STREAM AND FLAT FAN TOPDRESS APPLICATION OF UREA AMMONIUM NITRATE IN WINTER WHEAT (*Triticum aestivum* L.)

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STREAME AND FLATFAN TOPDRESS

APPLICATION OF UREA AMMONIUM NITRATE IN

WINTER WHEAT (*Triticum aestivum* L.)

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ABSTRACT

STREAM AND FLAT FAN TOPDRESS APPLICATION OF UREA AMMONIUM NITRATE IN WINTER WHEAT (*Triticum aestivum* L.)

Changing the application method of nitrogen (N) fertilizer has the potential to increase grain yield in winter wheat (*Triticum aestivum* L.). The objective of this study was to evaluate the use of streamer nozzle application using urea ammonium nitrate (UAN) versus flat fan nozzle application. The experiment was conducted at the Robert L. Westerman Irrigation Research Station at Lake Carl Blackwell, OK (LCB), and at the EFAW Research Field near Stillwater, OK for two years (2006-2007, and 2007-2008). Additional sites were established in 2007-2008 at the Perkins Research Station at Perkins, OK, and another site at the Robert L. Westerman Irrigation Research Station at Lake Carl Blackwell, OK. The experimental design was a randomized complete block with three replications. Treatments included four N rate combinations applied in three different methods; 1. streamer nozzle topdress application of liquid UAN; 2. flat fan nozzle topdress application of liquid UAN; and 3. granular urea applied to the surface without incorporation. Nitrogen rate combinations were 0 – 45, 0 – 90, 45 – 45, and 45 – 90 kg N ha^{-1}, preplant and topdress application rates respectively. Excessive rainfall in 2007 at both sites resulted in highly variable, and extremely low wheat grain yields (< 700 kg ha^{-1} in all plots), with a great amount of variation occurring between N rate treatments. The adverse weather conditions resulted in the check plot producing higher yields than half of the other treatments thus restricting proper evaluation of N rates and method of

application for this year. In 2008 an increase in grain yields was observed from topdress N application with the streamer nozzle. A benefit was observed from utilizing the streamer nozzle for topdress application at the higher N rate combinations (0 – 90, 45 – 45, and 45 – 90 kg N ha^{-1}) however the increase in yield observed at the highest N rate combination was not significant. A small increase in yield was seen when using the flat fan nozzle over the streamer nozzle at the 0 – 45 kg N ha^{-1} rate. The benefits of fertilizing with the streamer nozzle tended to be more evident at the middle two N rate combinations (0 – 90 and 45 – 45 kg N ha^{-1}) where N was limiting early in the season.

CHAPTER I

INTRODUCTION

With nitrogen use efficiency (NUE) of cereal grains being 33% on average world wide and with the rising cost of and demand for fertilizer, it is important to employ better and more efficient methods of N application. In recent years, as the price of solid fertilizer sources has gone up rapidly, the price of liquid N has increased at a much slower rate, now making it comparable to or in some cases cheaper than solid N fertilizer. As many producers move towards a split application of fertilizer due to increased cost effectiveness, more producers are utilizing liquid N sources for their fertilizer applications. Because of this finding, a more effective method of topdress N application is needed The objective of this study was to evaluate the use of streamer nozzle application using urea ammonium nitrate (UAN) versus flat fan nozzle application. These trials were established in the fall of 2006 at two sites in Stillwater, OK consisting of 12 treatments arranged in a randomized complete block design (RCBD) with three replications. Treatments consisted of a check plot and three methods of N fertilizer application (flat fan UAN, streamer nozzle UAN and granular UREA broadcast) at 0-45, 0-90, 45-45, and 45-90 kg N ha^{-1} N rate combinations. Identifying the optimum application method for N fertilizer is specifically important in variable rate technology which is one of the precision agriculture techniques being employed to increase efficiency, and maximize net returns of crop producers.

CHAPTER II

REVIEW OF LITERATURE

The price of nitrogen fertilizer continues to rise from an average price of \$0.66 kg^{-1} actual N for urea in 2002 to \$1.10 kg^{-1} of N for urea in 2005 (U.S. Department of Energy 2006). Current prices of fertilizer N exceed \$1.32 kg^{-1} N (NASS 2008). The cause of this steep increase in price is tied to the rising cost of natural gas which is the primary energy source in ammonia production, (Huang, 2007). With this rise in cost of N fertilizer it becomes more important every year for producers to increase their N use efficiency (NUE) so as to maximize production while minimizing one of their largest inputs. The current NUE for cereal crop production is 33% world wide with an estimated average of 29% in developing countries and 42% for the developed countries (Raun and Johnson, 1999). These low NUE values can be attributed to plant nitrogen loss as NH_3 (Francis et al., 1993) denitrification, (Hilton et al., 1994), and surface runoff and leaching (Blevins et al., 1996; Chuchester and Richardson, 1992). A 1% global increase in NUE would result in an estimated savings of \$234,658,462 (Raun and Johnson, 1999). With fertilizer N prices three times that encountered in 1999, a 1% global increase in NUE would be worth close to 1 billion US dollars in 2008.

Nitrogen in the soil must undergo a series of changes to become available for plant uptake depending on its oxidation state. If the N is organic, it must first be converted into an inorganic form by bacteria in a process known as mineralization, the product of this is NH_4^+. Ammonium is a plant available source of N that due to its positive charge is held by the cation exchange complex of the soil and thus less susceptible to leaching from the soil; if the NH_4^+ is not taken up by the plant then it is subject to further changes in the soil system. Remaining NH_4^+ is susceptible to nitrification, a biological process that converts NH_4^+ into NO_3^-. Since nitrification is a biological process it speeds up greatly in warm, moist, well-aerated soils and slows down in soils with temperatures below 10 degrees °C. Nitrate, the product of nitrification, unlike NH_4^+ is water soluble and due to its negative charge it is not attached to the soil particles or soil organic matter making it highly susceptible to leaching. Because of this it is recommended that fall applied NH_4^+ fertilizers not be applied until the average soil temperature is below 10 degrees °C. Losses due to leaching are greater in coarse textured soils with low water holding capacity such as sandy soils than they are in fine textured soils such as clay or silt loams. Leaching can occur any time there is excess water in the soil profile.

Nitrogen Source

Nitrate (NO_3^-) in the soil is susceptible to conversion into N gasses by bacteria in a process called denitrification. This process occurs in anaerobic environments when denitrifying bacteria use NO_3^- as the electron acceptor in the metabolic process instead of oxygen. Denitrification is generally limited to the topsoil due to its requirement for water logged soils with high organic matter content for use as an energy source for the bacteria. Like other biological processes, denitrification is affected by temperature and can proceed rapidly in soils with a warm temperature that have been water logged for 2 or more days.

Nitrogen will either enter the plant through absorption by the roots in the form of nitrate (NO_3^-), as ammonium (NH_4^+), or through direct uptake by the leaves. Each pathway has its own benefits and draw backs, soil N that is absorbed through the roots is available for plant uptake for a longer period of time. However, N is subject to loss through leaching, denitrification and immobilization. Nitrogen lost to leaching can range anywhere from 0 to 40 kg ha^{-1} depending on soil conditions, texture and management practices (Raun et.al., 1997). Denitrification and immobilization tend to account for a much smaller percentage of N loss than leaching. Foliar applied N is absorbed directly by the plant eliminating many of the sources of N loss that soil systems are subject to, however foliar N is susceptible to a range of different sources of N loss including volatilization, runoff, or if applied when temperatures are high can lead to crop damage in the form of burning. Between ammonia volatilization and gaseous plant N loss producers could lose from 0-50 kg ha^{-1} from volatilization and 10-80 kg ha^{-1} from gaseous plant N loss each year (Raun et.al., 1997).

Urea ($CO(NH_2)_2$) is a solid N fertilizer containing 46% nitrogen, that is widely used in both solid and liquid fertilizers worldwide. All N fertilizers are produced initially using anhydrous ammonia as a source, which is produced by combining atmospheric N with CO_2 at 1200 °C at 500 atm with the Haber-Bosch process. Urea is produced by combining anhydrous ammonia (NH_3) with carbon dioxide (CO_2). In addition to its reasonably low price compared to other N sources, urea's easy storage and handling characteristics make it the most desirable solid nitrogen fertilizer worldwide.

Upon entering the soil, urea cannot be utilized by the plants. First it must be converted into NH_4^+ where it can then be utilized by the plant or further converted into nitrate (NO_3^-). The conversion of urea to ammonium occurs in a two step process. When urea combines with water (hydrolyzes), it then reacts with the enzyme urease forming ammonium carbonate $(NH_4)_2CO_3$. Ammonium carbonate is unstable and decomposes rapidly to form ammonia gas (NH_3) and carbon dioxide (CO_2). The ammonia gas produced is chemically identical to commercial anhydrous ammonia. If the ammonia gas comes in contact with water, it reacts to form NH_4^+. If NH_4^+ comes in contact with the soil, it binds to the clay and organic matter particles in the soil where it is held on the cation exchange complex. When surface applying urea if there is just enough moisture present to hydrolyze the urea but not enough to convert it to ammonium and carry it to the soil, then ammonia gas can escape into the atmosphere through volatilization. Volatilization is favored by high soil pH, warm temperatures, wet soils under drying conditions, and crop residues that insulate the urea from the soil. (Johnson et al., 2006, Dorn. 2000).

Ammonium nitrate (NH_4NO_3) is a N fertilizer containing 34% N by weight, it is commonly found in a granular form. It contains both the NH_4^+ and NO_3^- forms of N and is created by combining NH_3 with nitric acid (HNO_3). In addition to being applied directly ammonium nitrate is also used as a source of nitrogen in many dry and liquid fertilizer blends (Eckert 2001). Ammonium nitrate dissolves in water breaking down into NH_4^+ and NO_3^- fractions, both forms are plant available N forms and are readily taken up by the roots. (Dorn. 2000) The NO_3^- remains in solution while NH_4^+ becomes bound by negatively charged soil particles. The relatively low price of ammonium nitrate and versatility when combining it with other fertilizer sources makes it a desirable product.

However in recent year's ammonium nitrate fertilizer use has declined due to the increased difficulty in obtaining it. Ammonium nitrate is less subject to volatilization losses than urea when surface applied without incorporation. This makes it a much more desirable fertilizer for use in hot dry climates where significant amounts of volatilization would occur if urea was to be utilized. However ammonium nitrate is highly susceptible to leaching losses in sandy soils. (Dinnes. 2002)

Urea ammonium nitrate (UAN) is a liquid N fertilizer created by combining urea with ammonium nitrate and water in a mixing chamber. The result is a clear liquid solution typically ranging from 28% to 32% N. Of the total N in both UAN-28 and UAN-32, 25% of the N is NO_3^-, 25% NH_4^+, and 50% as $(CO(NH_2)_2)$ (Dorn, 2000). Fertilizing with UAN allows greater precision of application than solid N fertilizers but costs more than either urea or ammonium nitrate.

Being made up of both urea and ammonium nitrate, UAN goes through the same processes before entering the plant. When applying UAN midseason timing of application is of major importance. Being a nitrogen solution UAN will salt out, meaning the dissolved salts precipitate out when the temperature drops to a certain degree. As a general guideline 28% non pressure solution salts out at -17°C and 32% solution salts out at 0°C, there can be some variation between products from different manufacturers. (Raun et. al 2006). Foliar application of UAN should be avoided if temperatures exceed 21°C due to the phototoxic effect that it can have on plants at high temperatures resulting in burning of the leaf area. If temperatures are above 21°C then UAN application should be postponed unless a rainfall or irrigation event of 1.3 cm or greater occurs within 2 days, otherwise a significant portion of UAN will be lost to volatilization. Conditions for increased volatilization are high soil temp, moist soil or heavy dew, high pH, light textured soils, and crop residue (Montana State University, 2007).

Application methods

Very little research has been done in the area of comparing differences in production resulting from variation in application method of midseason liquid N fertilizer. This research seeks to explore the differences that may arise between using a method that targets soil infiltration and using a method that focuses on foliar coverage. Flat fan is the typical application method used for commercial fertilizer and pesticide application today and has the advantage of better coverage of leaf area compared to the streamer nozzle. The benefits of the streamer over flat fan are the increased stream concentration of the fertilizer allowing for better saturation of the residue at the application site and better N incorporation, especially in a no-till environment. Another benefit is the decrease in foliar burn in comparison to flat fan resulting from application of fertilizer when temperatures are high.

Environmental Factors

In general, the streamer nozzle would be expected to yield better results when used to apply N fertilizer in a notill environment with warmer soils. This is due to the more concentrated streams when using the streamer nozzle, compared to the flat fan nozzle. As a result this could allow for more saturation of the fertilizer at the area of impact, as a result more of the fertilizer would be able to reach the soil where it can be taken up by the plants rather than trapped on the residue as would be the case with the flat fan nozzle. The flat fan nozzle would most likely benefit from environments with a high amount of canopy closure, allowing for more efficient foliar plant uptake. This would be especially beneficial later in the growing season as early applications may have little biomass to interact with. High application rates of fertilizer early in the season can be a problem as a high percentage of leaf burn on a small amount of biomass can have a detrimental effect on grain yield.

CHAPTER III

METHODOLOGY

Experimental sites were established in the fall of 2006 at the EFAW Research farm in Stillwater and the Lake Carl Blackwell (LCB) Research Station near Stillwater. Trials at Lake Carl Blackwell were located on a Port silt loam with a 0 to 1 percent slope while trials located at the EFAW research farm were located on a Norge Loam with a 1 to 5 percent slope. Initial soil test results are reported in Table 1. The experiment employed a randomized complete block design (RCBD) with twelve treatments and three replications comparing flat fan and streamer nozzle application of liquid UAN to granular urea applied to the surface without incorporation. Plot size measured 3.05 meters by 6.10 meters with 4.57 meter alleys separating replications.

The LCB West experiment was planted with Fanin variety at a rate of 86 kg ha^{-1} on October 5, 2006, and the plots at EFAW were planted using the variety Jagger at a rate of 90 kg ha^{-1} on October 23, 2006. Both locations had a row spacing of 15 cm.

In fall of 2007 two additional experiment sites were established, one at the Perkins Research Station near Perkins OK, and an additional site (LCB East) at the LCB research station. Initial soil test results are reported in Table 2. The trials located at the Perkins research station were on a teller fine sandy loam with a 1 to 3 percent slope and on a combination Konawa and Teller soils with a 3 to 8 percent slope. While the LCB East trials were located on a port silt loam with a 0 to 1 percent slope.

In 2007 the EFAW experiment was planted to 2174 at a rate of 67 kg ha^{-1} on October 19, 2007. Both the original LCB experiment (LCB West) and LCB East were planted to Jagger at a rate of 78 kg ha^{-1} on October 29, 2007. The Perkins experiment was planted to Fannin at a rate of 68 kg ha^{-1} on October 20, 2007. All experiments had a row spacing of 15cm.

The topdress application of nitrogen utilized UAN applied at Feekes 5 (Zadoks 3) using a self propelled sprayer with a 12 volt pump and a 3.05 meter boom with 6 nozzles with a spacing of 76 cm between nozzles. Each nozzle type was checked and the sprayer was calibrated prior to application to ensure accuracy of the application rate. The flat fan applications utilized the Tee Jet 8003VS nozzles with return valves open at 275.8 kPa to apply topdress nitrogen in the form of UAN at rates of 45 and 90 kg ha^{-1}. For the streamer applications the sprayer utilized the SJ3-04 streamer nozzle. Granular urea was measured and applied by hand on the required plots (Table 3). This was used as a standard for common side dress application methods. At harvest samples were collected and analyzed for yield.

The flat fan nozzle applies fertilizer in a thin fan targeting maximum leaf coverage. These nozzles can deliver rates from 11 to 168 kg ha^{-1} of fertilizer by adjusting speed and pressures. The nozzles used for this experiment had an 80 ^{o} angle of coverage though 110 ^{o} angles are also available.

The streamer spray nozzle is made to use the same nozzle bodies and caps as flat fan tips and was designed to deliver liquid fertilizer. The difference between the streamer and the flat fan spray nozzles is that the streamer delivers the fertilizer in three streams, one straight down and one to either side at an angle. The angle and number of streams used can vary depending on the type of streamer nozzle used; however for the purposes of this experiment the SJ3-04 streamer nozzle was used. It can deliver fertilizer rates from 11 to 168 kg ha^{-1} by adjusting speed and pressures rates.

Plots were harvested using a self-propelled Massey Ferguson 8XP combine. A Harvest Master yield-monitoring computer installed on the combine was used to record yield and grain moisture data, removing an area of 2 x 6 m from the center of each plot. Grain yield from each plot was determined. Statistical evaluation and analysis of variance were performed using SAS (SAS Inst., 2007). Data was analyzed by running proc glm on the treatment means and a contrast on the full factorial analysis.

CHAPTER IV

RESULTS AND DISCUSSION

For this study, we encountered adverse conditions in 2006-2007, characterized primarily by excess rainfall, from late April through early August, that seriously restricted both management and final collection of winter wheat grain yield. As a result, data for the summer 2007 harvest were highly suspect since individual plot yields seldom exceeded 700 kg ha^{-1}. Alternatively, the 2007-2008 winter wheat cropping cycle had near normal average yields approaching 1990 kg ha^{-1} over all four locations. Analysis of variance by year and site is reported in Table 4 and that included all 12 treatments. Significant differences due to treatment were not observed at either site in 2007, and with few exceptions few differences were observed for most sites in 2008 (Table 4). In order to evaluate the 8 treatments that comprised a complete factorial (2 methods of placement, flat fan and streamer, 2 preplant N rates, and 2 topdress N rates), treatments 1, 10, 11, and 12 were deleted. As a result, main effects and main effects interactions were evaluated using the full factorial arrangement of treatments in an analysis of variance model and are reported accordingly in Table 5. At Efaw in 2008, the streamer method of application was superior to the flat fan method of application, however, no differences were observed due to either preplant or topdress N rate, indicating that the streamer method likely resulted in less burn. At LCB-W, a significant increase in yield was observed when topdress N rates were increased from 45 to 90 kg N ha^{-1}. This was important to note since no differences were observed between the preplant N rates (main effect not significant), further suggesting that topdress N methods could be used to catch up, even when early season N stress was likely encountered. AT LCB-E a significant Preplant N * Topdress N interaction was detected, thus restricting interpretation of main effect means. In essence the interaction resulted in increased yields when no N was applied preplant but where 90 kg N ha^{-1} was applied topdress. Alternatively, when 45 kg N ha^{-1} was applied preplant, the topdress N rate of 90 kg N ha^{-1} resulted in decreased yields, almost 700 kg ha^{-1} less. This finding is consistent with knowledge that yield recovery can take place, even when no N is applied preplant (Table 5). At Perkins in 2008, no main effects of main effect interactions were observed, likely due to the extremely low yields found at this site that restricted proper interpretation of treatment effects.

As was anticipated due to the excessive mid-season rainfall in 2007, experimental CV's were high at both sites in 2007, and that restricted treatment evaluation. Alternatively, CV's were lower in 2008, and environmental conditions led to near normal yield levels. This was not noted at Perkins in 2008 where the experimental CV was high, likely due to treatment placement on known different in soil types. This could have been avoided, but was recognized too late.

2007

Limited treatment differences were detected for the 2006-2007 cropping cycle due to the excessive moisture present from February through May, 2007 (total of

519.7 mm of rainfall). Despite the limited ability in detecting treatment differences (Table 4), it was considered important to present and discuss the data in order to properly evaluate any trends.

At EFAW in 2007 the highest yielding plots were the 0-90 kg N ha^{-1} (preplant – topdress) application rate combination with a UAN streamer nozzle (664 kg ha^{-1}). The 45-45 kg N ha^{-1} application rate with granular urea applied to the surface without incorporation resulted in a yield of 655 kg ha^{-1}, and the 45-90 kg N ha^{-1} application rate with a UAN flat fan nozzle had a yield of 653 kg ha^{-1} (Figure 1). The check plot had higher yields than most treatments other than the three previously mentioned rate combinations and application methods. Application methods illustrated a limited response to applied N at this site and year. The variable yields from this site were also more a result of excess moisture, in addition to a late freeze that occurred on April 5th 2007, when the wheat was in the boot stage, than application method and/or N rates. Foliar application rates of liquid UAN, applied at Feekes 5 (Zadoks 3), resulted in no significant leaf burn from either the flat fan or the streamer nozzles at this site and year. On the day of fertilizer application the maximum daily temperature for this site was 25°C (77°F) with a minimum temperature of 12°C (54°F). The lowest yield, 462 kg ha^{-1}, was found at the 45-45 kg N ha^{-1} application rate with a UAN flat fan nozzle. Average wheat grain yields for this site in 2007 were 566 kg ha^{-1}.

At LCB West in 2007, the check plot, yielded 43 kg ha^{-1}(Figure 2), and had a higher yield than all other application methods and treatment N rate combinations. However, this is a misleading statistic since yield levels were so low, thus restricting what can be interpreted from the data. The varied yields that came out of this site showed that yield had less to do with application method or N rates and more to do with excessive moisture and cold temperatures. At the time of application, Feekes 5 (Zadoks 3), neither of the two foliar application methods, streamer and flat fan, for liquid UAN application resulted in noticeable leaf burn at this site and year. On the day of fertilizer application the maximum daily temperature for this site was 25°C (77°F) with a minimum temperature of 12°C (54°F). The maximum yield observed was from the check at 43 kg ha^{-1}, with the lowest yield, 20 kg ha^{-1}, occurring with the 0-90 kg ha^{-1} application rate and a UAN streamer nozzle. Average wheat grain yields for this site in 2007 were 28 kg ha^{-1}.

2008

At EFAW in 2008 wheat grain yield increased with N rate, with a greater response being observed between plots receiving different N rates rather than different N rate combinations (0 – 45 vs. 45 – 45 and 0 – 90 vs. 45 – 90)(Figure 3). At the highest fertilizer application rate using a UAN flat fan nozzle, this resulted in an increase in yield of 250 kg ha^{-1} over the UAN streamer nozzle at the 45-90 kg N ha^{-1} rate (Figure 3Topdress application of liquid UAN was carried out at Feekes 5 (Zadoks 3) growth stage. Of the two foliar application methods for applying liquid UAN observed in this study, the treatments utilizing the UAN flat fan nozzle suffered from mild leaf burn at the higher N rate combinations (45-45 and 45-90 kg N ha^{-1}) with no significant damage at the lower rate combinations. However the treatments that utilized the UAN streamer nozzle seldom showed significant leaf burn at any N rate combination. On the day of topdress fertilizer application, the maximum daily temperature for this site was 14°C (58°F) with a minimum temperature of -6°C (22°F). The maximum yield observed was 1626 kg ha^{-1}, at the 45-90 kg N ha^{-1} application rate with a UAN flat fan nozzle, with the lowest yield, 981 kg ha $^{-1}$, occurring at the 0-45 kg N ha^{-1} application rate with a UAN streamer nozzle. Average yield for this site in 2008 was 1247 kg ha^{-1}.

At LCB West in 2008, the UAN flat fan application method at the 0-90 kg N ha^{-1} rate yielded higher than all other application methods and rates (Figure 4). With the exception of the previously mentioned rate, the UAN streamer nozzle had higher yields than all other application methods at all other N rate combinations. In general this resulted in a better overall response to the UAN streamer nozzle application method over the UAN flat fan nozzle and granular urea applied to the surface without incorporation. Of the two foliar application methods for applying liquid UAN, the treatments utilizing the UAN flat fan nozzle visually suffered more from mild leaf burn at the higher N rate and combinations (45-45 and 45-90 kg N ha^{-1}) than the other methods of application. However the treatments that utilized the UAN streamer nozzle seldom showed noticeable leaf burn. Topdress foliar fertilizer application was applied at Feekes 5 (Zadoks 3) growth stage. On the day of fertilizer application the maximum daily temperature for this site was 19°C (66°F) with a minimum temperature of 0°C (32°F). The maximum yield observed was 3047 kg ha^{-1}, at the 0-90 kg N ha^{-1} application rate with a UAN flat fan nozzle, with the lowest yield, 1675 kg ha $^{-1}$, occurring in the check plot(0-N). Average yield for this site in 2008 was 2733 kg ha^{-1}.

Yield was highly variable at LCB East in 2008 with the UAN streamer nozzle method of application producing higher yields at the 0-45 and 45-45 kg N ha^{-1} rate combinations compared to other methods and rates. However, at the high N rate combination (45-90 kg N ha^{-1}) the UAN flat fan nozzle method of application resulted in higher yields over the UAN streamer nozzle (Figure 5). Foliar application rates of liquid UAN, applied at Feekes 5 (Zadoks 3), resulted in no significant leaf burn from either the UAN flat fan or the UAN streamer nozzles at this site and year. On the day of fertilizer application the maximum daily temperature for this site was 19°C (66°F) with a minimum temperature of 0°C (32°F). Yields were similar for the two application methods at the 0-90 kg N ha^{-1} rate combination, likely because temperatures were below the 21°C (70°F) threshold where burn from foliar applications of liquid N are expected. The maximum yield observed was 2384 kg ha^{-1}, at the 0-90 kg N ha^{-1} application rate combination with a UAN flat fan nozzle, with the lowest yield, 1911 kg ha^{-1}, occurring in the check plot (0-N). Average yield for this site in 2008 was 2209 kg ha^{-1}.

At Perkins in 2008 the low topdress N rates (0-45 and 0-90 kg N ha^{-1}), utilizing the UAN flat fan nozzle yielded higher than the other application methods (Figure 6). At the higher levels of N application (45-45 and 45-90 kg N ha^{-1} split application) the treatments utilizing the UAN streamer nozzle for the topdress method had higher yields than UAN applied with the flat fan nozzle or granular urea. Reduced yields were observed at the 0-90 kg N ha^{-1} N rate combination possibly due to the trial being placed on top of two different soil series (Konowa and Teller soils, with a 3 to 8 percent slope and a Teller fine sandy loam with a 1 to 3 percent slope). The random placement of treatments resulted in most of the 0-90 kg N ha^{-1} rate combinations being located in a poorer, dryer soil (the Konowa soil) which resulted in reduced yields. Topdress application of liquid UAN was carried out at Feekes 5 (Zadoks 3) growth stage. Of the two foliar application methods for applying liquid UAN observed in this study, the treatments utilizing the UAN flat fan nozzle suffered from mild leaf burn at the higher N rate combinations (45-45 and 45-90 kg N ha^{-1}) with no significant damage at the lower rate combinations. However the treatments that utilized the UAN streamer nozzle seldom showed significant leaf burn at any N rate combination. On the day of fertilizer application the maximum daily temperature at this site was 16°C (60°F) with a minimum temperature of -4°C (25°F). No significant difference in leaf burn was observed between plots that had received preplant N fertilization and those that only had topdress N applied. The maximum yield observed was 1801 kg ha^{-1}, at the 45-90 kg N ha^{-1} N rate combination with a UAN streamer nozzle, with the lowest yield, 721 kg ha $^{-1}$, occurring at the 0-90 kg N ha^{-1} rate combination with urea applied to the surface without incorporation in the granular form. Average yield for this site in 2008 was 1279 kg ha^{-1}.

The relationship between grain yield and application method over all N rate combinations for all locations for 2008 is reported in Figure 7. The 2007 year was excluded (both sites) since yield levels were so low (< 700 kg ha^{-1}) in all plots. Combining data over sites and years can be highly misleading, due to heterogeneity of error variance, none-the-less this was done to discover possible trends. The data reported here covered a wide range of environments and growing conditions. With the exception of the 0-45 kg N ha^{-1} rate combination, where the observed difference in yield was slight, there was an observed benefit to using the UAN streamer nozzle over the other two application methods as the ideal method of N application at all N rate combinations. Although this data is not conclusive, for the environmental conditions encountered in this study, a benefit was observed from utilizing the UAN streamer nozzle for topdress application of liquid UAN in winter wheat when compared to the flat fan method of application.

CHAPTER V

CONCLUSIONS

Varying rate and application methods of N fertilization were employed in this experiment to observe the effects of differences in N application rate, time, and method on wheat grain yield. Farmers use a wide range of methods to apply N fertilizer and this study compared three common application methods to determine if a benefit could be observed.

Inclement weather in 2007 resulted in highly variable, and extremely low (< 700 kg ha^{-1} in all plots), yields with a great amount of variation occurring between N rate treatments. The adverse weather conditions resulted in the check plot producing higher yields than many treatments receiving N. Each of the three higher N rate combinations (0-90, 45-45, and 45-90 kg N ha^{-1}) had maximum yields achieved from a different application method. This variation shows that for the 2006 – 2007 growing season in this area, weather had a greater impact on grain yield than either N rate or application method.

Average grain yield from 2008 resulted in yield increases when topdress application was carried out utilizing the UAN streamer nozzle. All of the higher N rate combinations (0-90, 45-45, and 45-90 kg N ha^{-1}) showed an increase in grain yield when the UAN streamer nozzle method of application was utilized compared to applications utilizing the UAN flat fan nozzle. Grain yields for the 0-45 kg N ha^{-1} rate combination were similar for all application methods with the UAN flat fan producing yields only 11 kg ha^{-1} higher than the treatments utilizing the UAN streamer nozzle. Average grain yield for all N rate combinations was greater than the check plot yield in 2008, thus providing an opportunity to properly evaluate treatment effects that was virtually impossible in 2007. The highest grain yield was 2118 kg ha^{-1} at the 45-90 kg N ha^{-1} rate combination utilizing the UAN streamer nozzle for the topdress application. Treatments utilizing the UAN flat fan nozzle occasionally resulted in mild leaf burn, however, no noticeable leaf burn was observed in any treatment utilizing the UAN streamer nozzles. The observed benefits of applying liquid UAN as a topdress fertilizer with the UAN streamer nozzle became more evident at higher N rates possibly due to better saturation at the point of impact allowing the fertilizer to soak through the residue better and reduced leaf burn. Little benefit was observed between the streamer and flat fan methods of topdress N application at the higher N rate combinations and where preplant N was applied. For future consideration in addition to further replication of the study, I would recommend adding a 45-90 kg N ha^{-1} rate combination with the granular urea applied to the surface without incorporation as it will allow for better analysis of the results. This study would benefit from additional sensor readings and a quantitative measurement of leaf burn. I feel that additional years of data will be of benefit to this trial as it will allow for better analysis of the observed trends and may lead to the discovery of other trends that were not apparent from only one year of data in typical growing conditions.

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Table 1. Initial surface (0-15cm) soil test results EFAW and Lake Carl Blackwell West, OK 2006

Location	pH	NO_3-N	P	K
		kg ha^{-1}	mg kg^{-1}	
Lake Carl Blackwell West	5.4	50	29	249
Classification: Port silt loam, 0 to 1 percent slope				
EFAW	5	40	89	412
Classification: Norge loam, 1 to 3 and 3 to 5 percent slope				

pH – 1:1 soil: water; K and P – Mehlich III;

Table 2. Initial surface (0-15cm) soil test results Perkins and Lake Carl Blackwell East, OK 2007

Location	pH	NO_3-N	P	K
		kg ha^{-1}	mg kg^{-1}	
Lake Carl Blackwell East	5.5	44	37	279
Classification: Port silt loam, 0 to 1 percent slope				
Perkins	6.8	19	20	270
Classification: Teller fine sandy loam, 1 to 3 percent slope and Konawa and Teller soils, 3 to 8 percent slope, eroded				

pH – 1:1 soil: water; K and P – Mehlich III;

Table 3. Treatment structure employed for topdress nitrogen study at EFAW, Lake Carl Blackwell, and Perkins, 2007 and 2008.

Treatment	Application type	* Pre-plant, kg N ha^{-1}	Topdress, kg N ha^{-1}	Total N rate, kg ha^{-1}
1	Check	0	0	0
2	UAN Flat Fan	0	45	45
3	UAN Flat Fan	0	90	90
4	UAN Stream	0	45	45
5	UAN Stream	0	90	90
6	UAN Flat Fan	45*	45	90
7	UAN Flat Fan	45*	90	135
8	UAN Stream	45*	45	90
9	UAN Stream	45*	90	135
10	Urea	0	45	45
11	Urea	0	90	90
12	Urea	45*	45	90

UAN - Urea ammonium nitrate, 28-0-0 N-P-K
Flat Fan - Flat fan nozzles for foliar UAN delivery
Stream – Stream (3 separate holes) nozzles for foliar UAN delivery
* - Preplant N surface applied directly after planting.

Table 4. Analysis of variance and for grain yield, topdress nitrogen trial at 5 locations, 2007 – 2008.

		2007		2008			
Source of variation	df	EFAW	LCB W	EFAW	LCB W	LCB E	Perkins
		---------------------------------Mean squares-------------------------------					
Rep	2	7187**	561	74307	9363	98980**	139159
Trt	11	14019	179	117901	398259***	70051**	339481
Overall mean		566	28	1247	2733	2209	1279
Residual error	22	22057	235	85700	36529	16587	469771
SED		121	13	239	156	105	560
CV, %		26	55	23	7	6	54

@, *, **, *** - - Significant at the 0.1, 0.01, 0.05, and 0.001 probability levels, respectively.
SED – Standard error of the difference between two equally replicated means
LCB - Lake Carl Blackwell

Table 5. Analysis of variance and significance levels of full factorial effects of method of placement, preplant N, and topdress N at 4 locations, 2008.

Source of Variation	df	Efaw	LCB-W	LCB-E	Perk
Rep	2	ns	ns	*	ns
Method	1	*	ns	ns	ns
Preplant N	1	ns	ns	ns	ns
Topdress N	1	ns	**	**	ns
Method*Preplant N	1	ns	ns	ns	ns
Method*Topdress N	1	ns	ns	ns	ns
Preplant N * Topdress N	1	ns	ns	*	ns
Method * Preplant N * Topdress N	1	ns	ns	ns	ns
Residual	14	111470	27950	15793	605173

**, *, @ - significant at the 0.01, 0.05, and 0.10 probability levels, respectively.

Source of Variation	Efaw	LCB-W	LCB-E	Perk
	Main Effect Yield Means			
Method				
Flat Fan	1136	2813	2293	1266
Streamer	1452	2895	2237	1480
Preplant N				
00	1311	2826	2229	1308
45	1277	2882	2300	1438
Topdress N				
45	1213	2736	2175	1421
90	1376	2972	2355	1325
Preplant N*Topdress N				
00 - 45	1249	2656	2079	1360
00 - 90	1373	2997	3080	1256
45 - 45	1176	2817	2272	1483
45 - 90	1378	2947	2329	1393

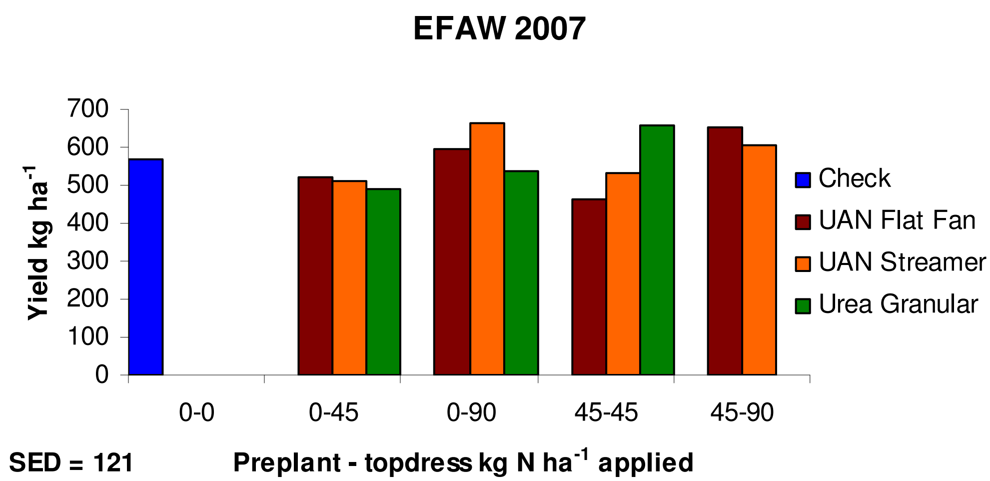


Figure 1. Grain yield for four N rate treatments where each N rate was applied in the form of liquid UAN utilizing either the flat fan or streamer nozzles, or granular urea applied to the surface without incorporation, EFAW 2007.
SED - Standard error of the difference between two equally replicated means

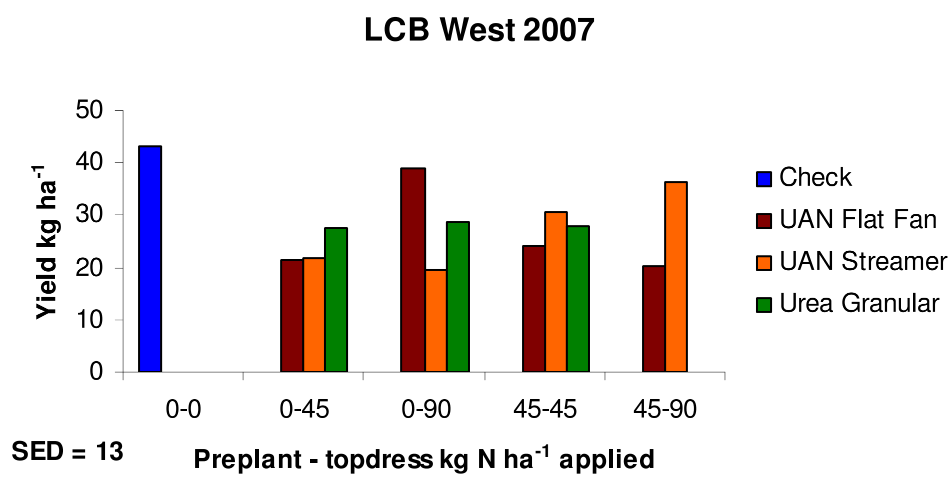


Figure 2. Grain yield for four N rate treatments where each N rate was applied in the form of liquid UAN utilizing either the flat fan or streamer nozzles, or granular urea applied to the surface without incorporation, Lake Carl Blackwell West 2007.
SED - Standard error of the difference between two equally replicated means

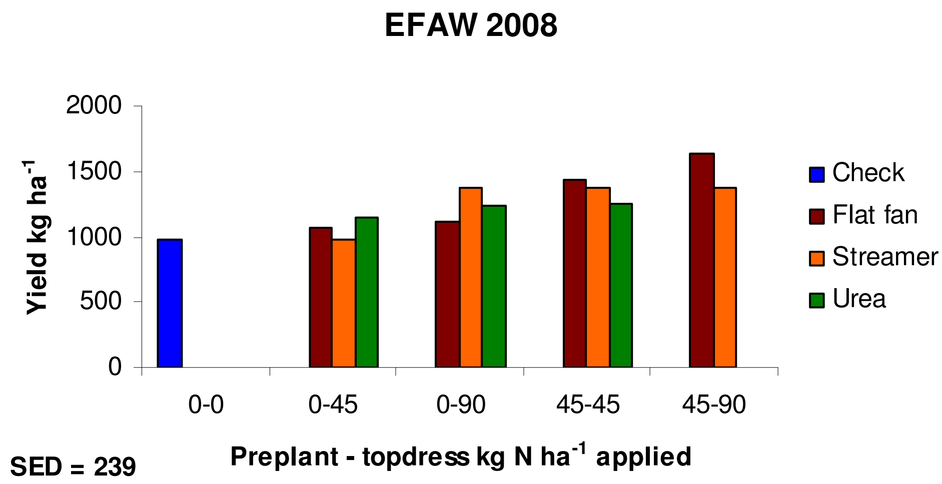


Figure 3. Grain yield for four N rate treatments where each N rate was applied in the form of liquid UAN utilizing either the flat fan or streamer nozzles, or granular urea applied to the surface without incorporation, EFAW 2008.
SED - Standard error of the difference between two equally replicated means

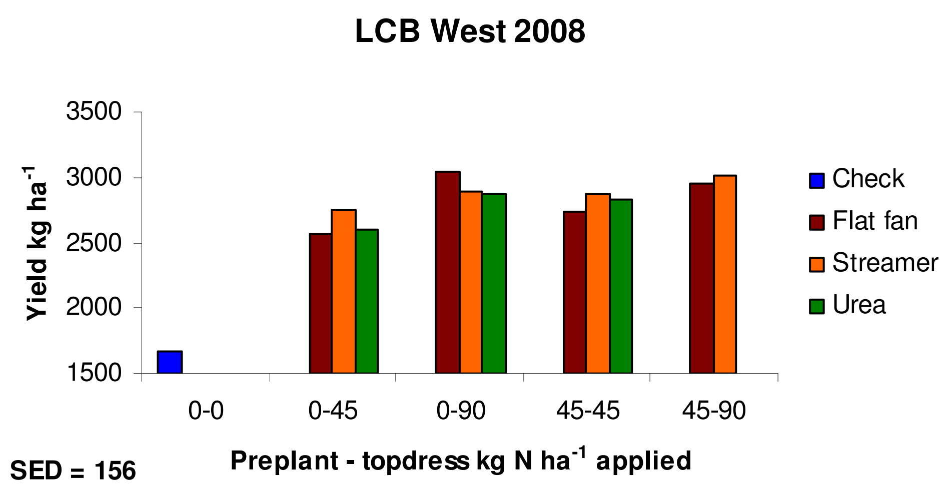


Figure 4. Grain yield for four N rate treatments where each N rate was applied in the form of liquid UAN utilizing either the flat fan or streamer nozzles, or granular urea applied to the surface without incorporation, Lake Carl Blackwell West 2008.
SED - Standard error of the difference between two equally replicated means

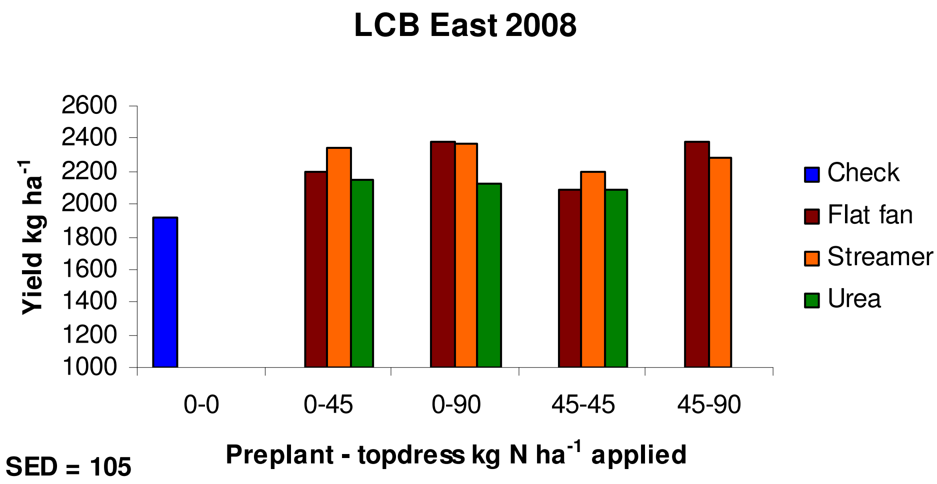


Figure 5. Grain yield for four N rate treatments where each N rate was applied in the form of liquid UAN utilizing either the flat fan or streamer nozzles, or granular urea applied to the surface without incorporation, Lake Carl Blackwell East 2008.
SED - Standard error of the difference between two equally replicated means

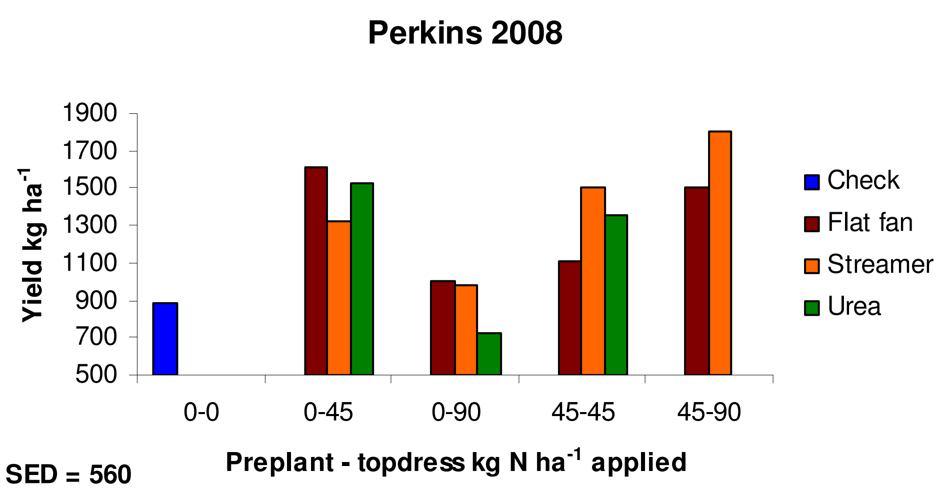


Figure 6. Grain yield for four N rate treatments where each N rate was applied in the form of liquid UAN utilizing either the flat fan or streamer nozzles, or granular urea applied to the surface without incorporation, Perkins 2008.
SED - Standard error of the difference between two equally replicated means

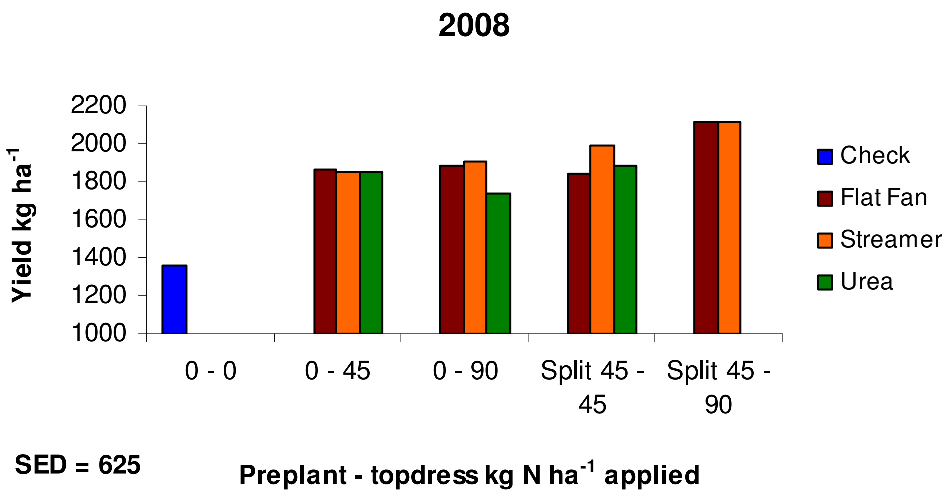
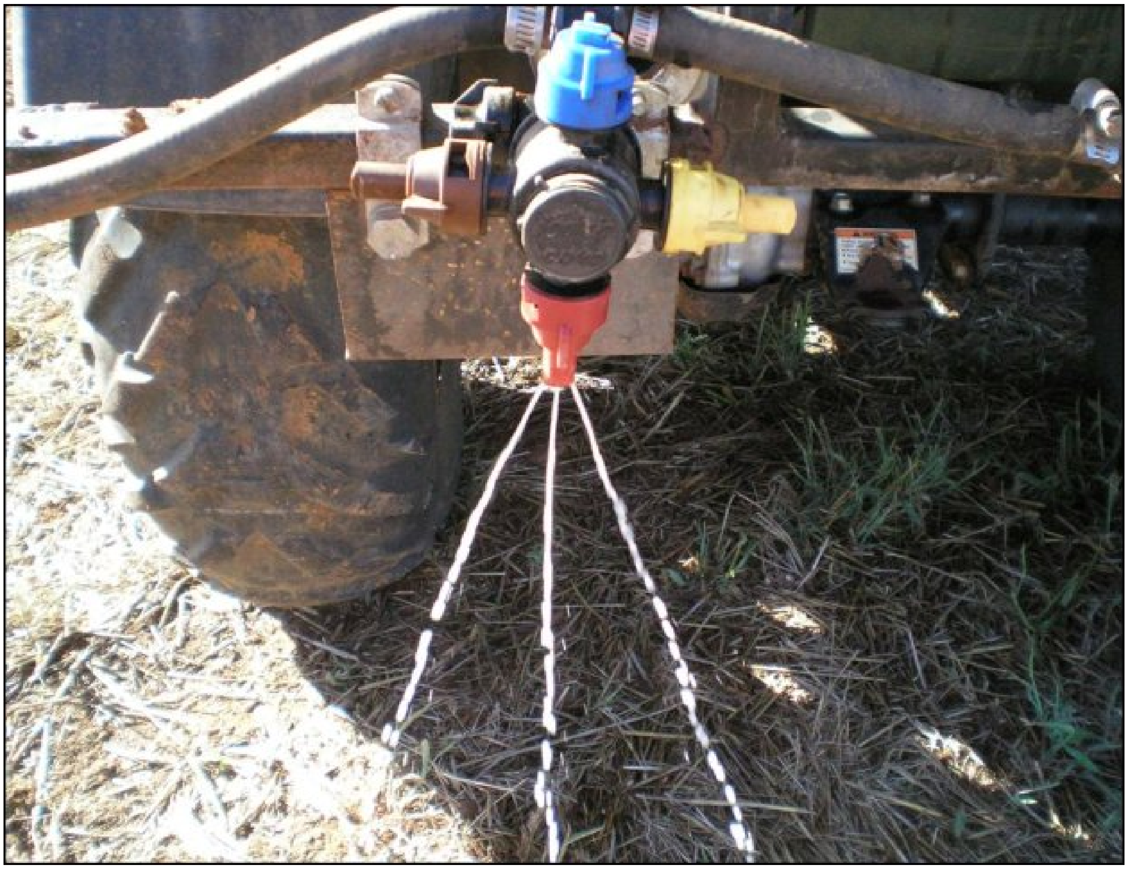


Figure 7. Grain yield for four N rate treatments where each N rate was applied in the form of liquid UAN utilizing either the flat fan or streamer nozzles, or granular urea applied to the surface without incorporation, averaged over all locations in 2008. SED - Standard error of the difference between two equally replicated means

APPENDIX

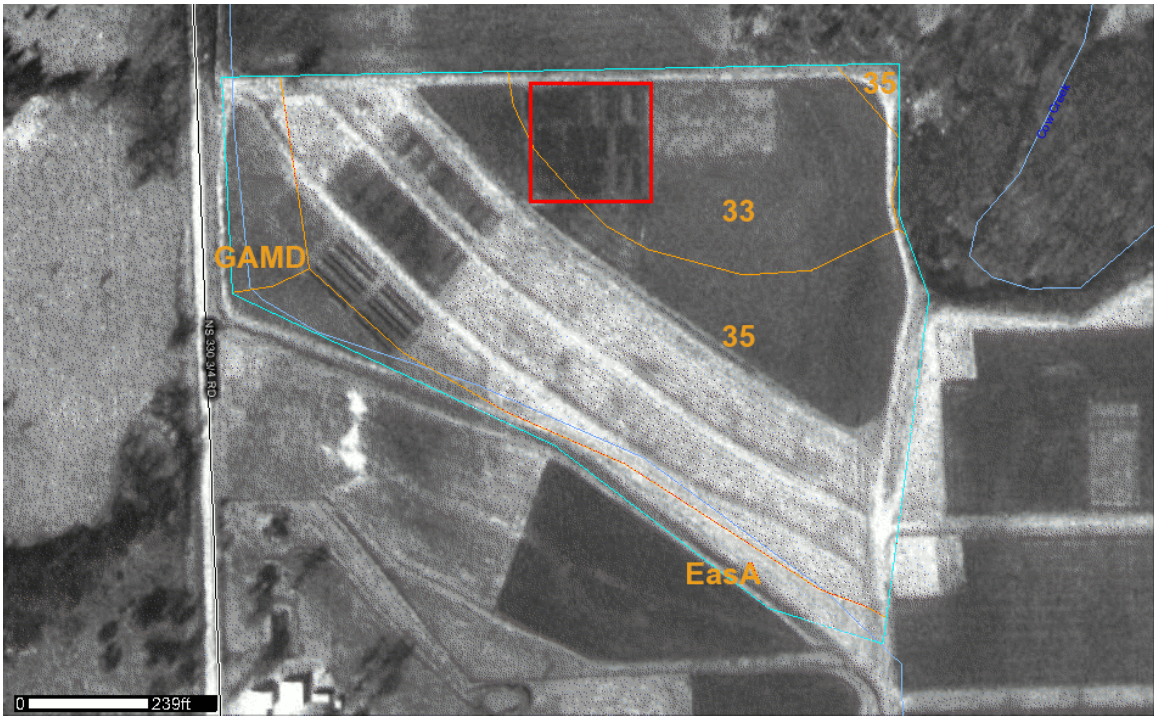
Appendix Figure 8. Flat fan nozzle for the topdress application of liquid UAN.



Appendix Figure 9. Streamer nozzle for the topdress application of liquid UAN.

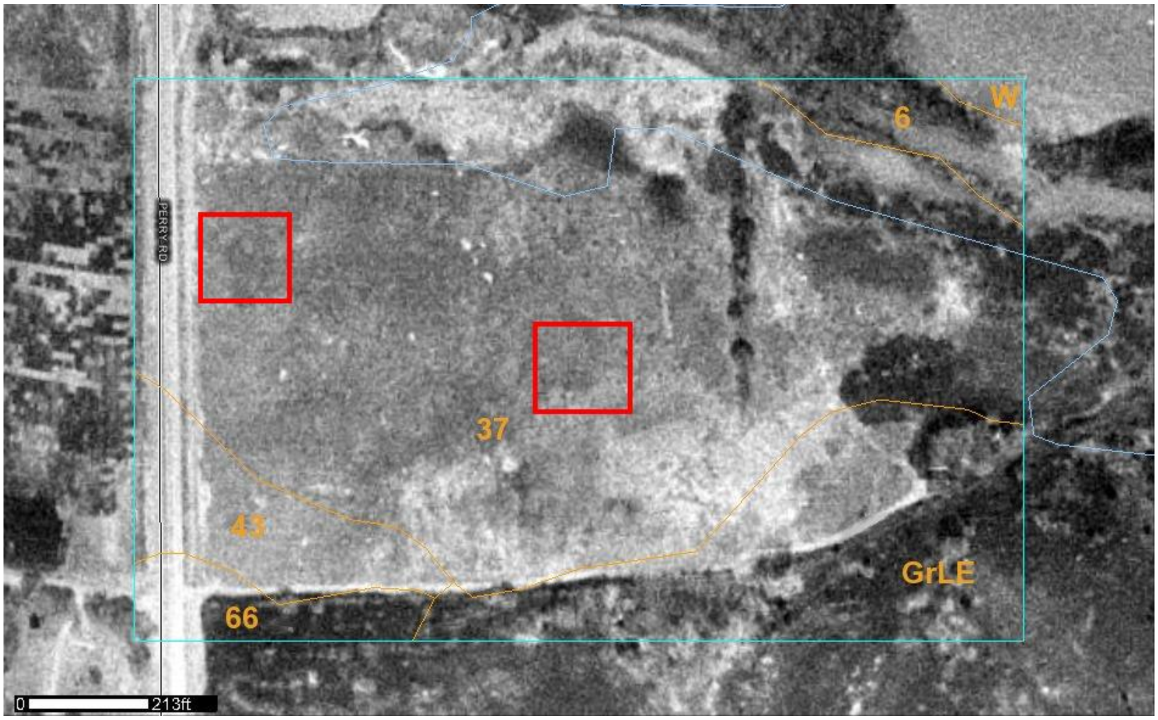
Map Unit Symbol	Map Unit Name
24	Konawa fine sandy loam, 1 to 3 percent slopes
56	Teller fine sandy loam, 1 to 3 percent slopes
59	Konawa and Teller soils, 3 to 8 percent slope, eroded

Appendix Figure 10. Soil series map and index for the Perkins research field. The area outlined in red represents the area occupied by the topdress nitrogen trial.



Map Unit Symbol	Map Unit Name
33	Norge loam, 1 to 3 percent slope
35	Norge loam, 3 to 5 percent slope, eroded
EasA	Easpur loam, 0 to 1 percent slope, occasionally flooded
GAMD	Grainola-Ashport-Mulhall complex, 0 to 8 percent slope

Appendix Figure 11. Soil series map and index for the EFAW research field. The area outlined in red represents the area occupied by the topdress nitrogen trial.



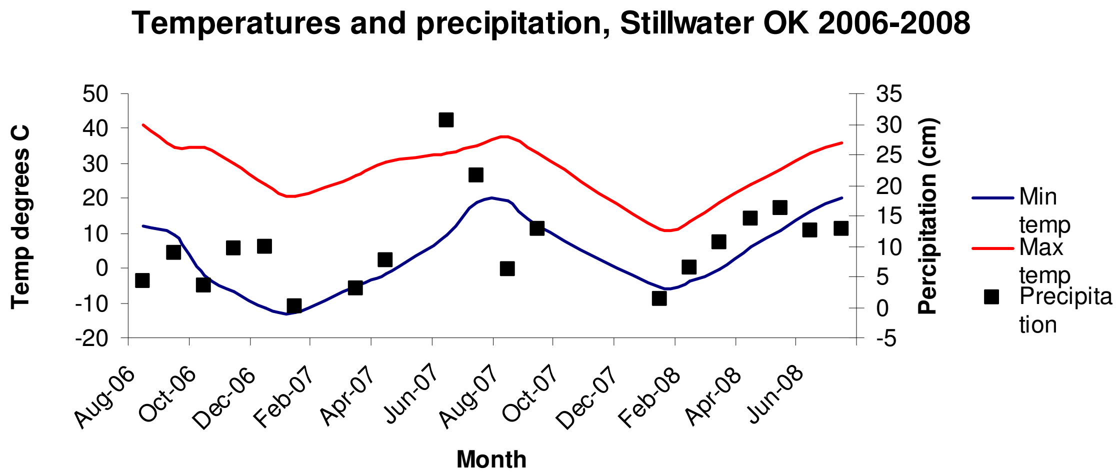
Map Unit Symbol	Map Unit Name
6	Pulaski fine sandy loam, 0 to 1 percent slope, frequently flooded
37	Port silt loam, 0 to 1 percent slope, occasionally flooded
43	Pulaski fine sandy loam, 0 to 1 percent slope, occasionally flooded
66	Masham silty clay loam, 5 to 20 percent slope
GrLE	Grainola-Lucien complex, 5 to 12 percent slope, rocky
W	Water

Appendix Figure 12. Soil series map and index for the Lake Carl Blackwell research field. The area outlined in red represents the area occupied by the topdress nitrogen trials.

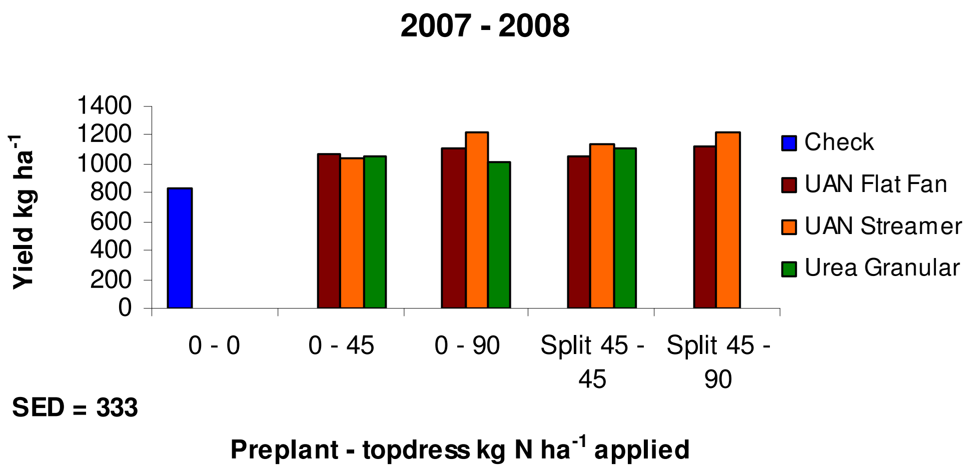
Appendix Figure 13. Winter wheat grain yields in kg ha^{-1}, by replication and treatment, Perkins 2008.

Application Method	N rate combination	Rep-trt.	Yield (kg ha^{-1})	Rep-trt.	Yield (kg ha^{-1})	Rep-trt.	Yield (kg ha^{-1})
Check	0-0	**101**	486	**201**	1155	**301**	1011
UAN Flat Fan	0-45	**102**	782	**202**	1820	**302**	2235
UAN Flat Fan	0-90	**103**	696	**203**	1214	**303**	1108
UAN Stream	0-45	**104**	2083	**204**	602	**304**	635
UAN Stream	0-90	**105**	1933	**205**	648	**305**	1939
UAN Flat Fan	45-45	**106**	1315	**206**	459	**306**	2601
UAN Flat Fan	45-90	**107**	805	**207**	489	**307**	1661
UAN Stream	45-45	**108**	1682	**208**	1856	**308**	983
UAN Stream	45-90	**109**	2156	**209**	2458	**309**	789
Urea	0-45	**110**	1920	**210**	769	**310**	1898
Urea	0-90	**111**	770	**211**	614	**311**	779
Urea	45-90	**112**	1100	**212**	1987	**312**	978

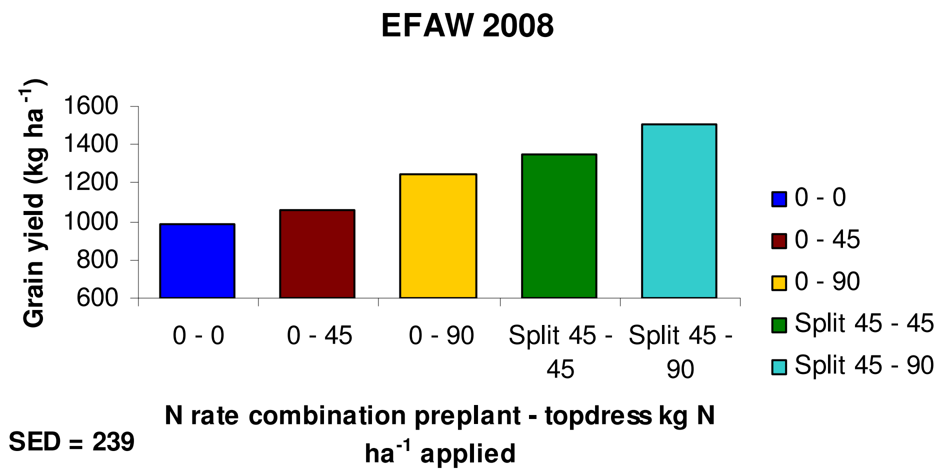
UAN - Urea ammonium nitrate, 28-0-0 N-P-K
Flat Fan - Flat fan nozzles for foliar UAN delivery
Stream – Stream (3 separate holes) nozzles for foliar UAN delivery
X-X, denotes preplant and topdress N rates, respectively (kg N ha^{-1})



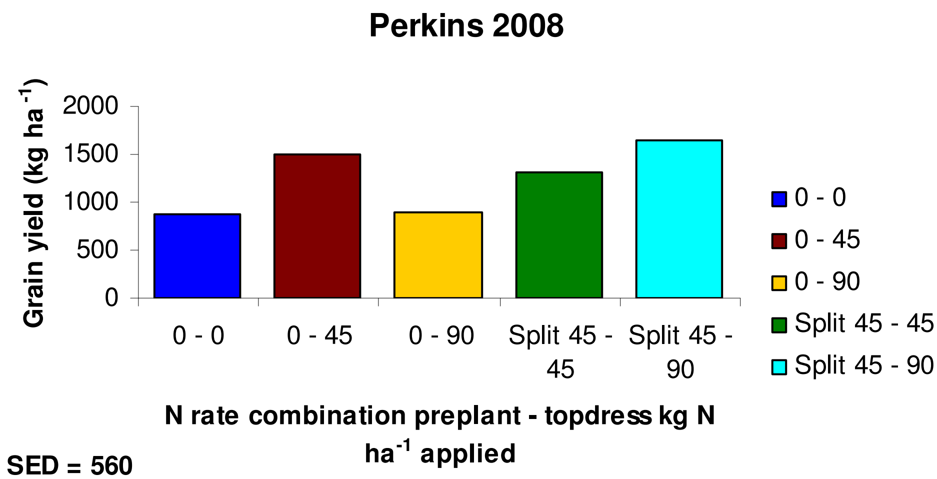
Appendix Figure 14. Average minimum and maximum temperature, in degrees Celsius, and precipitation amounts in cm for Stillwater OK. Temperatures and precipitation recorded from August 2006 to July 2008 by the Oklahoma Climatological Survey. (www.climate.ok.gov)



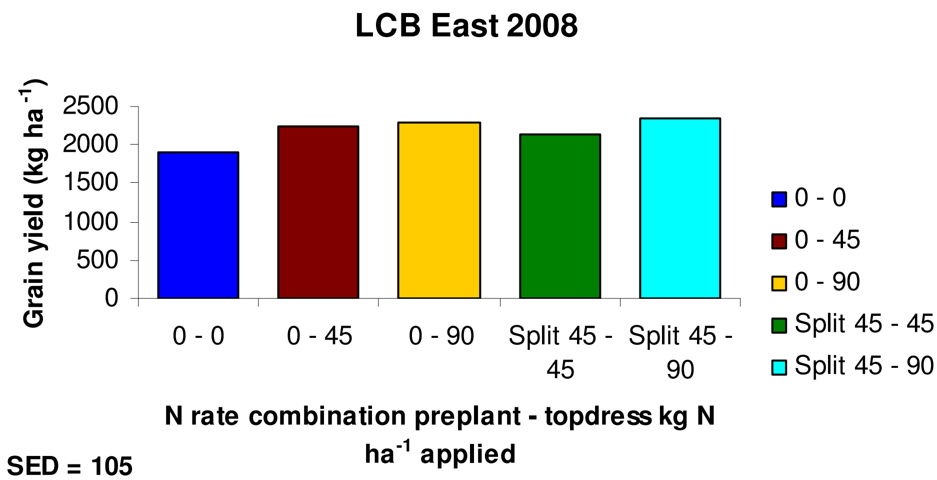
Appendix Figure 15. Grain yield for four N rate treatments where each N rate was applied in the form of liquid UAN utilizing either the flat fan or streamer nozzles, or granular urea applied to the surface without incorporation, 2007 and 2008.
SED - Standard error of the difference between two equally replicated means



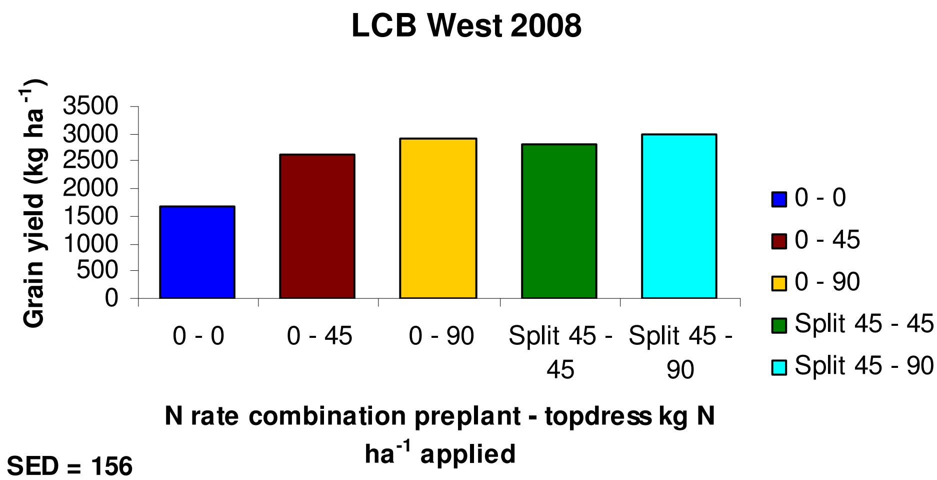
Appendix Figure 16. Grain yield for five N rate combinations where each N rate was applied in the form of liquid UAN utilizing either the flat fan or streamer nozzles, or granular urea applied to the surface without incorporation, EFAW 2008.
SED - Standard error of the difference between two equally replicated means



Appendix Figure 17. Grain yield for five N rate combinations where each N rate was applied in the form of liquid UAN utilizing either the flat fan or streamer nozzles, or granular urea applied to the surface without incorporation, Perkins 2008.
SED - Standard error of the difference between two equally replicated means

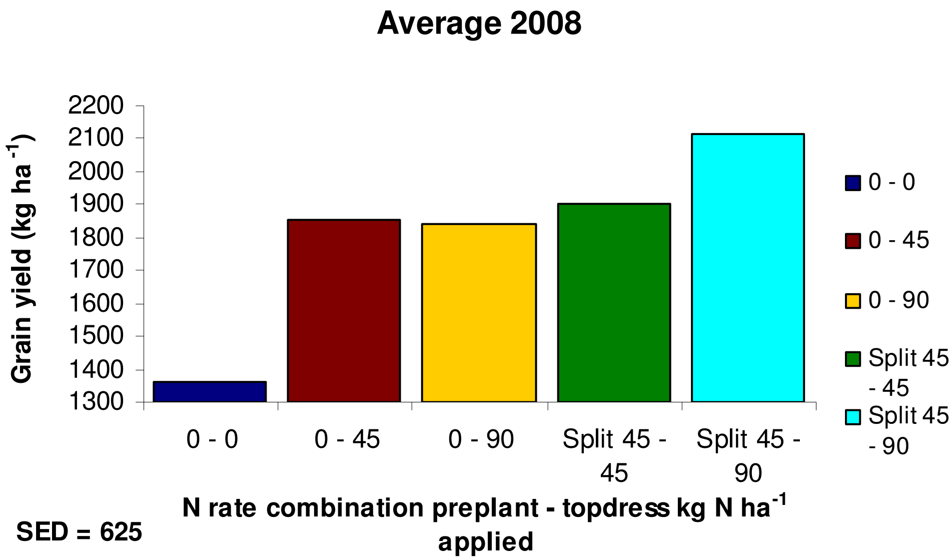


Appendix Figure 18. Grain yield for five N rate combinations where each N rate was applied in the form of liquid UAN utilizing either the flat fan or streamer nozzles, or granular urea applied to the surface without incorporation, Lake Carl Blackwell East 2008.
SED - Standard error of the difference between two equally replicated means



Appendix Figure 19. Grain yield for five N rate combinations where each N rate was applied in the form of liquid UAN utilizing either the flat fan or streamer nozzles, or granular urea applied to the surface without incorporation, Lake Carl Blackwell West 2008.

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



Appendix Figure 20. Grain yield for five N rate combinations where each N rate was applied in the form of liquid UAN utilizing either the flat fan or streamer nozzles, or granular urea applied to the surface without incorporation, combined totals for 2008. SED - Standard error of the difference between two equally replicated means

Appendix Figure 21. Effect of N rate on grain yield for EFAW, LCB, and Perkins OK 2007 and 2008. Grain yields are reported in kg ha^{-1}.

N Rate	EFAW 2007	LCB West 2007	EFAW 2008	LCB West 2008	LCB East 2008	Perkins 2008
0-0	567	43	980	1675	1911	884
0-45	506	23	1061	2639	2230	1489
0-90	599	2	1245	2933	2291	904
45-45	549	27	1350	2817	2124	1322
45-90	628	28	1501	2978	2331	1654
SED	121	12	239	156	105	560

SED - Standard error of the difference between two equally replicated means
LCB - Lake Carl Blackwell
X-X, denotes preplant and topdress N rates, respectively (kg N ha^{-1})

Appendix Figure 22. Dates of field activities, seeding rates, and varieties planted for the 2006–2008 crop years.

Date	Location	Event
09/27/06	EFAW	Applied initial fertilizer application for TDN trial
09/28/06	Lake Carl Blackwell	Applied initial fertilizer application for TDN trial
10/05/06	Lake Carl Blackwell	Planted TDN trial with variety Fanin @ 42 lb/ac seeding rate
10/09/06	EFAW	Planted TDN trial with variety Jagger @ 80 lb/ac seeding rate
03/02/07	EFAW	Applied the top-dress fertilizer applications
03/05/07	Lake Carl Blackwell	Applied the top-dress fertilizer applications
06/14/07	EFAW	Harvest
07/05/07	Lake Carl Blackwell	Hand harvest
10/09/07	EFAW	Applied initial fertilizer application for TDN trial
10/19/07	EFAW	Planted TDN trial with variety 2174 @ 65 lbs/ac seeding rate
10/20/07	Perkins	Planted TDN trial with variety fanin @ 61 lb/ac seeding rate. Applied initial fertilizer application for TDN trial
10/29/07	Lake Carl Blackwell	Planted TDN trial with variety jagger @ 75 lb/ac seeding rate
11/1/07	Lake Carl Blackwell	Applied initial fertilizer application for TDN trial
2/27/08	Perkins	Applied the top-dress fertilizer applications
2/27/08	EFAW	Applied the top-dress fertilizer applications
2/29/08	Lake Carl Blackwell	Applied the top-dress fertilizer applications
06/19/08	EFAW	Harvest
06/20/08	Perkins	Harvest
06/23/08	Lake Carl Blackwell	Harvest

VITA

Brandon Blaine England

Candidate for the Degree of

Master of Science or Arts

Thesis: STREAM AND FLAT FAN TOPDRESS APPLICATION OF UREA AMMONIUM NITRATE IN WINTER WHEAT (*Triticum aestivum* L.)

Major Field: Plant and Soil Sciences

Biographical:

Personal Data:

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Graduated from Panola High School, Panola, Oklahoma in May 2002. Received Associates degree from Eastern Oklahoma State College Wilburton, Oklahoma 2004. Received a Bachelors of Science degree in Rangeland Management from Oklahoma State University Stillwater Oklahoma 2006. Completed the requirements for Masters of Science degree with a major in Plant and Soil Science at Oklahoma State University in December, 2008.

Experience: Worked as a stocker and floor manager at a grocery store (2000-2004); employed by Eastern Oklahoma State College as a greenhouse technician, (2002-2004); employed by Oklahoma State University, Department of Plant and Soil Sciences, as an undergraduate research assistant (2004-2006). Employed by Oklahoma State University, Department of Plant and Soil Sciences, as a graduate research assistant 2006-present.

Professional Memberships: ASA CSSA SSSA

Name: Brandon England Date of Degree: December, 2008

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: STREAM AND FLAT FAN TOPDRESS APPLICATION OF UREA AMMONIUM NITRATE IN WINTER WHEAT (*Triticum aestivum* L.)

Pages in Study: 49 Candidate for the Degree of Master of Science

Major Field: Plant and Soil Science

Scope and Method of Study:
This study was conducted to compare two different methods of topdress application of liquid UAN (urea ammonium nitrate) for winter wheat, the streamer nozzle and the flat fan nozzle, and to evaluate the differences in grain yield that would arise from the two application methods. The experiment was conducted at the Robert L. Westerman Research Station at Lake Carl Blackwell, OK (LCB), the EFAW Research Station at Stillwater, OK, and the Perkins Research Station at Perkins, OK for two years. Treatments were three N rates applied at four different N rate combinations, with three different application methods; 1. streamer nozzle application of liquid UAN; 2. flat fan nozzle application of liquid UAN; 3. granular urea hand applied to the surface without incorporation.

Findings and Conclusions:

Inclement weather in 2007 at both sites resulted in highly variable, and extremely low (< 700 kg ha^{-1} in all plots), yields with a great amount of variation occurring between N rate treatments. The adverse weather conditions resulted in the check plot producing higher yields than half of the other treatments showing a greater response to weather than either N rate or application method for this year. In 2008 an increase in grain yields was observed from topdress application with the streamer nozzle. A benefit was observed from utilizing the streamer nozzle for topdress application at the higher N rate combinations (0 – 90, 45 – 45, and 45 – 90 kg N ha^{-1}) with the increase in yield being slight (4 kg ha^{-1}) at the highest N rate combination. A small increase in yield (11 kg ha^{-1}) was seen when using the flat fan nozzle over the streamer nozzle at the 0 – 45 kg N ha^{-1} rate. The benefits of fertilizing with the streamer nozzle tended to be more evident at the middle two N rate combinations (0 – 90 and 45 – 45 kg N ha^{-1}) where nitrogen was somewhat limited.

ADVISER'S APPROVAL: Dr. William R. Raun