar N rate on wheat grain yield and protein.

CHAPTER IV

METHODOLOGY

Experimental Conditions and Treatments

Three winter wheat field sites were selected in Oklahoma to establish the droplet size experiments. These experiments were located at Efaw, Perkins, and Lake Carl Blackwell (LCB). Soil series for each location and soil test results are listed in Tables 1 and 2. Each experimental site used a randomized complete block design with three replications and ten treatments (Table 3). In 2011, Perkins and LCB plot size was 3.05 by 9.14 m. The Efaw site had a plot size of 3.05 by 6.10 m. In 2012, Perkin had a plot size of 3.05 by 9.14 m and the Efaw and LCB plot sizes were 3.05 by 6.10 m. Experimental sites that were planted in the fall of 2011 had good planting conditions for stand establishment. Planting conditions for the fall of 2012 were less than desirable; dry soil conditions and lack of rainfall led to uneven plant emergence at all sites, partly due to the low amounts of precipitation during planting and early growth stages. The LCB site was abandoned and moved to another location near the previous one. The new site at LCB was planted later in the growing season, when growing conditions were more favorable. Table 4 and Table 5 describes planting date, seeding rate, variety selection, top-dress application, foliar N application, and grain harvest for each site used in this experiment for both years.

Table 6 reports the average temperature and monthly rainfall during the growing season for each location for both years. In 2011 experimental sites, Perkins and LCB, received 44.8 kg ha^{-1} top-dress rate of nitrogen at the Feekes 5 growth stage (Large, 1954). The Efaw location did not receive top-dress N. In 2012, the Efaw and Perkins location each received 44.8 kg ha^{-1} of N preplant and top-dress, while the LCB location received 67.2 kg ha^{-1} of N and 28 kg ha^{-1} of P_2O_5, but did not receive any top-dress N due to the high rate of preplant that was applied.

At all locations and both years foliar N was applied in the form of urea ammonium nitrate (UAN, 28-0-0) mixed in a 1:1 solution with water to prevent excessive foliar burn. Foliar N applications were applied post anthesis to each site (Table 4-5).Three droplet sizes: fine, medium, and, coarse were established for this experiment using the ASBAE Standard 572.1 (ASBAE, 2009). Treatment 1 consisted of a check, which received all preplant and top-dress application of nitrogen, but did not receive an application of foliar N. Treatments 2 through 10 received a rate of UAN ranging from 11.2 to 22.4 kg N ha^{-1} with treatments 2 through 4 also containing an adjuvant in the mixture (Table 3).The adjuvant that was chosen in this experiment was ChemSurf 90 manufactured by CHEMORSE, LTD, which is a non-ionic surfactant that improves wetting and spreading while also containing a sticker that helps decrease spray deposits from being washed off the plant (ChemSurf 90, 1997). The UAN and adjuvant was applied 50.8 cm above the crop using an ATV equipped with a 3.05 m spray boom and nozzles 50.8 cm apart (Figure 1). Foliar nitrogen rate and droplet size for each specific treatment were controlled using a pressurized canister with a pressure valve, nozzle tip type, and the ATV was equipped with a speedometer.

Measurements, Data Collection, and Data Analysis

Three to five days following application of foliar nitrogen rates; 15 flag leafs were randomly selected in each plot for total nitrogen analysis. At crop maturity each plot was harvested using a Massey Ferguson 8XP combine equipped with subsampling and yield data capabilities. During trial harvest, grain subsamples were collected in addition to moisture content and yield for each plot. Grain subsamples from each plot were analyzed for GPC. Both flag leaf and grain subsamples were ground with a Wiley mill and further analyzed with a LECO Truspec CN dry combustion analyzer (Schepers et al., 1989). Protein concentrations of the grain and flag leaf were calculated by using the nitrogen to protein conversion factor (Tkachuk, 1977).

$$Grain\ Protein\ Concentration\ (\%) = N\% \times 5.7$$

$$Flag\ Leaf\ \ Protein\ Concentration\ (\%) = N\% \times 6.25$$

Nitrogen uptake was calculated by the following equation:

$$Nuptake\ (kg\ ha^{-1}) = \left(\frac{N\%}{100}\right) \times Yield\ kg\ ha^{-1}$$

Grain yield, grain protein concentration, grain N uptake, and flag leaf protein concentration data were analyzed by using PROC GLM (SAS Institute, 2003). Single degree of freedom contrasts and mean separation using the Least Significant Difference (LSD) were also used to analyze treatment effects. All data analysis employed the SAS 9.3 software (SAS Institute, 2003).

CHAPTER V

RESULTS

Results 2011-2012

Growing conditions during the 2011-2012 season were adequate for high quality wheat production, except for a late season outbreak of leaf rust that infected all of the trials and reduced the flag leaf surface area. Foliar nitrogen applications were made at Perkins and LCB preceding a rainstorm, 5 and 16mm of rainfall, respectively, therefore altering the drying time of the foliar N application on the two trials. Foliar N applications at Efaw were concluded after the rainfall event allowing adequate time for fertilizer drying and movement into the plants. The addition of the adjuvant to the treatments did show increased foliar burn, mainly on the awns of the wheat heads. No significant yield decreases were observed when analyzing the adjuvant and non-adjuvant treatments (Tables 7, 8, and 9). No visual awn burn was reported on any of the other treatments that were applied in the trials. Analysis of variance and mean separation was accomplished by droplet size and foliar nitrogen rate excluding adjuvant and check treatments for grain yield, grain protein percent, grain N uptake, and flag leaf protein percent (Tables 7, 8, and 9, for Efaw, Lake Carl Blackwell, and Perkins).

Grain Yield

Grain yields were not significantly different at the Efaw and Perkins locations when analyzed by treatment (Table 7 and 9). Grain yields in 2012 were variable across locations, with many locations having the check in the top two highest yielding treatments. Coefficient of variation values were 19, 20, and 19% for Efaw, LCB, and Perkins, respectively (Tables 7, 8, and 9) Average yields were 1948, 1624, and 1106 kg ha^{-1} at Efaw, LCB, and Perkins, respectively. Lower yields were expected at Perkins due to the sandier composition of the soil, which reduces the amount of plant available water. At the LCB location, treatment and droplet size were significant factors that affected in grain yield (Figure 3 and Table 8). Treatment nine (22.4 kg N ha^{-1}, medium droplet size) had the highest average yield overall with 2174 kg ha^{-1} (Figure 3).The trend with the medium droplet size continued with treatment three (11.4 kg N ha^{-1}, medium droplet size with adjuvant) having the second highest average yield with 2036 kg ha^{-1} followed by the check treatment with 1855 kg ha^{-1} (Figure 3). When analyzing the means by droplet size the medium sized droplet had the highest yield, 1924 kg ha^{-1} followed by the fine droplet, 1526 kg ha^{-1}, followed by the coarse droplet size and a yield of, 1342 kg ha^{-1} (Figure 7). The medium droplet size increased yields by an average of 490 kg ha^{-1} when compared to the other droplet sizes. Yield also showed a significant (Table 9) inverse response to foliar nitrogen rate (r^2=0.99) at the Perkins location, likely due to increased foliar burn rates (Figure 8). No significant differences (α=.05) were detected at Perkins and Efaw to droplet size or nitrogen rate.

Grain Protein

Grain protein concentrations were variable and not consistent at all sites in 2012 and were not significant as a function of treatment at the 5% alpha level (Figures 2-4, Tables 7-9). Average grain protein concentrations were 13.9, 9.2, and 11.9 % at Efaw, LCB, and Perkins, respectively. Lower protein levels at Lake Carl Blackwell when compared to the other locations could be attributed to varietal differences in the wheat (Duster at LCB, Centerfield at Efaw and Perkins) or by more foliar N being lost due to a rainstorm event that occurred after application. Foliar N applications including the adjuvant mixture were not significant at the 5% level when analyzing grain protein concentration at all sites. When analyzing the effects of droplet size and foliar N rate on grain protein content, a linear response (r^2=0.99) to foliar N rate for grain protein content was observed at the Efaw location (Figure 5). Also at the Efaw location, the check versus foliar N application analysis was significant (Table 7) and the foliar N applications produced approximately a 10% increase in grain protein concentration (Figure 6). Grain protein concentration differences were not detected at Lake Carl Blackwell and Perkins when analyzing the means of droplet size or nitrogen rate.

Nitrogen Uptake

The main effect of treatment was not significant for nitrogen uptake over all locations in 2012. Nitrogen uptake paralleled response of grain yield to treatment at all locations. At the Perkins location, a significant inverse linear response (r^2=0.99) was shown as a function of N rate (Figure 8). Increasing the amount of foliar N rate decreased the amount of N that was taken up by the plant. No significant (α=.05) treatment differences were observed at Lake Carl Blackwell, but droplet size was highly significant (α=.01) in a contrast analysis (Table 8). When analyzing the means of droplet size at LCB by a single degree of freedom contrast, droplet size was found to be significant (α=.05). The average N uptake for all droplet sizes was 25.44 kg N ha^{-1}. The medium sized droplet achieved the highest N uptake at 31 kg N ha^{-1} followed by 24, and 21 kg N ha^{-1} for the fine and coarse droplet sizes, respectively (Figure 7).

Flag Leaf Total Nitrogen

Flag leaf total N was not significant as a function of treatment over all locations in 2012 (Tables 7, 8, and 9). When analyzing the Perkins location, the check plot had a significantly (Table 9) lower flag leaf concentration average compared to all other treatments (Figure 9). The average of the check treatments was 1.5 g kg^{-1} while the foliar N applications average was 1.7 g kg^{-1}, which resulted in a 12% increase in flag leaf total N concentration (Figure 9).

Results 2012-2013

Growing conditions for the 2012-2013 season started off very poorly. Due to a lack of precipitation while planting, seedling emergence varied across locations and treatments. All three sites, Efaw, LCB, and Perkins, eventually had complete seedling emergence with precipitation occurring post planting. The drought continued into the later part of winter causing the LCB trial to be abandoned. Luckily, at LCB there was an area of bulk wheat adjacent to the original trial that was in good condition to support a new trial being placed there. During the spring months precipitation amounts increased, which led to an increase in plant tillering and more uniform plant densities. Although the fall was very dry, spring rains helped produce average yields for the three locations.

Foliar N applications for all three sites were applied during the morning hours with no ensuing rainfall. More foliar burn was recorded this year, with all treatments showing some signs of awn burn from the foliar N applications (Figure 10). This could be attributed to the higher temperatures (18 C) in 2013 compared to 2012 (17 C) while applying the foliar N. No foliar diseases were reported for all three locations unlike 2012 where leaf rust was present. Analyses of variance and associated means by treatment, droplet size and foliar nitrogen rate for grain yield, grain protein percent, grain N uptake, and flag leaf protein percent are reported in Tables 7, 8, and 9 for Efaw, Lake Carl Blackwell, and Perkins, respectively.

Grain Yield

Grain yields in 2013 were not significant when analyzed by treatment over all locations. Unlike 2012, grain yields were variable between each location but were not as variable within each location. Coefficient of variation values for Efaw, LCB, and Perkins were 14.2, 6.0, and 10.8, respectively (Tables 10, 11 and 12). Average grain yields for Efaw, LCB, and Perkins were 1729, 4182, and 1814 kg ha^{-1}, respectively. Lower yields were expected at Efaw and Perkins locations due to the early harsh growing conditions that were present at planting and early fall and winter growth. Again, like 2012, the addition of an adjuvant to the 11.2 kg N ha^{-1} treatments did not result in any significant difference in yield when compared to the 11.2 kg N ha^{-1} treatments without an adjuvant.

At the Efaw location, single degree of freedom contrasts were significant (Table 10), noting the quadratic response to foliar N rate (Figure 11). When analyzing the LCB location, the interaction of droplet size and N rate revealed significant effects on yield (Table 11). Using a Fischer's $LSD_{.05}$ test for the interaction of droplet size and foliar N rate, the coarse droplet size and a foliar N rate of 11.2 kg N ha^{-1} produced the highest yield, 4359 kg ha^{-1}, followed by the medium droplet size and foliar N rate of 22.4 kg N ha^{-1} with a grain yield of 4321 kg ha^{-1} (Figure 12). At the Perkins location, yield showed a significant linear response to N rate when analyzed using a single degree of freedom contrasts (Table 12 and Figure 13). Also at Perkins, the 11.2 versus 22.4 kg N ha^{-1} single degree of freedom contrast analysis was significant at the alpha 5% level (Table 12). The 11.2 kg N ha^{-1} foliar N rate produced a yield of 1756 kg ha^{-1} while the 22.4 kg N ha^{-1} foliar N rate increased the yield by approximately 10%, 1966 kg ha^{-1}(Figure 13).

Grain Protein

Grain protein concentrations at Efaw and Perkins were not significant at the alpha 5% level in 2013 (Table 10 and 12). Although the main effect of treatment was not significant at Efaw, a single degree of freedom contrast revealed grain protein had a significant linear response to nitrogen rate (Table 10). At the LCB location, grain protein showed a significant response to treatment (Table 11). Using a Fischer's $LSD_{.05}$, treatment two, 11.2 kg N ha^{-1}, fine droplet size, and including an adjuvant, produced the highest protein concentration, 14.7%. The second and third highest protein concentrations were treatment three, 11.2 kg N ha^{-1}, medium droplet size, and including an adjuvant, and treatment four, 11.2 kg N ha^{-1}, coarse droplet size, and including an adjuvant, with protein concentrations of 14.4 and 14.3 % respectively (Table 11). The trend of increasing grain protein concentrations by decreasing droplet size and including an adjuvant in the mixture is consistent with the adjuvant versus none contrast that was significant at the alpha 5% level. With the addition of an adjuvant in the 1:1 UAN foliar N mixture, grain protein increased by 6% over the non-adjuvant treatments, 14.5 and 13.6 %, respectively (Figure 14). Also at the LCB location, a single degree of freedom contrast between the check versus foliar N treatments showed a highly significant (Table 11) difference between the two methods. Foliar N applications increased grain protein concentration by approximately 9.5% compared to the check treatment, 14.0 and 12.7%, respectively (Figure 15).

Nitrogen Uptake

At the Efaw location, nitrogen uptake showed a significant quadratic response to nitrogen rate when using a single degree of freedom contrast (Table 10). At LCB, contrasts revealed a significant response to the interaction of droplet size and foliar N rate (Table 11 and Figure 16). Nitrogen uptake also showed a significant linear response to N rate at LCB (Table 11). Also at LCB, the check versus foliar N application treatment was significantly different (Table 11). Nitrogen uptake was highest with the foliar N applications with an uptake of 103 kg N ha^{-1} compared to the check that had an uptake of 89 kg N ha^{-1}, this resulted in a 13.5% increase of foliar N uptake between the foliar N application and check treatments (Figure 17).

Flag Leaf Total Nitrogen

Flag leaf total N concentration in 2013 was not affected by treatment over all locations. Average flag leaf total N concentrations were 2.1, 2.4, and 1.4.g kg^{-1} for Efaw, LCB, and Perkins, respectively. At the LCB location, flag leaf total N showed a significant linear response to nitrogen rate when analyzed by a single degree of freedom contrast analysis (Figure 18). Also at LCB flag leaf total N showed a highly significant difference (α=.01) from the check treatments to the foliar N treatments by a single degree of freedom contrast analysis (Figure 19). Unlike 2012 and other locations in 2013, LCB showed a significant difference in the adjuvant versus none single degree of freedom contrast analysis (Figure 20). Like the LCB location, the Perkins location showed a highly significant linear response to nitrogen rate (Figure 21) and a highly significant difference between the check and the foliar N treatments (Figure 22) both by single degree of freedom contrast analyses (Table 12).

CHAPTER VI

CONCLUSIONS

The objective of this study was to evaluate the effects of droplet size and foliar N rate on wheat grain yield and protein. The results from this study were variable across all locations and years. Treatment differences were found to be significant for grain yield at LCB in 2012. The medium droplet size with either 11.2 or 22.4 kg N ha^{-1} resulted in the highest yields while differences between fine and coarse droplet sizes were small. Although grain yield was to a certain extent influenced by droplet size and nitrogen rate, in general, differences were small when foliar N was applied after anthesis. However, it is important to note that, producers should select nitrogen rate based on environmental factors such as: soil moisture, temperature, humidity and crop conditions: crop health and potential yield. Higher temperatures with lower soil moisture contents will result in more foliar burn which presents more stress on the growing plant, which could decrease grain yields, evidenced at Perkins in 2012. High yield potential will require more nitrogen uptake to increase protein concentration as was observed at LCB in 2013.

For most locations and years grain protein concentration was increased linearly with higher rates of foliar N applied. On average most locations increased grain protein concentration by 2 percentage points when comparing the foliar N treatments to the check. In 2013, at LCB, grain protein was affected by treatment whereby adjuvant use and fine droplet size were significant. The greatest increase in grain protein concentration, 1.3 % protein over the check, included the fine droplet size with a foliar N rate of 11.2 kg N ha^{-1} with the addition of an adjuvant. The addition of an adjuvant at LCB in 2013 raised protein concentration to 0.9% over the non-adjuvant treatments.

Further data collection is needed at more locations in order to refine the droplet size and nitrogen rate. More winter wheat varieties should also be included in this study to determine if the interaction of variety, droplet size, and nitrogen rate. Also, further studies on adjuvants and the effects of environmental factors: soil moisture, temperature, humidity, etc., need to be conducted to determine the most efficient processes to increase nitrogen uptake in late season foliar N applications.

REFERENCES

American Society of Agricultural and Biological Engineers. Spray Nozzle Classification by Droplet Spectra. 2009. ANSI/ASAE S572.1.

Bale, M. D. and M. E. Ryan. 1977. Wheat Protein Premiums and Price Differentials. American Journal of Agricultural Economics, Vol. 59, No. 3: 530-532.

ChemSurf 90©. CHEMORSE, LTD. 4685 Merle Hay Road, Suite 204 Des Moines, Iowa 50322.

Daniel, C. and Triboi, E. 2000. Effect of temperature and nitrogen nutrition on the grain composition of winter wheat: effects on gliadin content and composition. J. Cer.Sci. 32:45–56.

Debaeke, P., Aussenac, T., Fabre, J.L., Hilaire, A., Pujol, B.,Thuries, L. 1996. Grain nitrogen content of winter bread wheat(Triticum aestivum L.) as related to crop management and to the previous crop. Eur. J. Agron. 5: 273–286.

Fowler, D.B. and J. Brydon. 1989. No-till winter wheat production on the Canadian prairies :Timing of nitrogen fertilizers. Agron. J. 81: 817-825.

Garrido-Lestache, E., R. J. Lopez-Bellido, L. Lopez-Bellido. 2004. Effect on N rate, timing and Splitting and N type on bread-making quality in hard red spring wheat under rainfed Mediterranean conditions. Field Crops Research, 85: 213-236.

.Gauer, L.E., C.A. Grant, D.T. Gehl, L.D. Bailey. 1992. Effects of nitrogen fertilization on grain protein content, nitrogen uptake, and nitrogen use efficiency of six spring wheat (Triticum aestivum L.) cultivars, in relation to estimated moisture supply. Can. J. Plant Sci. 72: 235-241.

Gooding, M.J. and Davies, W.P. 1997. Wheat Production and Utilization. CAB International,Wallingford, UK.

Holloway, P.J., M.C. Butler Ellis, D.A. Webb, N.M. Western, C.R. Tuck, A.L. Hayes, P.C.H.Miller. 2000. Effects of some agricultural tank-mix adjuvants on the deposition efficiency of aqueous sprays on foliage. Crop Protection. 19: 27-37.

Kansas City Board of Trade. 2010. HRW Wheat Futures Contract Amendments Pass. [Online]. Available at http://www.kcbt.com/news_2.asp?id=819 (verified 2 May 2013). KCBT, Kansas City, MO.

Kramer, T.H. 1978. Environmental and Genetic Variation For Protein Content in Winter Wheat (Triticum aestivum L.). Euphytica 28: 209-218.

Lake, J. R. 1977. The Effect of Drop Size and Velocity on the Performance of Agricultural Sprays. Pestic. Sci. 8: 515-520.

Large, E.C. 1954. Growth stages in cereals. Plant Pathol. 3: 128-129.

Mercer, G.N. 2007. A simple diffusion model of the effect of droplet size and spread area on foliar uptake of hydrophilic compounds. Pesticide Biochemistry and Physiology. 88: 128-133.

Rao, A.C.S., Smith, J.L., Jandhyala, V.K., Papendick, R.I., Parr,J.F. 1993. Cultivar and climatic effects on the protein content of soft white winter wheat. Agron. J. 85, 1023–1028.

Raun, W.R. and G.V. Johnson. Improving Nitrogen Use Efficiency for Cereal Production. Agron. J.91: 357-363.

SAS Institute. 2003. SAS/STAT User's Guide: Release 9.1 ed. SAS Inst., Cary, NC.

Schepers, J. S., D.D. Francis, and M.T. Thompson. 1989. Simultaneous determination of total C, total N and 15N on soil and plant material. Commun. Soil Sci. Plant Anal. 20: 949-959.

Stone, P.J. and Savin, R. 2000. Grain quality and its physiological determinants. In: Satorre, M.H., Slafer, G.A. (Eds.), Wheat, Ecology and Physiology of Yield Determination. Food ProductsPress, New York, pp. 85–120.

Tkachuk, R. 1977. Calculation of the nitrogen-to-protein conversion factor. P. 78-82. In J. H. Hulse et al. (ed) Nutritional standards and methods of evaluation for food legume breeders. Int. Dev. Res Ctr., Ottawa, ON.

U.S. Department of Agriculture- Economic Research Service. 2012. Wheat Background. 2012. http://www.ers.usda.gov/topics/crops/wheat/background.aspx (verified 25 September 2012). USDA-ERS, Washington, D.C.

Woodward, H.J. and A.G. Bly. 1998. Relationship of Nitrogen Management to Winter Wheat Yield and Grain Protein in South Dakota. J. Plant Nutr., 21(2): 217-233.

Woodward, H.J. and A.G. Bly. 2003. Nitrogen Management: Foliar Nitrogen Application Timing Influence on Grain Yield and Protein Concentration of Hard Red Winter and Spring Wheat. Agron. J. 95: 335-338.

Woolfolk C.W., W. R. Raun, G.V. Johnson, W. E. Thomasen, R.W. Mullen, K. J. Wynn and K.W. Freeman. 2002. Influence of late season Foliar nitrogen applications on yield and grain nitrogen in winter wheat. Agron J. 94: 429-434.

Wuest, S.B. and K.G. Cassman. 1992b. Fertilizer-nitrogen use efficiency of irrigated wheat: II. Partitioning efficiency of preplant versus late-season application. Agron. J. 84: 689 -694.

TABLES

Table 1. Experimental site description, soil series, Efaw, Perkins and Lake Carl Blackwell,2011-2013.

Location	Soil Series
Efaw	Norge (Fine-silty, mixed, thermic Udic Paleustolls)
Perkins	Konawa (Fine-loamy, mixed, active, thermic Ultic Haplustalfs) and Teller (Fine-loamy, mixed, active, thermic Udic Argiustolls)
Lake Carl Blackwell	Port (Fine-silty, mixed, thermic Cumulic Haplustolls)

Table 2. Surface (0-15cm) soil test results from Efaw and Perkins 2012-2013.

*Soil Test	Efaw	Perkins
NH-4 kg ha^{-1} [a]	27.1	21.35
NO-3 kg ha^{-1} [a]	27.1	8.43
P kg ha^{-1} [b]	49.66	17.4
K kg ha^{-1} [b]	418.88	278.88
pH [c]	4.705	6.795
Total N% [d]	0.083	0.046
Organic C% [d]	0.723	0.571
O.M.	1.651	1.378

*Lake Carl Blackwell was not included in the test results due to moving the trial from the original trial area.

[a] NO_3-N and NH_4-N: KCl extraction

[b] K and P: Mehlich III extraction

[c] pH: 1:1 Soil:Water

[d] Total N and Organic C: LECO Truspec CN dry combustion analyzer

Table 3. Treatment structure describing droplet size and N rate used for the three site selections, Efaw, Perkins, and Lake Carl Blackwell (2011-2013).

Treatment	Foliar N (kg ha^{-1})	Droplet size	Nozzle	PSI	MPH
1	0	—	—	—	—
2	10	Fine, with adjuvant	FC- TR110-015	25	5
3	10	Medium, with adjuvant	GRD120-01	60	5
4	10	Coarse, with adjuvant	GRD120-015	25	5
5	10	Fine	FC- TR110-015	25	5
6	10	Medium	GRD 120-01	60	5
7	10	Coarse	GRD 120-015	25	5
8	20	Fine	FC-TR110-02	60	5
9	20	Medium	GRD120-02	60	5
10	20	Coarse	GRD120-02	40	4

Table 4.Planting, N applications, and harvest dates for Efaw, Perkins, and Lake Carl Blackwell experiments 2011-2012.

	Lake Carl Blackwell	**Efaw**	**Perkins**
Procedure			
Variety	Endurance	Centerfield	Centerfield
Seeding Rate (kg ha $^{-1}$)	100	100	100
Planting Date	2011 Oct 14	2011 Oct 15	2011 Oct 13
Top Dress Application	2012 Feb 24	N/A	2012 Feb 24
Foliar N Application	2012 Apr 13	2012 Apr 25	2012 Apr 13
Grain Harvest	2012 Jun 4	2012 Jun 11	2012 Jun 12

Table 5. Planting, N applications, and harvest dates for Efaw, Perkins, and Lake Carl Blackwell experiments 2012-2013.

	Lake Carl Blackwell	Efaw	Perkins
Procedure			
Variety	Duster	Duster	Centerfield
Seeding Rate kg ha^{-1}	100	100	100
Preplant Nitrogen	*67.2 kg ha^{-1} N, 28 kg ha^{-1} of P2O5	44.8 kg ha^{-1} N	44.8 kg ha^{-1} N
Planting Date	2012 Nov 12	2012 Oct 12	2012 Oct 8
Top Dress Application	N/A	44.8 kg ha^{-1} N	44.8 kg ha^{-1} N
Foliar N Application	2013 May 13	2013 May 14	2013 May 13
Grain Harvest	2013 June 25	2013 June 20	2013 June 14

*Nitrogen and P_2O_5 were applied as Urea (46-0-0) and Diammonium Phosphate (18-46-0).

Table 6.Average temperature and monthly rainfall during the growing seasons (2011-2013) for Efaw, Lake Carl Blackwell, and Perkins.

Efaw				
	Temperature (C)		Rainfall (mm)	
Month	2012	2013	2012	2013
October	16.11	15.56	21.59	15.49
November	9.44	11.11	66.55	11.43
December	4.44	5.56	54.61	10.92
January	5.56	3.89	24.38	25.40
February	6.11	4.44	74.42	78.99
March	15.56	8.33	99.57	28.45
April	18.33	12.78	156.46	135.38
May	22.78	18.33	28.45	152.91
June	26.11	25.00	54.86	93.22

Lake Carl Blackwell				
	Temperature (C)		Rainfall (mm)	
Month	2012	2013	2012	2013
October	15.56	15.00	77.22	11.68
November	8.89	10.56	59.44	13.97
December	3.33	5.00	61.98	11.18
January	4.44	3.33	30.99	26.42
February	5.56	3.89	66.04	84.84
March	15.00	8.33	87.38	13.72
April	17.22	12.22	109.73	153.67
May	22.22	18.33	14.22	235.71
June	25.56	25.00	85.09	140.21

Perkins				
	Temperature (C)		Rainfall (mm)	
Month	2012	2013	2012	2013
October	16.67	15.56	73.15	22.10
November	10.00	11.67	96.77	16.51
December	4.44	6.11	52.58	15.24
January	5.56	4.44	24.38	44.70
February	6.67	5.00	61.21	83.57
March	15.56	8.89	114.81	13.72
April	17.78	12.22	128.52	129.54
May	23.33	18.33	28.45	171.20
June	26.11	25.00	73.91	104.65

Table 7. Analysis of variance, single degree of freedom contrasts, and treatment means for grain yield, grain protein, grain N uptake, and flag leaf protein Efaw, OK, 2012.

				------------------------Grain-----------------------------			-------Flag Leaf-----
				Yield kg ha^{-1}	Protein %	N uptake kg ha^{-1}	Total N g kg^{-1}
				Mean squares			
Source of variation			df				
Rep			2	84739.51	1.011	96.80	1.573
Trt			9	76659.94	0.612	34.22	5.272
Contrast							
N Rate Linear			1	5205.87	3.36*	2.35	6.19
N Rate Quad			1	14711.84	0.19	16.88	2.39
Check vs Other			1	304786.95	2.12*	53.78	8.20
11.2 vs 22.4 kg N ha^{-1}			1	15920.42	0.91	0.46	13.01
Droplet Size			2	65242.74	0.25	35.83	7.71
Adjuvant vs None			1	7019.94	0.67	0.54	0.60
Interaction (Foliar N * Droplet Size)			2	3152.54	0.81	13.93	0.31
Residual error			17	134358.50	0.443	102.29	3.520
SED				299.29	0.543	8.258	1.532
CV				18.81	4.804	21.31	11.48
r^2				0.262	0.486	0.214	0.468
Treatment				Treatment means			
Foliar N kg ha^{-1}	Droplet Size	Adjuvant					
0	None	No		2251	13.06	51.49	1.5
11.2	Fine	Yes		1896	14.30	47.57	1.7
11.2	Medium	Yes		1780	14.11	44.01	1.5
11.2	Coarse	Yes		2049	13.74	49.86	1.6
11.2	Fine	No		1825	13.56	43.43	1.5
11.2	Medium	No		2072	13.50	49.21	1.4
11.2	Coarse	No		1947	13.94	47.77	1.7
22.4	Fine	No		1730	14.22	43.39	1.7
22.4	Medium	No		2064	14.55	52.74	1.7
22.4	Coarse	No		1871	13.57	45.23	1.9
			$LSD_{.05}$	NS	NS	NS	NS

*,** - Significant at the 0.05 and 0.01 probability levels, respectively

SED-Standard error of the difference between two equally replicated means

[a] denotes significant differences in means by a $LSD_{.05}$

Table 8. Analysis of variance, single degree of freedom contrasts, and treatment means for grain yield, grain protein, grain N uptake, and flag leaf protein LCB, OK, 2012.

			Grain			Flag Leaf
			Yield kg ha^{-1}	Protein %	N uptake kg ha^{-1}	Total N g kg^{-1}
			Mean squares			
Source of variation			df			
Rep			2	72592.25	0.877*	14.17	4.664*
Trt			9	300923.50*	0.219	82.08	1.418
Contrast							
N Rate Linear			1	152564.95	0.044	47.49	0.001
N Rate Quad			1	231132.00	0.149	72.83	0.052
Check vs Other			1	1788069.23	0.003	50.48	1.057
11.2 vs 22.4 kg N ha^{-1}			1	249940.98	0.005	63.89	1.970
Droplet Size			2	895884.49**	0.007	250.53**	0.496
Adjuvant vs None			1	65042.63	0.562	31.38	1.127
Interaction (Foliar N * Droplet Size)			2	137286.90	0.131	47.41	1.424
Residual error			18	108184.09	0.175	33.53	1.018
SED				268.56	0.342	4.734	0.8241
CV				20.24	4.576	22.16	5.715
r^2				0.594	0.541	0.560	0.5701
Treatment				Treatment means			
Foliar N kg ha^{-1}	Droplet Size	Adjuvant					
0	None	No		1855 abc[c]	9.19	30.02	1.7
11.2	Fine	Yes		1263 f	9.74	21.56	1.9
11.2	Medium	Yes		2036 ab	9.19	32.89	1.8
11.2	Coarse	Yes		1500 cdef	9.22	24.15	1.8
11.2	Fine	No		1375 def	8.85	21.27	1.7
11.2	Medium	No		1675 bcde	9.00	26.80	1.7
11.2	Coarse	No		1389 def	9.24	22.61	1.9
22.4	Fine	No		1677 bcd	8.80	26.00	1.7
22.4	Medium	No		2174 a	9.36	35.65	1.7
22.4	Coarse	No		1295 def	9.02	20.33	1.7
			$LSD_{.05}$	372	NS	NS	NS

*,** - Significant at the 0.05 and 0.01 probability levels, respectively
SED-Standard error of the difference between two equally replicated means
[a] denotes significant differences in means by a $LSD_{.05}$

Table 9. Analysis of variance, single degree of freedom contrasts, and treatment means for grain yield, grain protein, grain N uptake, and flag leaf protein Perkins, OK, 2012.

				------------------------Grain-----------------------------			-------Flag Leaf-----
				Yield kg ha^{-1}	Protein %	N uptake kg ha^{-1}	Total N g kg^{-1}
						Mean squares	
Source of variation			df				
Rep			2	21884.85	1.219*	1.682	7.777**
Trt			9	79452.76	0.305	34.40	2.049
Contrast							
N Rate Linear			1	208797.95*	0.002	91.59*	3.74
N Rate Quad			1	75098.79	0.268	20.34	2.45
Check vs Other			1	65790.53	0.043	34.63	7.15*
11.2 vs 22.4 kg N ha^{-1}			1	51996.68	0.180	14.36	4.41
Droplet Size			2	120182.13	0.100	48.60	0.018
Adjuvant vs None			1	85826.29	0.001	35.65	0.231
Interaction (Foliar N * Droplet Size)			2	86027.50	0.171	34.27	3.142
Residual error			18	41914.46	0.325	19.19	1.095
SED				167.16	0.466	3.577	0.854
CV				18.51	4.780	18.93	6.406
r^2				0.501	0.469	0.475	0.633
Treatment						Treatment means	
Foliar N kg ha^{-1}	Droplet Size	Adjuvant					
0	None	No		1246	12.05	26.37	1.5
11.2	Fine	Yes		1300	11.99	27.32	1.6
11.2	Medium	Yes		831	12.34	18.10	1.6
11.2	Coarse	Yes		971	11.26	19.10	1.6
11.2	Fine	No		1177	11.94	24.55	1.6
11.2	Medium	No		1253	11.70	25.65	1.7
11.2	Coarse	No		1086	11.93	22.76	1.5
22.4	Fine	No		1167	11.75	24.12	1.7
22.4	Medium	No		873	12.09	18.56	1.6
22.4	Coarse	No		1154	12.34	24.94	1.8
			$LSD_{.05}$	NS	NS	NS	NS

*,** - Significant at the 0.05 and 0.01 probability levels, respectively

SED-Standard error of the difference between two equally replicated means

[a] denotes significant differences in means by a $LSD_{.05}$

Table 10. Analysis of variance, single degree of freedom contrasts and treatment means for grain yield, grain protein, grain N uptake, and flag leaf protein Efaw, OK, 2013.

				Grain		Flag Leaf
			Yield kg ha^{-1}	Protein %	N uptake kg ha^{-1}	Total N g kg^{-1}
				Mean squares		
Source of variation			df			
Rep			2	233686.58*	0.73	118.71*	1.66
Trt			9	51483.88	0.37	38.41	1.75
Contrast						
N Rate Linear			1	9193.99	1.81	1.37	2.37
N Rate Quad			1	307984.30*	0.08	209.83*	0.36
Check vs Other			1	42020.91	1.69	88.11	4.15
11.2 vs 22.4 kg N ha^{-1}			1	113186.48	0.83	43.28	3.18
Droplet Size			2	957.99	0.09	3.11	3.64
Adjuvant vs None			1	16405.25	0.34	2.44	1.03
Interaction (Foliar N * Droplet Size)			2	105010.35	0.13	70.36	0.46
Residual error			18	59948.38	0.43	33.14	2.68
SED				199.91	0.54	4.70	1.34
CV				14.16	4.13	12.00	7.71
r^2				0.46	0.38	0.49	0.28
Treatment					Treatment means		
Foliar N kg ha^{-1}	Droplet Size	Adjuvant					
0	None	No		1617	15.16	42.83	2.0
11.2	Fine	Yes		1684	16.31	47.92	2.2
11.2	Medium	Yes		1721	15.80	47.65	2.1
11.2	Coarse	Yes		1858	15.86	51.67	2.1
11.2	Fine	No		1736	15.73	47.89	2.2
11.2	Medium	No		1970	15.51	53.55	2.0
11.2	Coarse	No		1737	15.90	48.02	2.1
22.4	Fine	No		1833	16.12	51.80	2.2
22.4	Medium	No		1539	16.26	43.78	2.1
22.4	Coarse	No		1596	16.05	44.56	2.2
			$LSD_{.05}$	NS	NS	NS	NS

*,** - Significant at the 0.05 and 0.01 probability levels, respectively

SED-Standard error of the difference between two equally replicated means

[a] denotes significant differences in means by a $LSD_{.05}$

Table 11. Analysis of variance, single degree of freedom contrasts, and treatment means, for grain yield, grain protein, grain N uptake, and flag leaf protein LCB, OK, 2013.

				-----------------------Grain-----------------------------		-------Flag Leaf-----
			Yield kg ha^{-1}	Protein %	N uptake kg ha^{-1}	Total N g kg^{-1}
					Mean squares	
Source of variation		df				
Rep		2	344019.70*	11.30**	135.36	34.31**
Trt		9	134832.62	1.19*	148.16	2.63
Contrast						
N Rate Linear		1	129592.27	3.29*	500.53*	7.63*
N Rate Quad		1	95541.32	0.01	50.90	0.36
Check vs Other		1	80247.37	4.91**	523.97*	12.52**
11.2 vs 22.4 kg N ha^{-1}		1	67136.69	0.14	13.79	0.23
Droplet Size		2	116287.97	0.85	56.59	0.72
Adjuvant vs None		1	207877.07	2.75*	0.20	7.32*
Interaction (Foliar N * Droplet Size)		2	311369.15*	0.46	289.80*	0.44
Residual error		18	1133781.76	0.42	78.47	1.31
SED			869.40	0.53	7.23	0.93
CV			6.001	4.68	8.72	4.77
r^2			0.63	0.81	0.53	0.80
Treatment					Treatment means	
Foliar N kg ha^{-1}	Droplet Size	Adjuvant				
0	None	No	4027	12.65 g	89.03	2.2
11.2	Fine	Yes	4013	14.70 a	103.00	2.5
11.2	Medium	Yes	3978	14.40 ab	100.23	2.5
11.2	Coarse	Yes	4299	14.30 abc	107.82	2.5
11.2	Fine	No	4563	14.00 abcdef	111.90	2.4
11.2	Medium	No	3955	13.44 bcdefg	93.12	2.4
11.2	Coarse	No	4416	13.61 abcdefg	105.40	2.4
22.4	Fine	No	4026	14.25 abcd	100.48	2.4
22.4	Medium	No	4321	14.14 abcde	107.30	2.4
22.4	Coarse	No	4221	13.20 cdefg	97.39	2.3
		$LSD_{.05}$	NS	1.11	NS	NS

*,** - Significant at the 0.05 and 0.01 probability levels, respectively

SED-Standard error of the difference between two equally replicated means

[a] denotes significant differences in means by a $LSD_{.05}$

Table 12. Analysis of variance, single degree of freedom contrasts, and treatment means, for grain yield, grain protein, grain N uptake, and flag leaf protein Perkins, OK, 2013.

		Grain Yield kg ha^{-1}	Grain Protein %	Grain N uptake kg ha^{-1}	Flag Leaf Total N g kg^{-1}
		Mean squares			
Source of variation	df				
Rep	2	131379.14*	0.18	75.68	10.33**
Trt	9	64729.37	0.22	39.76	3.28
Contrast					
N Rate Linear	1	177039.90*	0.14	116.25	12.90**
N Rate Quad	1	23304.25	0.01	11.14	1.26
Check vs Other	1	38753.63	0.45	43.98	18.15**
11.2 vs 22.4 kg N ha^{-1}	1	173026.87*	0.01	85.48	1.12
Droplet Size	2	20426.93	0.49	17.23	2.23
Adjuvant vs None	1	3229.67	0.12	6.34	1.40
Interaction (Foliar N * Droplet Size)	2	31449.49	0.04	17.61	0.41
Residual error	18	38191.55	0.50	28.06	1.53
SED		159.57	0.58	4.33	1.01
CV		10.77	5.37	12.58	8.25
r^2		0.55	0.21	0.50	0.66

Treatment: Foliar N kg ha^{-1}	Droplet Size	Adjuvant	Grain Yield kg ha^{-1}	Grain Protein %	Grain N uptake kg ha^{-1}	Flag Leaf Total N g kg^{-1}
			Treatment means			
0	None	No	1706	12.85	38.49	1.3
11.2	Fine	Yes	1856	13.34	43.45	1.4
11.2	Medium	Yes	1547	12.92	36.05	1.4
11.2	Coarse	Yes	1826	13.22	42.32	1.5
11.2	Fine	No	1877	13.17	43.45	1.8
11.2	Medium	No	1770	13.04	40.53	1.5
11.2	Coarse	No	1661	13.74	40.42	1.6
22.4	Fine	No	1906	13.19	43.88	1.6
22.4	Medium	No	2050	13.16	47.29	1.6
22.4	Coarse	No	1941	13.55	46.30	1.6
		$LSD_{.05}$	NS	NS	NS	NS

*,** - Significant at the 0.05 and 0.01 probability levels, respectively

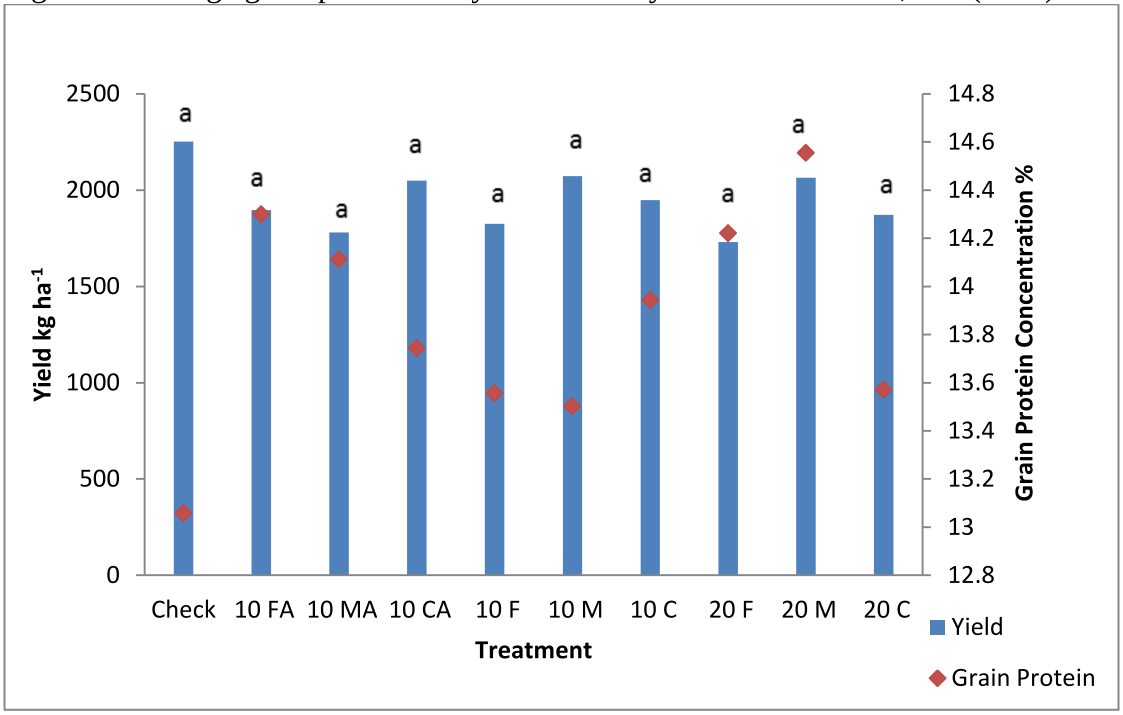
SED-Standard error of the difference between two equally replicated means

[a] denotes significant differences in means by a $LSD_{.05}$

FIGURES

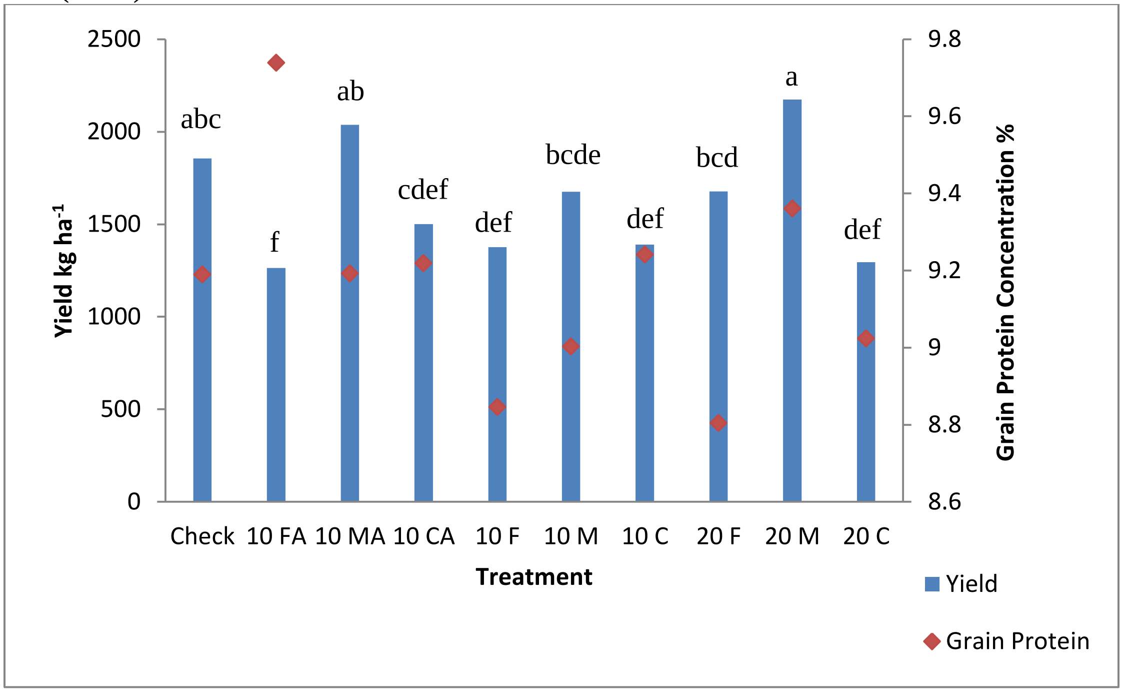
Figure 1. Application equipment and method used to apply late season foliar N on trials at Efaw, LCB, and Perkins for the 2011-2013 growing seasons.

Figure 2. Average grain protein and yield values by treatment at Efaw, OK (2012).



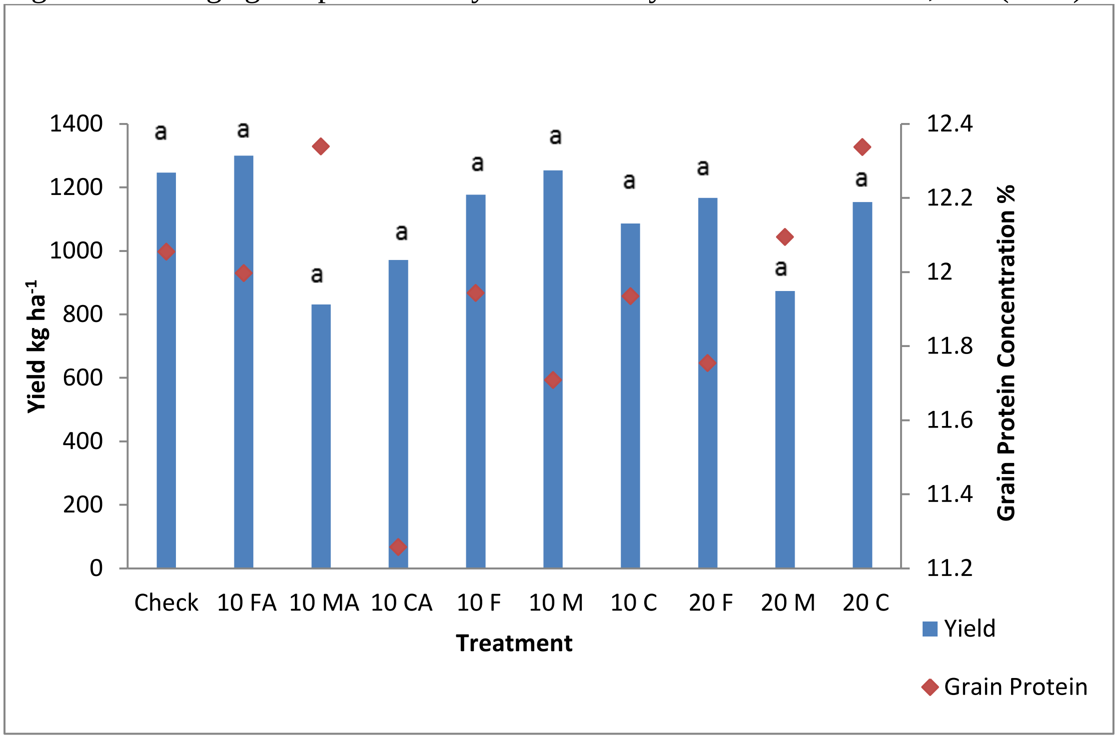
[a] Denotes significant differences in means of grain yields. $LSD_{.05}$.

Figure 3. Average grain protein and yield values by treatment at Lake Carl Blackwell, OK (2012)



[a] Denotes significant differences in means of grain yields. $LSD_{.05}$.

Figure 4. Average grain protein and yield values by treatment at Perkins, OK (2012).



[a] Denotes significant differences in means of grain yields. $LSD_{.05}$.

Figure 5. Relationship of flag leaf total N and grain protein content with foliar nitrogen rate at Efaw, OK, 2012. Grain protein showed a linear response to nitrogen rate α=.05.

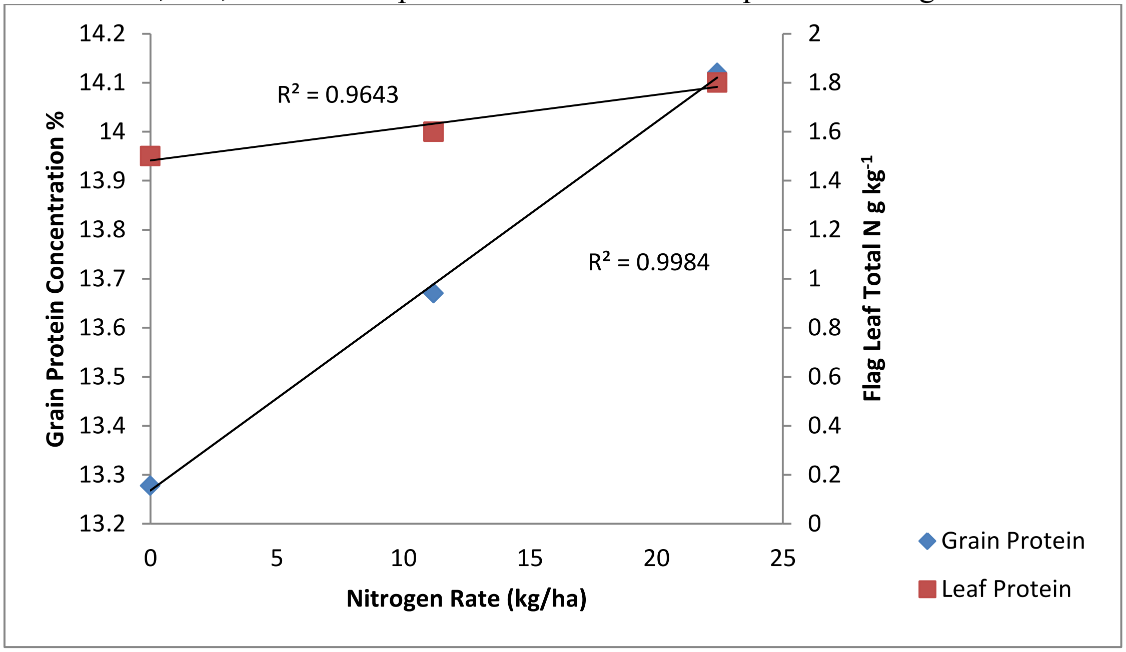


Figure 6. Relationship of flag leaf total N and grain protein content with the check treatment and foliar N treatments at Efaw, OK (2012). The check vs other contrast analysis for grain protein was significant at the α=.05 level.

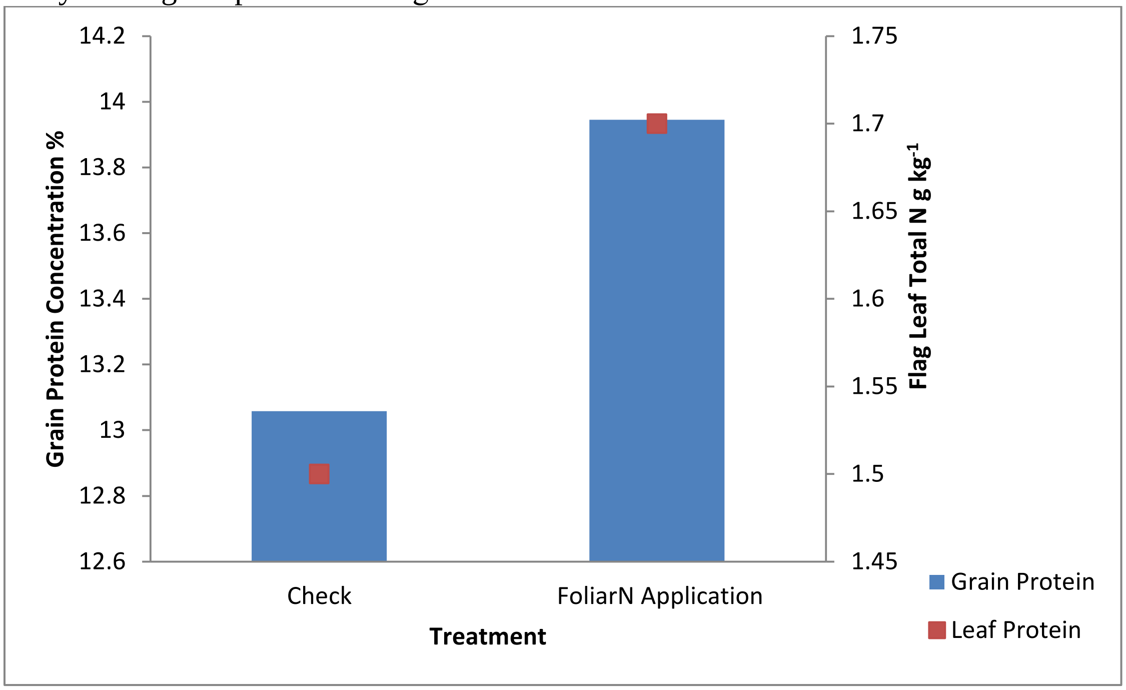
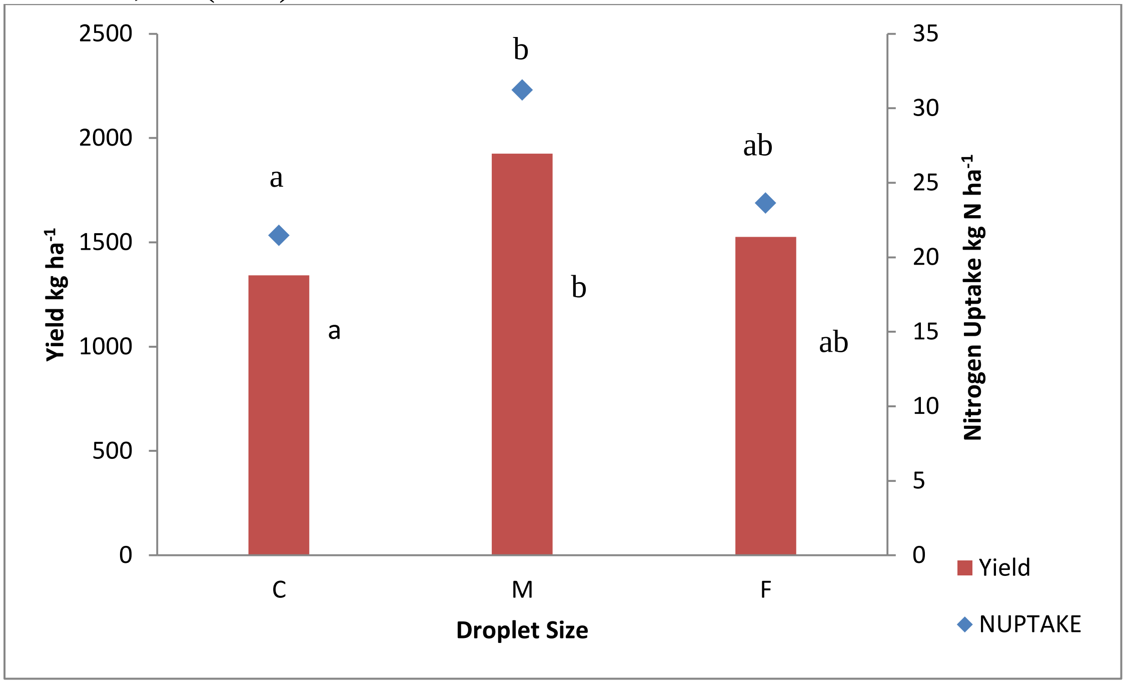
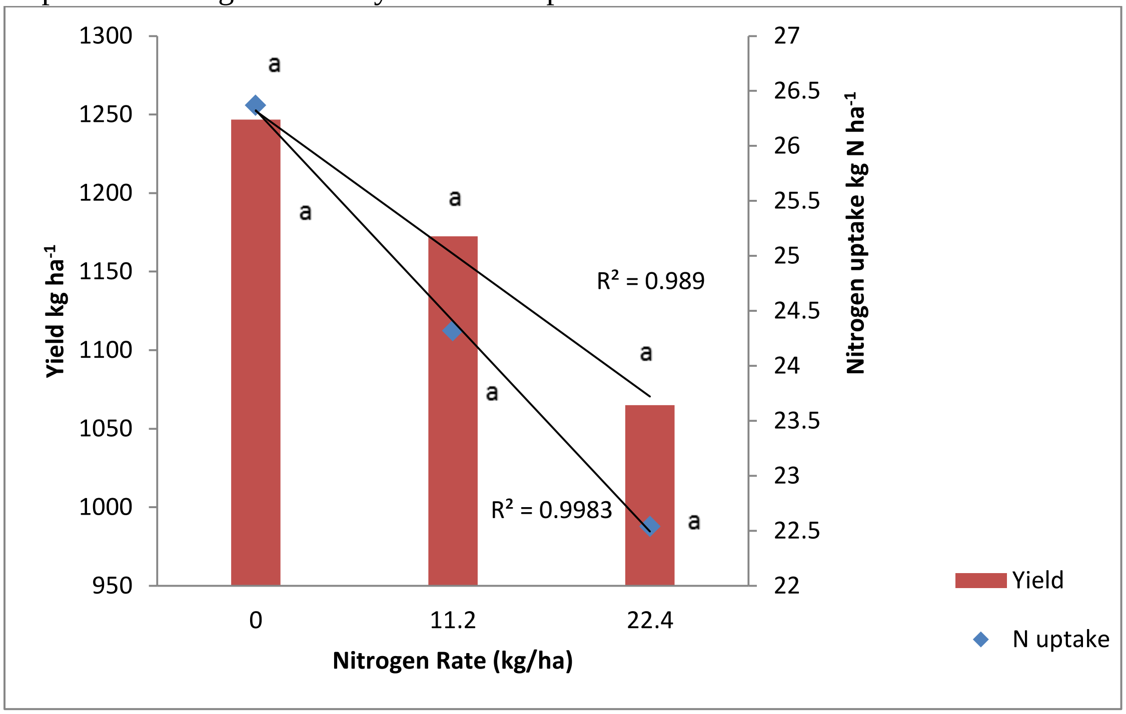


Figure 7. Relationship of yield and nitrogen uptake with droplet size at Lake Carl Blackwell, OK (2012).



[a] denotes significant differences in means. $LSD_{.05}$.

Figure 8. Relationship of yield and nitrogen uptake with nitrogen rate at Perkins, OK (2012). Single degree of freedom contrasts revealed an inverse linear response to nitrogen rate for yield and N uptake.



[a] denotes significant differences in means. $LSD_{.05}$

Figure 9. Relationship of flag leaf total N and grain protein content with the check treatment and the foliar N treatments at Perkins, OK, 2012. The check vs other contrast analysis for flag leaf protein was significant at the α=.05 level.

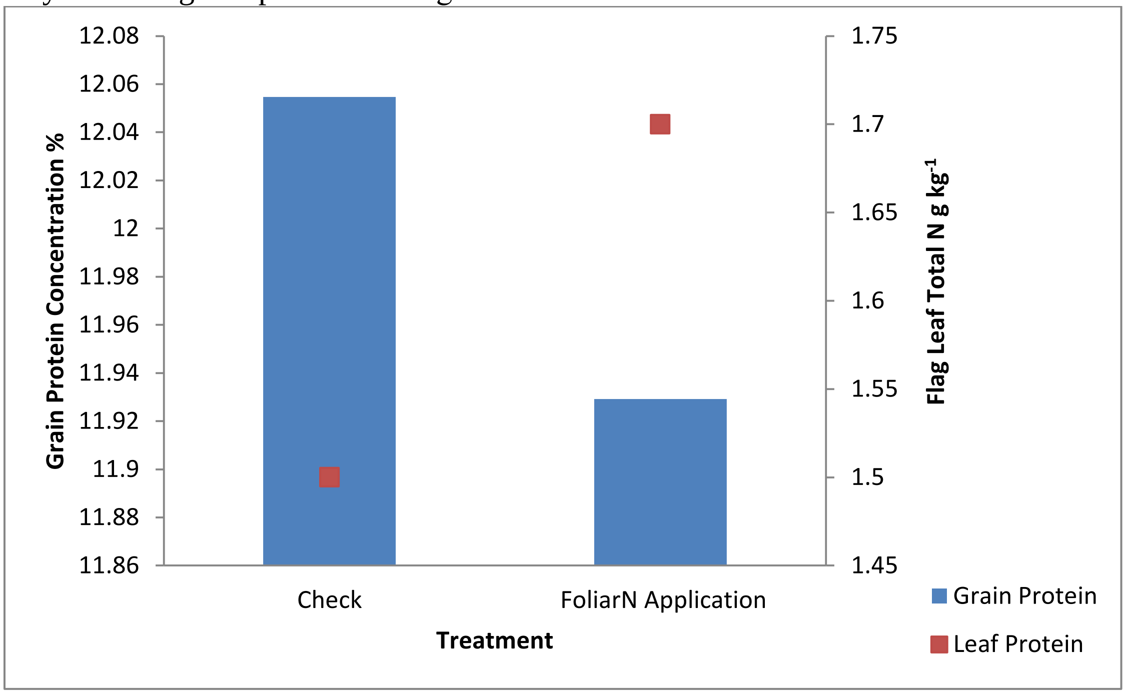


Figure 10. Foliar N burn was more frequent over all treatments in the 2012-2013 growing season. On the left the check treatment shows no clear visual signs of awn burn compared to the right which shows the increased signs of foliar N burn.

Figure 11. Relationship of yield with foliar N rate at Efaw, OK, 2013.

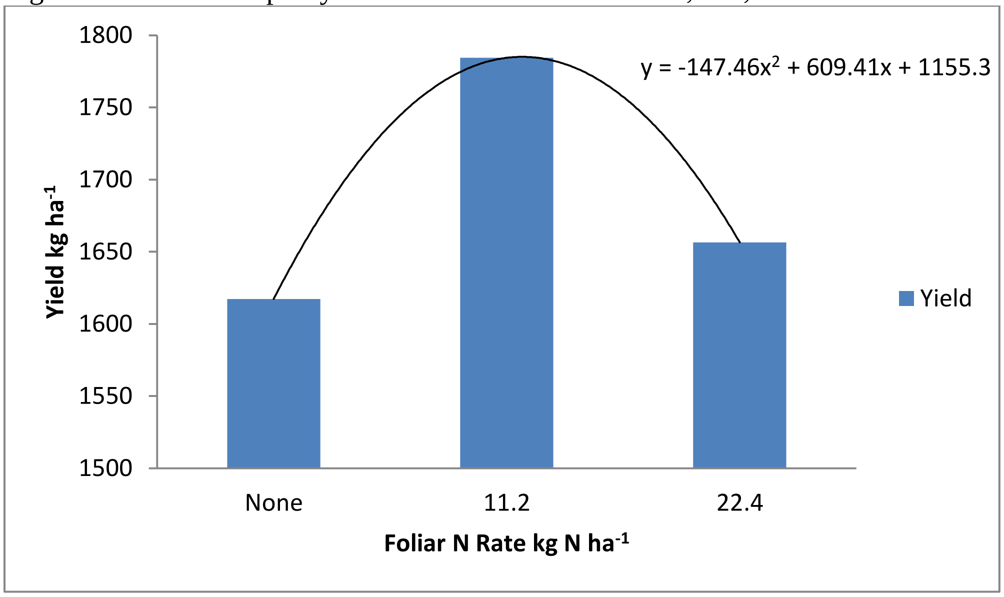
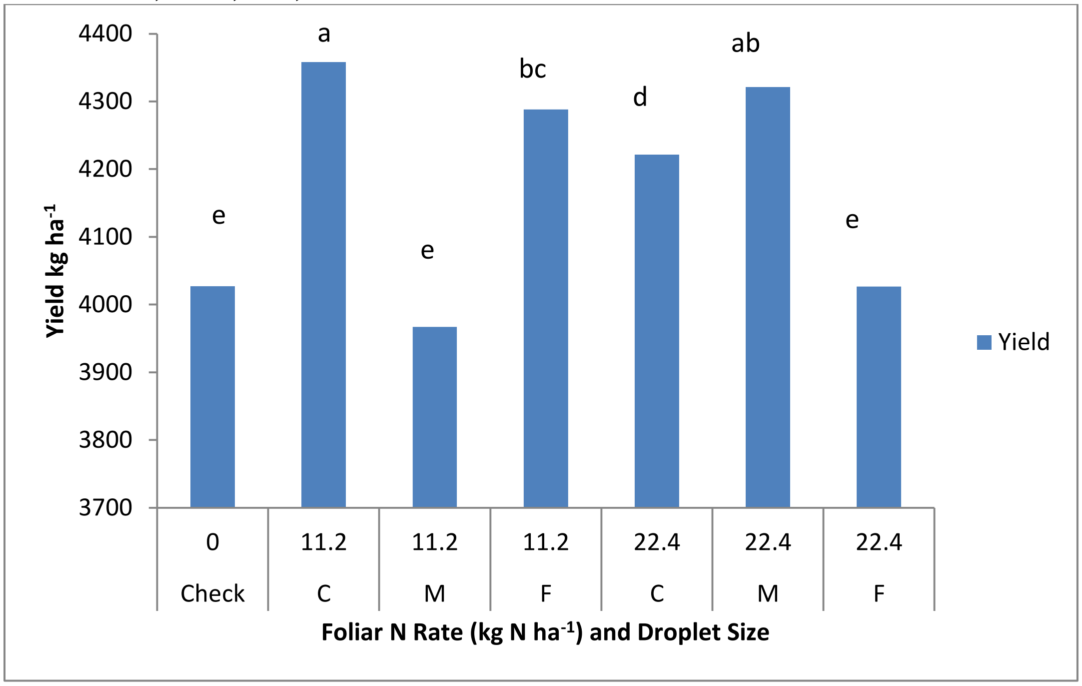


Figure 12. Treatment comparisons for grain yield as influenced by droplet size and foliar N rate, LCB, OK, 2013.



[a] denotes significant differences in means. $LSD_{.05}$ = 60 kg ha^{-1}

Figure 13. Relationship of grain yield and foliar N rate at Perkins, OK, 2013. Grain yield had both a significant linear response to foliar N rate and a significant difference between the 11.2 and 22.4 kg N ha^{-1} foliar N rates.

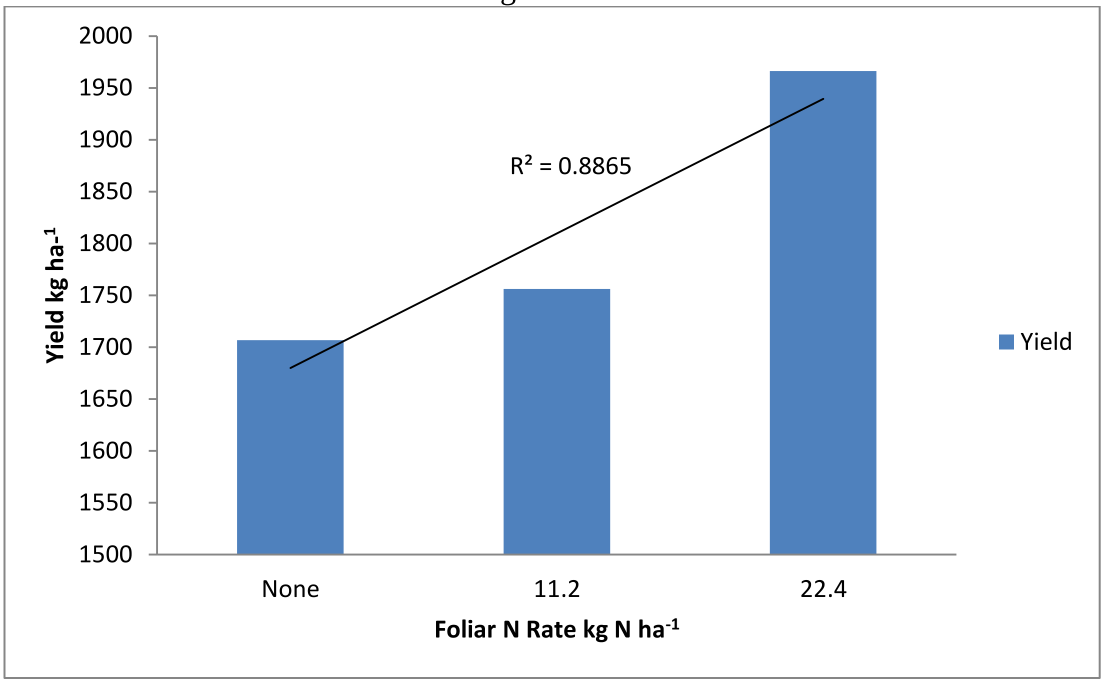


Figure 14. Grain protein concentration differences between non-adjuvant and adjuvant foliar N treatments at LCB, 2013.

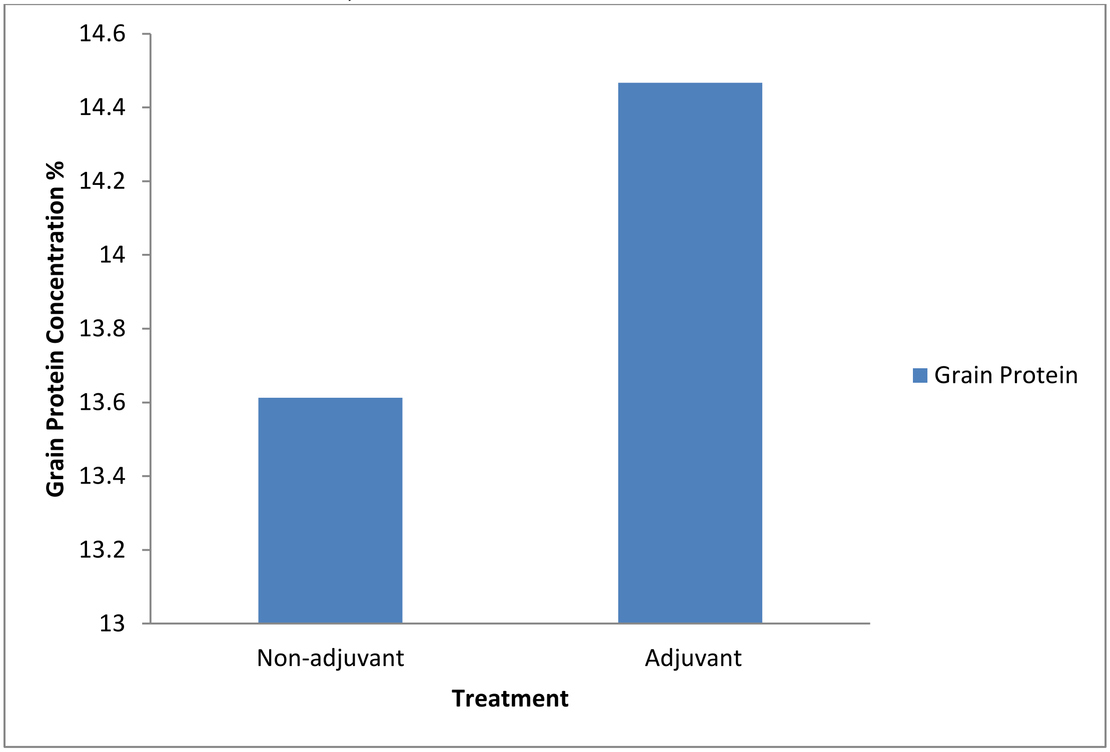


Figure 15. Grain protein concentration differences between the check and the foliar N application treatments, LCB, 2013.

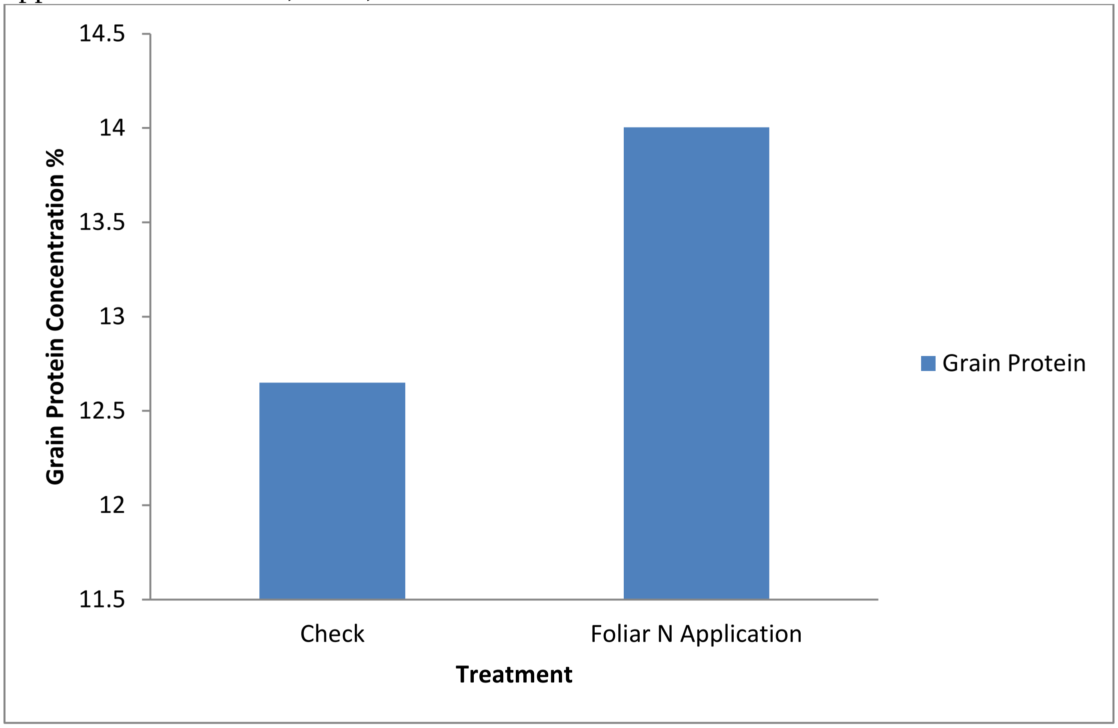
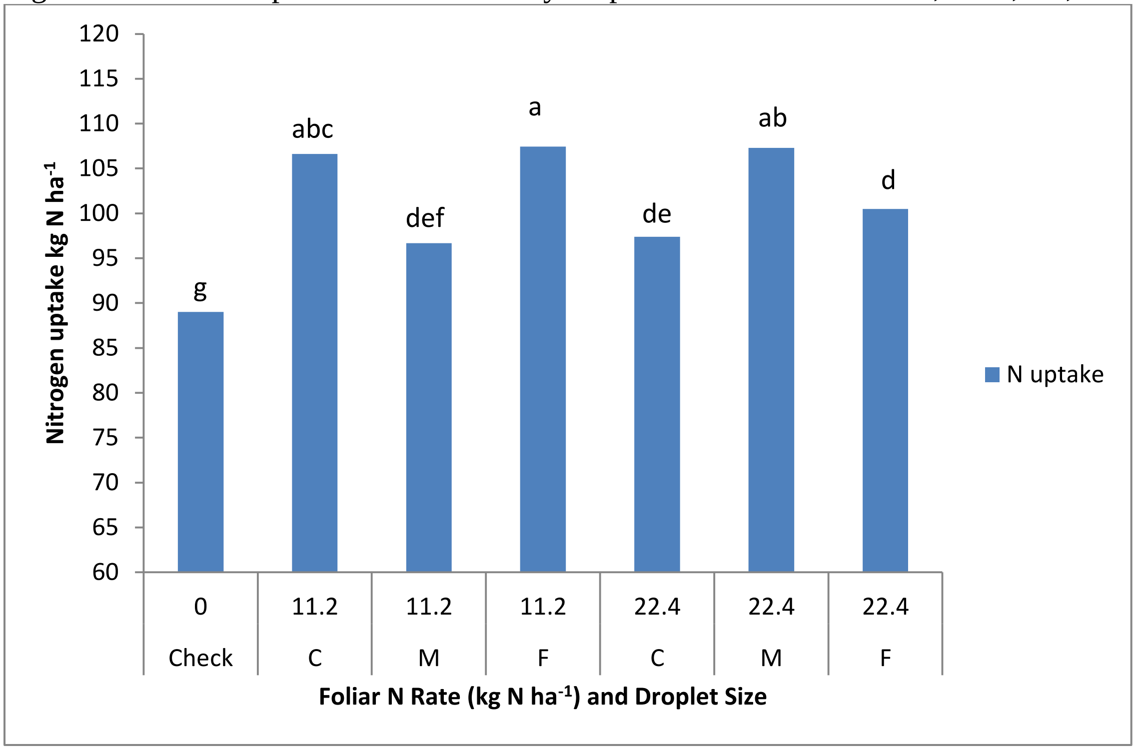


Figure 16. Grain N uptake as influenced by droplet size and foliar N rate, LCB,OK, 2013.



[a] denotes significant differences in means, $LSD_{.05}$ = 3.90 kg N ha $^{-1}$.

Figure 17.Grain N uptake mean differences between the check and the foliar N application treatments, LCB, OK, 2013.

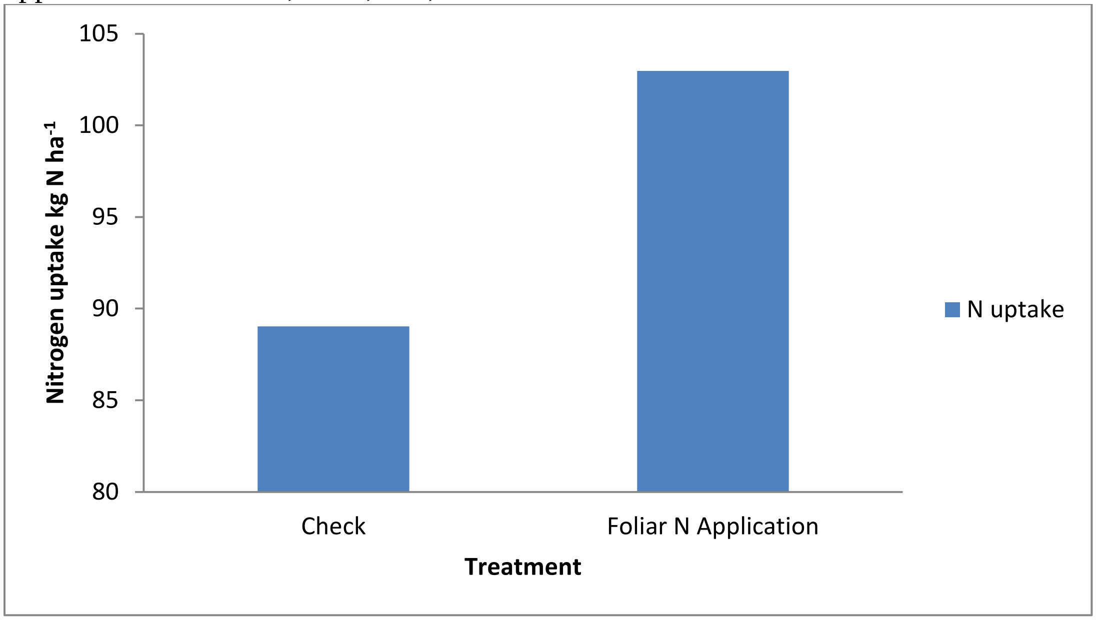


Figure 18. Relationship of flag leaf total N and foliar N rate, LCB, OK, 2013.

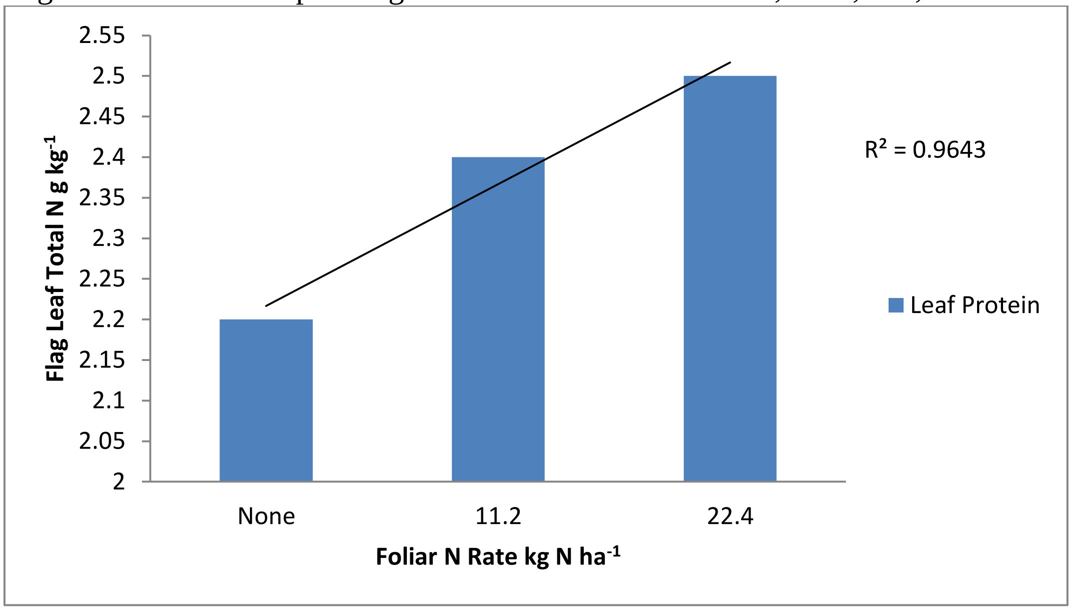


Figure 19. Relationship of flag leaf total N content with the check treatment and the foliar N treatments, LCB, OK, 2013.

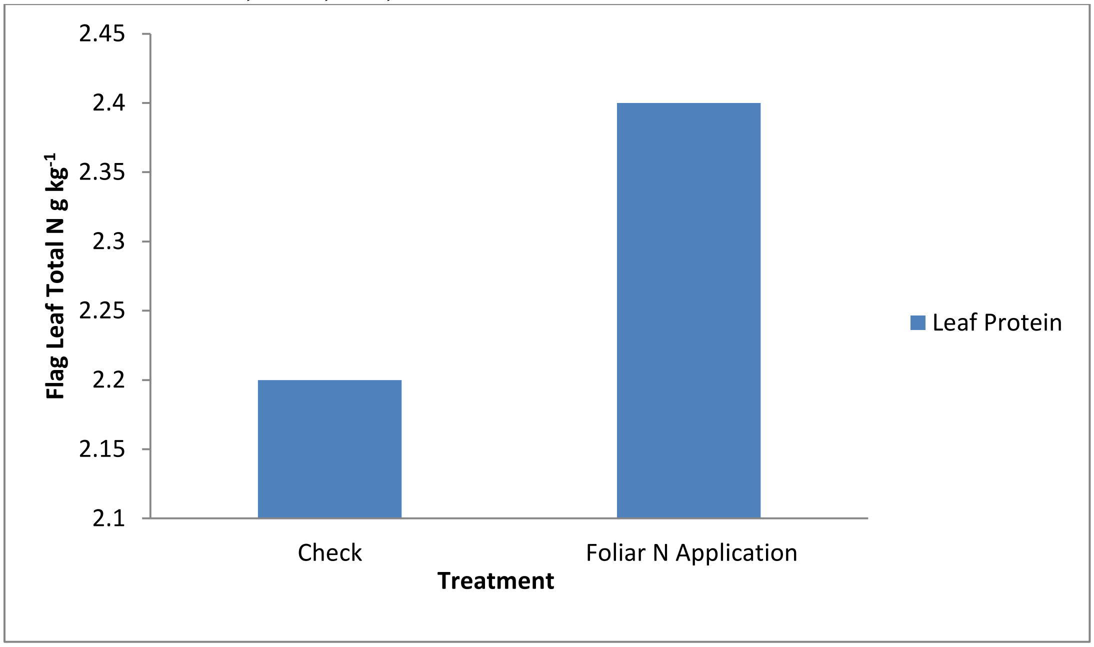


Figure 20.Relationship of flag leaf total N with the no adjuvant treatments and the adjuvant treatments, LCB, OK, 2013.

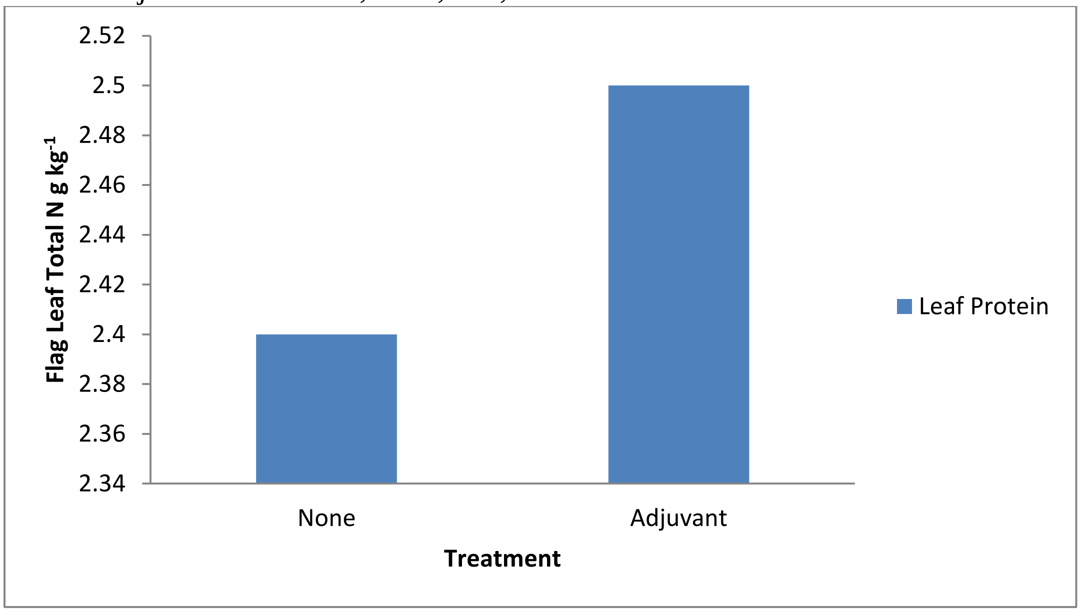


Figure 21.Relationship of flag leaf total N with foliar N rates, Perkins, OK, 2013.

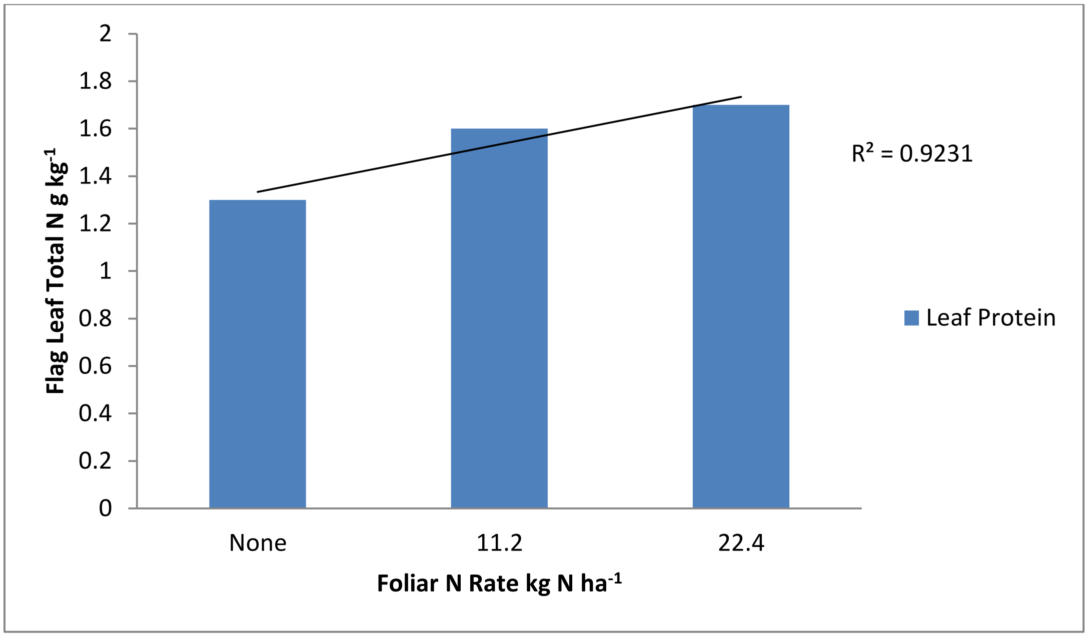
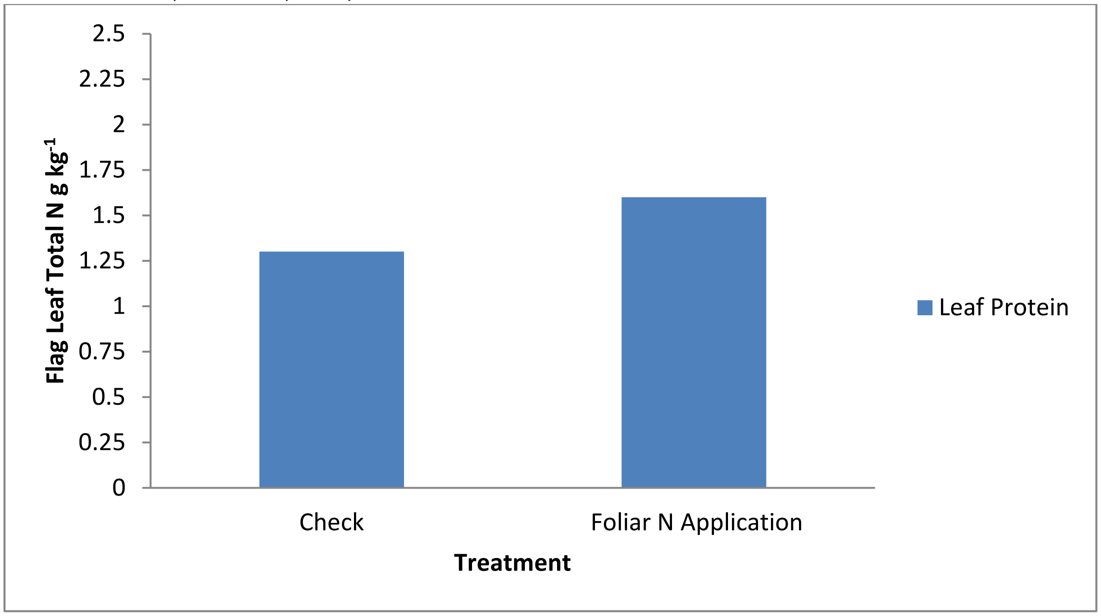


Figure 22.Relationship of flag leaf total N with the check treatment and the foliar N treatments, Perkins, OK, 2013.



APPENDICES

Figure A1. Treatment structure at Efaw (2011-2012).

Efaw- Droplet Size

2011-2012

Plot Size: 10' x 20'
Total Area: 100' x 140'

OBJECTIVE: To determine the effect of droplet size during foliar N applications on nitrogen uptake

TRT	Foliar N (lb N/ac)	Droplet Size	Nozzle	PSI	MPH
1	0	----	----	----	----
2	10	Fine, with adjuvant	FC-TR110-015	25	5
3	10	Medium, with adjuvant	GRD120-01	60	5
4	10	Coarse, with adjuvant	GRD120-015	25	5
5	10	Fine	FC-TR110-015	25	5
6	10	Medium	GRD120-01	60	5
7	10	Coarse	GRD120-015	25	5
8	20	Fine	FC-TR110-02	60	5
9	20	Medium	GRD120-02	60	5
10	20	Coarse	GRD120-02	40	4
Foliar N applied in the form of UAN (28-0-0)					
Collect 15 flag leafs per plot following applications					

Rep 3	8	2	alley	3	10	alley	6	5	alley	4	7	alley	1	9
Rep 2	5	4	alley	9	8	alley	6	3	alley	7	2	alley	1	10
Rep 1	2	3	alley	9	7	alley	8	10	alley	1	4	alley	6	5

Figure A2. Treatment structure at Lake Carl Blackwell (2011-2012).

LCB - DROPLET SIZE

2011-2012

Blanket application of 40 lbs N/ac applied at feekes 4 to all plots

Plot Size: 10' x 30'
Total Area: 150' x 140'

OBJECTIVE: To determine the effect of droplet size during foliar N applications on nitrogen uptake

TRT	Foliar N (lb N/ac)	Droplet Size	Nozzle	PSI	MPH
1	0	----	----	----	----
2	10	Fine, with adjuvant	FC-TR110-015	25	5
3	10	Medium, with adjuvant	GRD120-01	60	5
4	10	Coarse, with adjuvant	GRD120-015	25	5
5	10	Fine	FC-TR110-015	25	5
6	10	Medium	GRD120-01	60	5
7	10	Coarse	GRD120-015	25	5
8	20	Fine	FC-TR110-02	60	5
9	20	Medium	GRD120-02	60	5
10	20	Coarse	GRD120-02	40	4
Foliar N applied in the form of UAN (28-0-0)					
Collect 15 flag leafs per plot following applications					

Rep 3	10	5	alley	7	2	alley	4	3	alley	8	6	alley	1	9
Rep 2	8	6	alley	4	5	alley	10	3	alley	7	2	alley	1	9
Rep 1	1	9	alley	3	7	alley	2	5	alley	10	6	alley	8	4

Figure A3. Treatment structure at Perkins (2011-2012).

Perkins - Droplet Size

2011-2012

Blanket application of 40 lbs N/ac applied at feekes 4 to all plots

Plot Size: 10' x 30'
Total Area: 150' x 140'

OBJECTIVE: To determine the effect of droplet size during foliar N applications on nitrogen uptake

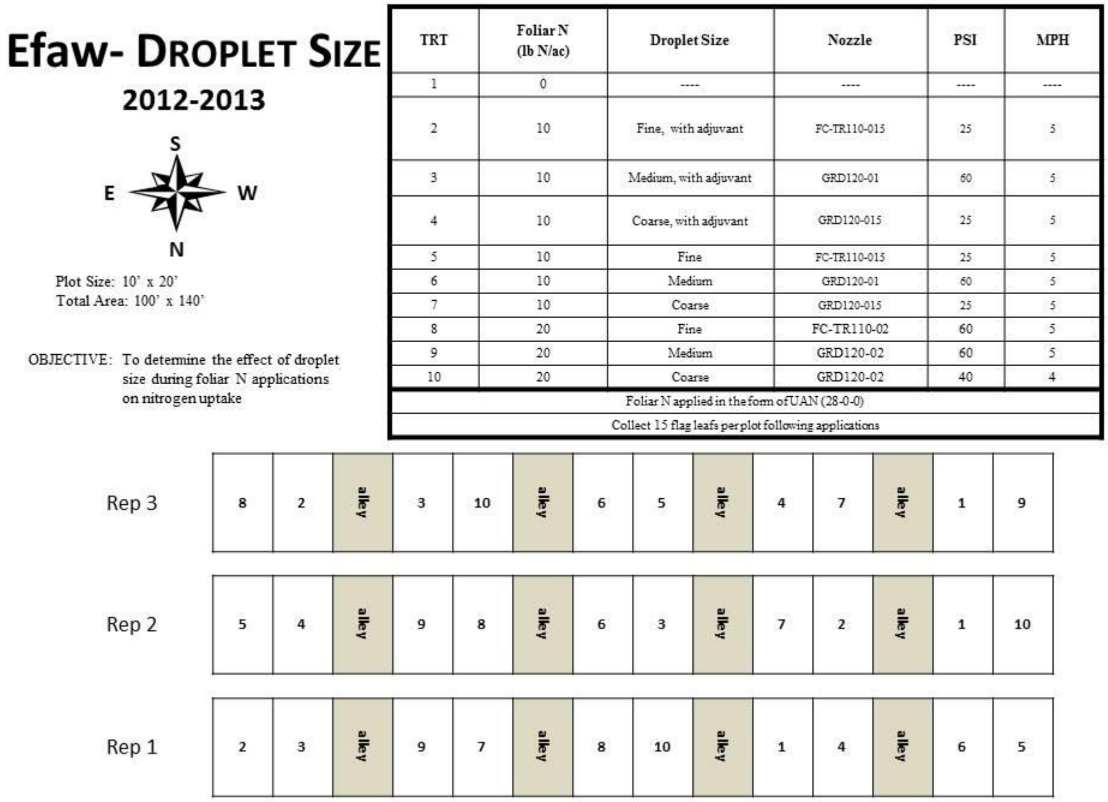
TRT	Foliar N (lb N/ac)	Droplet Size	Nozzle	PSI	MPH
1	0	----	----	----	----
2	10	Fine, with adjuvant	FC-TR110-015	25	5
3	10	Medium, with adjuvant	GRD120-01	60	5
4	10	Coarse, with adjuvant	GRD120-015	25	5
5	10	Fine	FC-TR110-015	25	5
6	10	Medium	GRD120-01	60	5
7	10	Coarse	GRD120-015	25	5
8	20	Fine	FC-TR110-02	60	5
9	20	Medium	GRD120-02	60	5
10	20	Coarse	GRD120-02	40	4

Foliar N applied in the form of UAN (28-0-0)

Collect 15 flag leafs per plot following applications

Rep 3	3	4	alley	10	9	alley	1	8	alley	6	2	alley	5	7
Rep 2	5	2	alley	6	3	alley	9	4	alley	7	8	alley	10	1
Rep 1	10	9	alley	8	5	alley	7	2	alley	4	1	alley	6	3

Figure A4. Treatment structure at Efaw (2012-2013).



TRT	Foliar N (lb N/ac)	Droplet Size	Nozzle	PSI	MPH
1	0	----	----	----	----
2	10	Fine, with adjuvant	FC-TR110-015	25	5
3	10	Medium, with adjuvant	GRD120-01	60	5
4	10	Coarse, with adjuvant	GRD120-015	25	5
5	10	Fine	FC-TR110-015	25	5
6	10	Medium	GRD120-01	60	5
7	10	Coarse	GRD120-015	25	5
8	20	Fine	FC-TR110-02	60	5
9	20	Medium	GRD120-02	60	5
10	20	Coarse	GRD120-02	40	4
Foliar N applied in the form of UAN (28-0-0)					
Collect 15 flag leafs per plot following applications					

Figure A5. Treatment structure at Lake Carl Blackwell (2012-2013).

LCB - DROPLET SIZE

2012-2013

Blanket application of 40 lbs N/ac applied at feekes 4 to all plots

Plot Size: 10' x 20'
Total Area: 80' x 140'

OBJECTIVE: To determine the effect of droplet size during foliar N applications on nitrogen uptake

TRT	Foliar N (lb N/ac)	Droplet Size	Nozzle	PSI	MPH
1	0	----	----	----	----
2	10	Fine, with adjuvant	FC-TR110-015	25	5
3	10	Medium, with adjuvant	GRD120-01	60	5
4	10	Coarse, with adjuvant	GRD120-015	25	5
5	10	Fine	FC-TR110-015	25	5
6	10	Medium	GRD120-01	60	5
7	10	Coarse	GRD120-015	25	5
8	20	Fine	FC-TR110-02	60	5
9	20	Medium	GRD120-02	60	5
10	20	Coarse	GRD120-02	40	4

Foliar N applied in the form of UAN (28-0-0)

Collect 15 flag leafs per plot following applications

Rep 3	10	5	alley	7	2	alley	4	3	alley	8	6	alley	1	9
Rep 2	8	6	alley	4	5	alley	10	3	alley	7	2	alley	1	9
Rep 1	1	9	alley	3	7	alley	2	5	alley	10	6	alley	8	4

Figure A6. Treatment structure at Perkins (2012-2013).

Perkins - Droplet Size

2012-2013

Blanket application of 40 lbs N/ac applied at feekes 4 to all plots

Plot Size: 10' x 30'
Total Area: 150' x 140'

OBJECTIVE: To determine the effect of droplet size during foliar N applications on nitrogen uptake

TRT	Foliar N (lb N/ac)	Droplet Size	Nozzle	PSI	MPH
1	0	----	----	----	----
2	10	Fine, with adjuvant	FC-TR110-015	25	5
3	10	Medium, with adjuvant	GRD120-01	60	5
4	10	Coarse, with adjuvant	GRD120-015	25	5
5	10	Fine	FC-TR110-015	25	5
6	10	Medium	GRD120-01	60	5
7	10	Coarse	GRD120-015	25	5
8	20	Fine	FC-TR110-02	60	5
9	20	Medium	GRD120-02	60	5
10	20	Coarse	GRD120-02	40	4
Foliar N applied in the form of UAN (28-0-0)					
Collect 15 flag leafs per plot following applications					

Rep 3	3	4	alley	10	9	alley	1	8	alley	6	2	alley	5	7
Rep 2	5	2	alley	6	3	alley	9	4	alley	7	8	alley	10	1
Rep 1	10	9	alley	8	5	alley	7	2	alley	4	1	alley	6	3

VITA

Ethan Cord Wyatt

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF DROPLET SIZE AND NITROGEN RATE ON PROTEIN CONTENT OF HARD RED WINTER WHEAT (TRITICUM AESTIVUM L.)

Major Field: Plant and Soil Sciences

Biographical:

Education:

Graduated from Chattanooga High School, Chattanooga, OK in May 2008.

Completed the requirements for the Bachelor of Science in Plant and Soil Sciences at Oklahoma State University, Stillwater, Oklahoma in May 2012.

Completed the requirements for the Master of Science in Plant and Soil Sciences at Oklahoma State University, Stillwater, Oklahoma in December, 2013.

Experience:

Employed by Crop Quest, Montezuma, KS and Dimmitt, TX, as an intern crop consultant (2010, 2011)

Employed by Oklahoma State University as an undergraduate research assistant (2009-2010, 2011-2012)

Employed by Oklahoma State University, Department of Plant and Soil Sciences, as a graduate research assistant (2012-Present).

Professional Memberships:

American Society of Agronomy 2008-Present
Crop Science Society of America 2008-Present
Soil Science Society of America 2008-Present