# OPTIMUM PREPLANT NITROGEN RATES FOR MAIZE (ZEA mays L.) AND SORGHUM (SORGHUM bicolor L.) PRODUCTION

By

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OPTIMUM PREPLANT NITROGEN RATES IN

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BICOLOR)

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Title of Study: OPTIMUM PREPLANT NITROGEN RATES IN MAIZE (ZEA mays L.) AND SORGHUM (SORGHUM BICOLOR)

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**Abstract:** Nitrogen Use Efficiency (NUE) for maize (Zea mays L.) production is low in the developed and developing world. Nitrogen application rates both preplant and sidedress need to be adjusted based on variables such as the environment, peak demand, and field-to-field variability which are known to change from one year to the next. This study was conducted to determine the minimum up-front fertilizer N rates, needed to improve mid-season fertilizer N use efficiencies, and determine periods of maximum N demand. Four field experiments were conducted where N as urea ammonium nitrate (UAN, 28-0-0, N-P-K) was applied preplant at rates of 0, 17, 34, 51, 67, and 168 kg N $ha^{-1}$. Preplant fertilizer was applied on April 6 for EFAW and Perkins, and April 7 Lake Carl Blackwell. Normalized difference vegetative index (NDVI) data were collected from the V6 to V10 growth stages. At V6, sidedress N was applied at rates of 168 kg N $ha^{-1}$ for treatments 8 through 14. Due to faculty-design-treatment-structure errors, this maize N study will be conducted in the 2017 growing season. This study will determine the minimum preplant N rate needed combined with sidedress N for maximum yields in maize. Grain sorghum (Sorghum bicolor L.) production similar to Maize (Zea mays L.) needs to take place at much higher levels of nitrogen use efficiency (NUE) than it is achieved today. Nitrogen application rates, both preplant and sidedress, need to be adjusted based on variables such as the environment, peak demand, and field to field variability which are known to change from one year to the next. This study was initiated to determine the minimum pre-plant fertilizer N rates needed to improve mid-season fertilizer N use efficiencies, and to determine periods of maximum N demand. Two field experiments were conducted where N as urea ammonium nitrate (UAN, 28-0-0, N-P-K) was applied preplant at rates of 0, 17, 34, 50, 67, and 101 kg N $ha^{-1}$. Preplant fertilizer was applied on April 6 for EFAW, and April 15 for Lake Carl Blackwell. Normalized difference vegetative index data were collected at 512, 732, 1080, and 1341 total degree day heat units. At 830 total degree day heat units, sidedress N was applied at a rate of 34 kg N $ha^{-1}$ for treatments 7 through 12. The preplant N rate for these studies was 67 kg N $ha^{-1}$ (Tables 6 and 7). In order to maximize yields, at least 34 kg N $ha^{-1}$ applied sidedress was needed.

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# CHAPTER I

## INTRODUCTION

The present world population of 7.4 billion people depends upon the availability and use of nitrogen (N). Nitrogen fertilizer is widely used for global cereal production, with the three main cereals being maize (Zea mays L), rice (Oryza sativa L.) and wheat (Triticum aestivum L.).

Nitrogen inputs for these cereal crops are significant on a world scale. Nitrogen use efficiency (NUE) for world cereal grain production is estimated at 33% (Raun and Johnson, 1999) and they further reported that 67% of the N that is applied is lost to the environment and/or sequestered in organic fractions. The portion of N that is unused has the potential to end up in the environment with significant negative environmental impact.

Present challenges are centered on improving global NUE through the utilization of mid-season sensor based-N management strategies. This resourceful field encumbers estimates of final grain yield utilizing estimated mid-season biomass, projected growth rates for the growing-environment and season in question, which ultimately leads to tailored fertilizer N rates. This approach delivers increases in NUE through customized fertilization rates for each unique set of growing conditions. Specifics regarding timing and application rate in regards to preplant N fertilizer are still vastly unpredictable. Nitrogen applied preplant is subject to increased rates of loss, resulting in economic and environmental concerns. Delayed or reduced applications of N are ideal so long as final grain yield is not sacrificed. This approach has the potential to increase NUE and provide a positive economic return to producers.Maize (Zea mays L.) accounts for the largest volume of cereal grain produced in the world. As per the USDA 2014-2015 World Agriculture Supply and Demand Estimates, 80 million acres of maize were harvested in the United States, with an average yield of 10.5 Mg/ha (168 bu/ac) (USDA, 2016). In 2015, the United States harvested 30,000,000 ha's maize (USDA, 2016). Maize consumption features a diverse range of applications. The United States Department of Agriculture reported maize use in livestock and human caloric intake as major segments of maize consumption (39.1% and 8.5%, respectively). The article further references the importance of maize for ethanol production, where 30.3% of American grown maize is used to produce ethanol. Overall, 925,252 Mg $ha^{-1}$ of maize were consumed and processed in the United States in 2015 (National Corn Growers Association, 2016).

According to the American Society of Agronomy, sorghum (Sorghum bicolor) is a drought tolerant annual crop that originated in the northeastern region of Africa over 6,000 years ago (Chakravorty, 2016). Chakravorty (2016) stated that the benefits of producing sorghum included genetic traits conferring drought resistance and reduced dependence on pesticide applications. Sorghum, therefore, is highly suitable for producers in arid regions, where corn would suffer due to extreme moisture and heat stress (Neild and Newman, 2016). Sorghum production is utilized globally through livestock feed, protein content for human consumption, and superior micronutrient levels (Chakravorty, 2016).

***Objective***

The objective of this study was to estimate the optimum preplant fertilizer N rate for maize (Zea mays L.) and sorghum (Sorghum bicolor) production.

CHAPTER II

REVIEW OF LITERATURE

***Rates of Fertilizer N Applied for Maize and Sorghum in the World***

*Maize*

Nitrogen is essential for maize production and is required in mass quantities, due to the high protein content it adds to grain (Butzen, 2016) (Table 1). Nitrogen application recommendations vary across the Corn Belt, and recommendations change depending on soil type, temperatures, and previous crop rotations. The state of Ohio recommends 168 kg N $ha^{-1}$ as anhydrous ammonia or UAN, as either preplant or a split application (Eckert, 1987). Illinois recommendations vary from 134 to 268 kg N $ha^{-1}$ when applied beneath the soil surface (Hoeft, 1987). Michigan applies a spilt application on sandy loam soils, ranging from 84 to 187 kg N $ha^{-1}$ (Vitosh, 1969-72). Purdue University provides several recommendations that start at 34 kg N $ha^{-1}$ and increase to 293 kg N $ha^{-1}$, with 221 kg $ha^{-1}$ of N applied to a corn-soybean rotation (Camberato and Nielsen, 2016). Maize field that was recently manured is recommended to receive 0 to 100 kg N $ha^{-1}$, and after established alfalfa 0 to 34 kg N $ha^{-1}$. Second year maize after alfalfa has a recommendation of 168 kg N $ha^{-1}$ to 224 kg N $ha^{-1}$, while corn with no manure applied should receive 112 kg N $ha^{-1}$

to 168 kg N $ha^{-1}$ (Mallarino, 1997). The University of Nebraska changes their rates depending on residual N, soil organic matter, and an expected yield goal for that growing season (Shapiro et al., 2008).

**Table 1.** Worldwide crops and grain N %

| Crop | Grain N, % |
|---|---|
| Maize (Colombia) | 1.55 |
| Maize (Argentina) | 1.24 |
| Maize (USA) | 1.25 |
| Maize (Minnesota) | 1.23 |
| Winter Wheat | 2.39 |
| Winter Wheat (Kansas) | 2.1 |
| Winter Wheat Forage | 2.46 |
| Spring Wheat (Ciudad Obregon) | 2.45 |
| Spring Wheat (Baja California) | 2.1 |
| Spring Wheat (Dakota's) | 2.4 |
| Wheat (Argentina) | 2.2 |
| Sorghum | 1.95 |
| Sorghum KANSAS | 1.96 |
| Spring Wheat (Canada) | 2.23 |
| Wheat S-Australia | 2 |
| Wheat E Australia | 2.25 |
| Bermudagrass | 2 |
| Spring Wheat Argentina | 1.95 |
| Spring Wheat (India) | 1.6 |
| Rice (India) | 1.28 |
| Cotton Lint | 8.64 |
| Durum Wheat | 2.24 |
| Canola (Canada) | 3.3 |

**Source** (Raun, 2016)

In recent years, producers in Oklahoma have transitioned to recommendations generated from seasonal normalized difference vegetation index (NDVI) sensor readings.

*Sorghum*

Sorghum is a summer annual crop, resembling maize, with slightly different traits. Espinoza (2016) suggested that N is the most limiting macronutrient in sorghum production in Arkansas, with nearly 50% of N removed from harvested grain. Tucker (2009) further explained that this will result in a lower amount of N needed midseason, due to efficient utilization of naturally supplied N. Espinoza (2016) further explaind that Arkansas's N recommendation rates ranged from 67 kg N $ha^{-1}$, following a dry land double cropping small grain to 168 kg N $ha^{-1}$ for irrigated sorghum. University of Nebraska-Lincoln recommends a minimum of 66 kg N $ha^{-1}$ of N to reach peak economic production (Hay and Rees, 2016). South Dakota Extension also calls for 66 kg N $ha^{-1}$ of N both in conventional and conservation tillage systems (Bly, 2015). Sorghum recommendations for Oklahoma follow maize NDVI practices.

***Optimum Application for Yield and NUE***

Nitrogen is vital for maize production and is the second largest limiting factor, falling closely behind water (Freeman et al., 2007). It is crucial that producers make the most economical and environmental management decisions when applying N. Freeman et al. (2007) stated that crop management practices could increase NUE and profitability, while decreasing environmental contamination associated with excessive applications of N. Due to the high potential for N loss, the amount of fertilizer that is applied early in the season is not always the amount available to the crop (Beegle and Philip, 2016). Beegle and Philip (2016) further explain that N losses can and should be reduced with practical management decisions such as source, timing, and application method.

*Maize*

Utilizing practices and increasing NUE in maize is necessary for increasing grower profitability and minimizing loss to the environment (Vetsch and Randall, 2003). There are many application methods to be utilized when applying preplant and midseason.  There are many application methods to be utilized when applying preplant and midseason N. Producers generally apply N before planting (preplant) in the fall or spring, followed by a midseason application at the six (V6) and eight (V8) leaf vegetative growth stages.

Fall applied N is generally in the form of anhydrous ammonia. Producers feel this is an advantageous management decision, because they are able to distribute their labor, time, and expense, as anhydrous is a less expensive form of N (Bundy, 1986; Randall and Schmitt, 1998).

Fall application carries a higher risk, as opposed to spring N applications. Potential for N loss may be elevated, followed by a decrease in grain yield.  Stevenson and Baldwin (1969) noted that a study was conducted in Ontario, MN that later revealed a higher grain yield with spring N application as opposed to mid-November fall applications, which resulted in reduced yields. According to Sanchez and Blackmer (1998), 50 to 60% of fall applied N will be lost through soil pathways before reaching the maize plant, at peak consumption periods.

Sawyer (2013) from Iowa State Extension and Outreach states that anhydrous ammonium applications carry the potential risk for burning of maize seedlings, due to high pH if applied close to furrow rows. Sawyer (2013) further states if anhydrous ammonia is applied there are precautionary measures that can be made to reduce risk of ammonium damage such as, waiting until soil conditions are favorable, injection depth is at least seven or more inches, postpone planting several days after application, inject N close to corn rows, and if uncontrollable apply at an angle. Nitrogen applied just prior to planting can carry the same risks as applying in the fall. As vital as it is to have available N for early growth stages, preplant N in the spring can also be lost to leaching, due to heavy rains or via volatilization when surface applied.

Environmental factors change from season to season, so it is difficult to predict the amount of preplant N that is needed. Brouder and Mengel (1996) later stated the importance of timing when it comes to early N application, and lack of noting risks associated with application 30 days before harvest, due to substantial loss that can occur. Brouder and Mengel (1996) later stated that volatilization via surface application can occur through the breakdown of ammonia gases when water cannot absorb those gaseous forms, typically found in surface applications of urea ammonium nitrate (UAN). Denitrification may also occur due to wet soils, compaction, unfavorable temperatures, or conditions that cause microorganisms to search for oxygen (Brouder and Mengel, 1996).

Edmonds et al. (2013) noted that banding and sidedressing are predominately beneficial when producing maize in N limited soils. Banding can be performed in various ways, and shows no reduction in yield when placed in the middle of every row (Durst and Beegle, 1999; Hefner and Tracy, 1995; Murrell, 2006; Lehrsch et al., 2000; Stecker, 1993; Vitosh et al., 1995). Banding can take place via surface or subsurface applied N, where it is easily accessible by the plant. Sidedress N is typically applied during the life cycle of the crop and often referred to as midseason. Durst and Beegle (1999) and Stecker (1993) later stated that sidedress is considered the best practice when maize rows are visible, so that N can be precisely placed near the maize, reducing plant loss and increasing NUE. Additional studies were conducted to study N application for maize, and N is commonly used by an individual row when spatial diversity is minimal (Johnson and Kurtz, 1974; Joleka and Randall, 1987; Sanchez et al., 1987; Blaylock et al., 1990).

While preplant applied N is vital at the early stages of seedling growth, we are now finding the importance of midseason N and how it affects yield potential. Sidedress N has the potential of improving efficiency, due to application immediately prior to rapid N uptake, lowering potential N loss (Bundy, 2006). Sidedress application allows producers to focus on maize planting, which can be extremely important during wet springs, as opposed to pre plant applications (Mengel, 1996).

Timing is critical, due to potential N loss such as leaching, denitrification, volatilization, and/or plant loss. Denitrification and leaching are variables that often cannot be controlled (Beegle and Philip, 2016). Furthermore, these two pathways can be reduced if N is applied, when maize utilizes N the most environmental conditions are best suitable. Soil moisture and water supply will advance N response further increasing yield potential (Al-Kaisi and Yin, 2003).

Ideal N management for maize production is best reflected with midseason application, as producers can validate mineralized and total N that has been accumulated (Sawyer et al., 2007). Nitrogen uptake response reaches 50% to 90%, when maize is 10 to 20 inches tall (Beegle and Philip, 2016). Girma et al. (2010) stated that N accumulation was observed between growth stages of V4 to V8, with an additional vast N accumulation between growth stages of V4 to V8, with an additional vast N accumulation between stages V8 and R2. Girma et al. (2010) later reported that there was an additional increase of N uptake from R2 to R4, followed by no additional dry matter N accumulation. Only 20% of total N is accumulated by V6, while N accumulation was 50% to 60% by R1 (Ma et al, 1999). Neild and Newman (2016) stated that growing degree days (GDD) should generally be 475 to 610 for maize. Neild and Newman (2016) further found that growing degree days were determined by the number of days from planting to sensing where temperatures were greater than 10 degrees Celsius.

*Sorghum*

Similar fertilization practices are present in the production and management of grain sorghum cropping systems. The key difference lies in timing of nutrient applications. Nitrogen is best applied before pollination to ensure that adequate N is available during grain fill. Tucker (2009) states that sorghum hybrids respond differently to N application and extract it from the soil in a more effective way. Nitrogen management practices employed in no-till sorghum, result in low N recovery and can result in higher N demand mid-season (Kastens et al., 2006). Numerous studies (Eckert, 1987; Fox and Piekielek, 1987; Fox et al., 1986; Maddux et al., 1984; Bandel et al., 1980 and 1984; Mengel et al., 1982) were conducted to evaluate N placement methods in no-till corn in the Corn Belt and Great Plains. Broadcast applications of UAN resulted in lower yields, due to volatilization or immobilization, as opposed to surface band applied N (Tucker, 2009). Mid-season N should be applied 30 to 35 days after planting (FOCUS, 2013). Rapid growth in sorghum begins 25 days after emergence at the sixth leaf stage and continues until early grain fill (Tucker, 2009). Espinoza (2016) reported that a minimal amount of N was used 20 days after planting, but 60% of its total N were used 60 days after emergence.

### ***Sensor Based Approaches that Enhance Mid-Season N Application***

Precision agriculture offers the promise of better utilizing producer time, money, and resources. As precision agriculture practices become more widely accepted and adopted, outlining the ideal field component for management inputs can become increasingly significant (Freeman et al., 2007).

Numerous elements can come into play, when considering fertilizer application and plant N utilization. Tubana el at. (2007) stated that customarily, producers were treating each field the same and base their N management application practices on yield goals. Tubana el at. (2007) later noted that producers formulated yield goals by taking a five-year crop average plus an addition of 10% to 30%, to assure an adequate amount of N for the growing season. Problems begin to occur when these practices are employed. No given year is the same, resulting in over or under application of N. Nitrogen fertilizers applied at higher rates than recommended for maize production can result in nitrate leaching due to N build up beneath the root zone (Al-Kaisi and Yin, 2003).

While environmental conditions are unpredictable, producers need an effective way to predict midseason N. Nitrogen recommendations by year are important since yield levels with the same N rate change drastically over time (Mohammed et al., 2013). Stanford (1973) found that optimum N use includes the N requirement of the expected yield level, amount of mineralized N found early in the season, and expected efficiency of N that will be applied. Scharf et al., (2005) stated that economically optimum fertilizer rates vary from field to field, due to high variability within those fields. Validation of N fertilizer predictions depends on efficiency, realistic estimates of grain yield, and residual N supply (Stanford, 1973).

Work by Stone et al. (1996a and 1996b) used handheld sensors to detect plant biomass and to then predict N uptake in winter wheat. Freeman et al. (2007) used sensors measuring red and near infrared (NIR), and where passive sensor data was used to calculate uncalibrated NDVI.

What later became known as the GreenSeeker sensor, measures NDVI by using a self-illuminated (active sensor) light source for both red and near infrared (NIR) wavelengths (660, and 780 nm, respectively). The GreenSeeker sensor computes NDVI as (NIR-red)/(NIR+red). Emitted NIR and red radiation returned from the sensed area (reflectance) are used accordingly. The GreenSeeker sensor has an area of measurement of 1 cm x 60 cm when used in a normal operating range of 60 cm to 100 cm above the crop canopy. The present configuration collects > 10 readings per second, and that are locally stored on an onboard IPAQ.

The NDVI index was also found to be a good predictor of winter wheat grain yield. Further refinement by Teal et al. (2006) used growing degree days (Tmin + Tmax)/2 – 4.4°C (GDD) and NDVI over various sites to better predict yield potential in maize, over locations and years. These results showed that normalizing NDVI using GDD over sites explained 73% of variability in yield. Additional work showed that the highest correlation of NDVI with corn grain yield was found at the V7 to V9 growth stages in maize (Freeman el at., 2007).

Using NDVI, producers are able to gather seasonal biomass readings to see the amount of N that is being utilized. Once producers have collected readings, they are able to use Oklahoma State University's Sensor Based Nitrogen Rate Calculator (SBNRC) to compute their mid-season N rates. They can also employ the response index (RI) between N applied preplant and the farmer check to derive mid-season fertilizer N rates. The response index (RI) is the ratio of grain yield and/or NDVI from an adequately N fertilized plot, divided by the farmer practice (Mullen et al. (2003). This form of precision technology embeds better management practices for producers and when used can increase grain yields, and improve NUE, while decreasing excess N in groundwater and gaseous emissions.

# CHAPTER III

## MATERIALS AND METHODS

*Maize*

In order to evaluate the effects of preplant N application in maize, multiple experiments were established. Four maize locations were used for the 2016 growing season. All trials were within the state of Oklahoma at EFAW, Lake Carell Blackwell, and Perkins.

A randomized complete block design with 14 treatments was used for all maize trials. The following treatment structure included a zero-N-check. Treatments 2 through 7 received 17, 34, 67, 101, 134, and 168 kg N $ha^{-1}$, applied preplant with no sidedress N. In addition, treatments 8 through 14 received 0, 17, 34, 67, 101, 134, 168 kg N $ha^{-1}$ and an additional 168 kg N $ha^{-1}$ applied midseason (Table 1). Urea Ammonium Nitrate (UAN) was used for both preplant and sidedress applications. Maize trials consisted of 3 replications with 3 m by 6-m plots, and 3 m alleys between each replication.

*Sorghum*

In order to evaluate the effects of preplant N application in sorghum, multiple experiments were established. Two sorghum locations were used for the 2016 growing season. Both trials were within the state of Oklahoma at EFAW and Lake Carl Blackwell.

A randomized complete block design with 12 treatments was used for the sorghum trials. The treatment structure included a zero-N-check with no N applied preplant or midseason. Treatments 2 through 6 received 17, 34, 67, and 101 kg N $ha^{-1}$ applied preplant, and no added N mid-season.  Treatments 7 through 12 received 0, 17, 34, 67, and 101 kg N $ha^{-1}$ applied preplant and an additional 34 kg N $ha^{-1}$ applied midseason (Table 2). Preplant soil samples were taken prior to preplant N application (Table 4 and 5). Urea Ammonium Nitrate (UAN) was used for both preplant and sidedress applications for this study. Sorghum trials had 3 replications, with 3 by 6 m plots and a 3m alley between each replication.

***Field Methodology***

*Maize*

For all trials, commercial pesticides were used to reduce the potential damage of insects and weeds. A Greenseeker hand held NDVI sensor was used for maize trials. The NDVI data were then used to predict biomass, throughout the growing season and to predict final grain yield. For maize trials NDVI was collected from V4 through R1, or tasseling. A John Deere four row MaxEmerge planter was used for maize trials. Conventional till sites were chisel plowed before planting for preparation of the seedbed. Maize for both conventional and no-tillage sites were planted at 65,000 seeds/ha. Maize sites were harvested with a Kincaid 8XP self-propelled combine. Grain yields were collected at harvest, subsampled, dried for 24 hours, ground and analyzed for total N content.

*Sorghum*

For all trials, commercial pesticides were used to reduce the potential damage of insects and weeds. A Greenseeker hand held NDVI sensor was used for sorghum trials. This NDVI data was then used to predict biomass, throughout the growing season and to predict grain yield potential. In sorghum trials, NDVI data was collected from V1 to V4. Field activities are reported in Table 3.  A John Deere four row MaxEmerge planter was used for both maize and sorghum trials. Conventional till sites were chisel plowed before planting for preparation of the seedbed. Sorghum for both conventional and no tillage sites, and hybrids were planted at 137,500 seeds/ha. Sorghum sites were harvested with a Kincaid 8XP self-propelled combine. Grain yields were collected at harvest, subsampled, dried for 24 hours, ground and analyzed for total N content.

# CHAPTER IV

# RESULTS AND DISCUSSION

## *Maize*

Due to error in treatment structure, further evaluation over the 2017 growing season will take place including four additional sites. With the corrections made, we hope to ensure results that will allow the determination of optimum preplant N rates for maize.

## *Sorghum*

### ***EFAW (2016)***

Yield data were collected at harvest and ranged from 3.60 to 6.50 Mg $ha^{-1}$ with an average of 5.13 Mg $ha^{-1}$ (Table 4). Treatment 11 (67 preplant + 34 top dress, Table 4) had numerically higher yields when compared to all other treatments. However, there was no significant difference in yield for all treatments. Normalized difference vegetative index readings were taken at 512 and 1342 total degree day heat units, where similarly, no statistical differences were found (Figures 1 and 3). Extreme within-trial variability was found, partly due to bird damage recorded for midseason readings. Furthermore, limited N response was noted due to extreme heat and inadequate rainfall prior to boot stage. According to Villalobos and Fereres (2016), critical soil water depletion (SWD) is 94 mm. They also state, that if SWD hits below 94, water stress will begin and have a negative effect on yield. The lowest water balance reached was

173 mm (Figure 6). Prior to preplant application, EFAW went without rainfall for 11 days. Post preplant application, EFAW went 10 days without rain, and accumulated 2.28mm when rainfall occurred. While treatment 11 accounted for the highest grain yield treatment 10 was seen to have the highest grain N uptake, total percent N, and grain protein. Both treatment 10 and 11 received 34 kg N $ha^{-1}$ sidedress, while treatment 10 received 50 kg N $ha^{-1}$ of preplant and treatment 11 received 67 kg N $ha^{-1}$ preplant.  Nitrogen Use Efficiency was computed using the difference method, which resulted in averages exceeding 100% for treatments 2 and 7. Seasonal rainfall was documented based on weather data available via the Oklahoma Mesonet (McPherson et al., 2007, Brock et al., 1995). Rainfall accumulation at EFAW from planting to harvest totaled 410 mm (Table 6).

***Lake Carl Blackwell (2016)***

Yield data was collected at harvest and ranged from 5.30 to 9.30 Mg $ha^{-1}$ with an average of 7.58 Mg $ha^{-1}$ (Table 4). Treatment 11 (67 preplant + 34 side dress, Table 4) had numerically higher yields when compared to all other treatments. However, there was no statistical difference between all 12 treatments, except for treatment 7 and 11. Both treatment 7 and 11 received 34 kg N $ha^{-1}$ sidedress, while treatment 7 received 0 kg N $ha^{-1}$ preplant N and treatment 11 received 67 kg N $ha^{-1}$ preplant (Table 4). Normalized difference vegetative index readings were taken at 732 and 1080 total degree day heat units, but no statistical differences were observed (Figures 2 and 4), due to experimental plot variability in all 3 replications, and this was likely a result of bird damage recorded during the production cycle. Treatment 11 accounted for the highest grain yields, grain N uptake, and total grain N. Treatment 11 received 67 kg N $ha^{-1}$ of preplant and 34 kg N $ha^{-1}$ of sidedress. Seasonal rainfall was documented based on weather data through the Oklahoma Mesonet (McPherson et al., 2007, Brock et al., 1995). Rainfall accumulation at Lake Carl Blackwell from planting to harvest totaled 411 mm (Table 7).

The EFAW site was conducted under no-tillage, while Lake Carl Blackwell was conventionally tilled. Differences between the two practices were thus expected. Tillage practices played a role when it came to final grain yield. The LCB site had significantly higher grain yields, when comparing treatment 11 at both sites. Treatment 11 (67 pre + 34 sidedress) was observed as the highest yielding treatment at both EFAW and Lake Carl Blackwell locations, and this was the second highest total N rate evaluated. Bird damage was logged, midseason at both locations. Damage records scored from 1 to 10, 10 accounting for the highest amount of damage throughout all sorghum trials. The average damage accounted for at both locations was 2, with a value of 10 being the most damage.

Moisture stress was documented at EFAW, due to limiting rainfall in June, while boot stage was occurring. Stichler and Fipps (2003) noted the extreme demand for water during boot stages because the potential head size has already been determined. The ultimate goal is to limit water stress in the plant during rapid growth, to further facilitate robust plant structure formation. Stichler and Fipps (2003 further state that water use during boot stage will be approximately 1,257 to 1,886 mm per hectare per day. Stichler and Fipps (2003) continue to elucidate that up to full bloom, sorghum will use about 203 to 254 mm per day. Moisture stress during this growth stage will lead to a reduction in yield. Water balance at this location fell below 94mm from May 25$^{th}$ through June 8$^{th}$ (Figure 6). Prior to preplant application, rainfall was omitted for 15 days. Post preplant application, rainfall was absent for 10 days. Lake Carl Blackwell accumulated 3.0mm when rainfall occurred. Both EFAW and LCB received the same amount of rainfall, but yields showed a significant increase at Lake Carl Blackwell, due to a more evenly distributed amount of rain throughout the growing season, especially during boot stage. Environmental differences play a crucial role when analyzing treatment response in row crop production. As stated by Teal et al. (2006), the environment is not controlled by a single factor but rather composite effects from soil fertility, climate, and external inputs.

Treatments 7, 10, and 11 had the highest yields at EFAW. All three treatments received 34 kg N $ha^{-1}$ as a sidedress application. Treatment 7 received 0 kg N $ha^{-1}$ preplant, treatment 10 had 50 kg N $ha^{-1}$ preplant, and treatment 11 had 67 kg N $ha^{-1}$ preplant. Treatments 5, 11, and 12 resulted in the highest yields at Lake Carl Blackwell. Treatment 5 received 67 kg N $ha^{-1}$ preplant, 0 kg N $ha^{-1}$ sidedress. Treatment 11 received 67 kg N $ha^{-1}$ preplant and 12 received 101 kg N $ha^{-1}$. Both treatments 11 and 12 received 34 kg N $ha^{-1}$ sidedress. Because treatment 11 resulted in the highest yield at both EFAW and Lake Carl Blackwell, it suggests the importance of both pre plant and sidedress N for maximum yields. As stated earlier, 60% of the total N is used 60 days after emergence (Espinoza, 2016). It is important that N is available, prior to the reproductive phase, where rapid growth takes place. Preplant N essential for early vegetative stages of growth, while midseason N is important for grain fill. Stichler and Fipps (2003) state if N becomes unavailable during rapid growth, yield potential decreases significantly.

# CHAPTER V

# CONCLUSION

No significant grain yield differences were observed between preplant N treatments (Table 4 and 5). Both locations showed apparent heat stress, while lacking soil moisture when sidedress N was applied. While water balance fell close, not below SWD, this was shown to decrease yield and increase variability throughout both plots. The extreme field variation and lack of N response requires further evaluation over the 2017 growing season, and that has now included 2 additional sites. We anticipate results that will allow the determination of optimum preplant N rates for sorghum.

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**Table 1.** Treatment structure, for maize experiments conducted, at EFAW, Lake Carl Blackwell, and Perkins, 2016.

| **Treatment** | **Preplant N (kg N $ha^{-1}$)** | **Sidedress N (kg N $ha^{-1}$)** | **Total N (kg N $ha^{-1}$)** |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 17 | 0 | 17 |
| 3 | 34 | 0 | 34 |
| 4 | 67 | 0 | 67 |
| 5 | 101 | 0 | 101 |
| 6 | 134 | 0 | 134 |
| 7 | 168 | 0 | 168 |
| 8 | 0 | 168 | 168 |
| 9 | 17 | 168 | 185 |
| 10 | 34 | 168 | 202 |
| 11 | 67 | 168 | 235 |
| 12 | 101 | 168 | 269 |
| 13 | 134 | 168 | 302 |
| 14 | 168 | 168 | 336 |

**Table 2.** Treatment structure, for sorghum experiments, conducted, at EFAW, and Lake Carl Blackwell, 2016.

| **Treatment** | **Preplant N ($kg\ N\ ha^{-1}$)** | **Sidedress N ($kg\ N\ ha^{-1}$)** | **Total N ($kg\ N\ ha^{-1}$)** |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 17 | 0 | 17 |
| 3 | 34 | 0 | 34 |
| 4 | 50 | 0 | 50 |
| 5 | 67 | 0 | 67 |
| 6 | 101 | 0 | 101 |
| 7 | 0 | 34 | 34 |
| 8 | 17 | 34 | 51 |
| 9 | 34 | 34 | 68 |
| 10 | 50 | 34 | 84 |
| 11 | 67 | 34 | 101 |
| 12 | 101 | 34 | 135 |

**Table 3.** Summary of Location, Soil Type, Tillage Method, Preplant N Date, Planting Date, Sidedress N Date, Seeding Population, and Harvest Date to to evaluate optimum N rate in sorghum, 2016, OK.

| Location | Soil Type | Tillage Method | Preplant N Date | Planting Date | Sidedress N Date | Seed Population (seeds/ha) | Harvest Date |
|---|---|---|---|---|---|---|---|
| EFAW | Norge Loam | No-till | 6-Apr-16 | 25-Apr-16 | 15-Jun-16 | 135,850 | 16-Aug-16 |
| Lake Carl Blackwell | Port-Oscar Complex | Conventional | 15-Apr-16 | 26-Apr-16 | 6-Jun-16 | 135,850 | 17-Aug-16 |

**Table 4.** Preplant soil test data, EFAW, OK 2016

| trt | NO3-N (ppm) | NH4-N (ppm) | K (ppm) | ICAP-P (ppm) | pH | TN % | OC % |
|---|---|---|---|---|---|---|---|
| 1 | 0.44 | 0.44 | 111.07 | 40.96 | 6.08 | 0.06 | 0.67 |
| 2 | 0.66 | 0.66 | 113.36 | 38.92 | 5.95 | 0.07 | 0.66 |
| 3 | 1.02 | 1.02 | 114.11 | 41.37 | 5.83 | 0.07 | 0.68 |
| 4 | 0.54 | 0.54 | 112.21 | 39.78 | 5.98 | 0.06 | 0.68 |
| 5 | 0.38 | 0.38 | 115.25 | 42.10 | 5.84 | 0.07 | 0.67 |
| 6 | 0.57 | 0.57 | 104.94 | 37.32 | 5.99 | 0.06 | 0.64 |
| 7 | 0.54 | 0.54 | 105.77 | 34.91 | 6.03 | 0.06 | 0.63 |
| 8 | 0.56 | 0.56 | 113.63 | 35.59 | 5.91 | 0.06 | 0.64 |
| 9 | 0.51 | 0.51 | 110.18 | 42.14 | 5.93 | 0.06 | 0.70 |
| 10 | 0.44 | 0.44 | 114.63 | 41.30 | 6.01 | 0.06 | 0.72 |
| 11 | 0.62 | 0.62 | 115.41 | 40.89 | 5.91 | 0.06 | 0.68 |
| 12 | 0.41 | 0.41 | 116.81 | 41.34 | 6.04 | 0.07 | 0.73 |

**Table 5.** Preplant soil test data, Lake Carl Blackwell, OK 2016

| trt | NO3-N (ppm) | NH4-N (ppm) | K (ppm) | ICAP-P (ppm) | pH | TN % | OC % |
|---|---|---|---|---|---|---|---|
| 1 | 0.10 | 4.97 | 149.81 | 17.22 | 5.69 | 0.09 | 0.90 |
| 2 | 0.12 | 4.62 | 142.51 | 15.90 | 5.77 | 0.10 | 0.92 |
| 3 | 0.11 | 5.54 | 158.24 | 26.10 | 5.60 | 0.09 | 0.97 |
| 4 | 0.11 | 5.02 | 153.34 | 23.20 | 5.61 | 0.09 | 0.91 |
| 5 | 0.13 | 5.37 | 164.40 | 22.28 | 5.69 | 0.09 | 0.91 |
| 6 | 0.10 | 4.60 | 149.22 | 11.46 | 5.75 | 0.10 | 0.96 |
| 7 | 0.13 | 5.23 | 150.99 | 21.12 | 5.57 | 0.09 | 0.88 |
| 8 | 0.09 | 5.38 | 164.21 | 23.11 | 5.76 | 0.10 | 0.97 |
| 9 | 0.10 | 4.90 | 160.08 | 22.94 | 5.80 | 0.09 | 0.95 |
| 10 | 0.11 | 4.78 | 156.91 | 20.85 | 5.60 | 0.10 | 0.90 |
| 11 | 0.09 | 4.98 | 166.43 | 28.32 | 5.66 | 0.09 | 0.91 |
| 12 | 0.10 | 4.87 | 166.79 | 19.50 | 5.62 | 0.10 | 0.94 |

**Table 6**. Treatment structure and sorghum grain yield and grain N uptake, EFAW, OK 2016

| Trt | Preplant N (kg N $ha^{-1}$) | Sidedress N (kg N $ha^{-1}$) | Grain Yield Mg $ha^{-1}$ | | NDVI 6/6/2016 | | NDVI 7/7/2016 | | Grain N uptake kg $ha^{-1}$ | | Total Nitrogen % | | NUE % | | Cummulative Heat Units | Precipitation (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Stddev | Mean | Stddev | Mean | Stddev | Mean | Stddev | Mean | Stddev | Mean | Stddev | | |
| 1 | 0 | 0 | $3.56^{A}$ | 0.43 | 0.69 | 0.04 | 0.78 | 0.02 | 34.46 | 4.76 | 0.97 | 0.02 | 0.00 | 0.00 | 2008.90 | 1039.0 |
| 2 | 17 | 0 | $3.56^{A}$ | 0.43 | 0.74 | 0.02 | 0.77 | 0.02 | 43.93 | 18.33 | 1.16 | 0.03 | 1.12 | 0.72 | | |
| 3 | 34 | 0 | $5.20^{A}$ | 0.84 | 0.75 | 0.10 | 0.81 | 0.02 | 66.78 | 20.54 | 1.27 | 0.19 | 0.96 | 0.61 | | |
| 4 | 50 | 0 | $4.52^{A}$ | 2.93 | 0.79 | 0.03 | 0.81 | 0.00 | 51.76 | 32.52 | 1.14 | 0.03 | 0.71 | 0.13 | | |
| 5 | 67 | 0 | $5.66^{A}$ | 1.41 | 0.73 | 0.10 | 0.80 | 0.02 | 73.39 | 23.97 | 1.16 | 0.14 | 0.58 | 0.36 | | |
| 6 | 101 | 0 | $5.61^{A}$ | 0.83 | 0.80 | 0.03 | 0.83 | 0.02 | 84.73 | 7.10 | 1.52 | 0.12 | 0.50 | 0.07 | | |
| 7 | 0 | 34 | $5.77^{A}$ | 1.26 | 0.70 | 0.08 | 0.80 | 0.02 | 71.36 | 14.86 | 1.24 | 0.02 | 1.10 | 0.44 | | |
| 8 | 17 | 34 | $5.22^{A}$ | 0.51 | 0.77 | 0.03 | 0.81 | 0.00 | 61.58 | 10.47 | 1.18 | 0.17 | 0.54 | 0.21 | | |
| 9 | 34 | 34 | $4.58^{A}$ | 1.86 | 0.78 | 0.02 | 0.80 | 0.01 | 54.09 | 24.68 | 1.17 | 0.10 | 0.29 | 0.37 | | |
| 10 | 50 | 34 | $6.42^{A}$ | 1.49 | 0.78 | 0.05 | 0.82 | 0.02 | 85.58 | 16.76 | 1.34 | 0.11 | 0.61 | 0.20 | | |
| 11 | 67 | 34 | $6.48^{A}$ | 1.04 | 0.78 | 0.05 | 0.81 | 0.00 | 77.44 | 19.40 | 1.18 | 0.13 | 0.43 | 0.19 | | |
| 12 | 101 | 34 | $4.94^{A}$ | 2.00 | 0.76 | 0.06 | 0.80 | 0.05 | 76.46 | 30.59 | 1.55 | 0.03 | 0.31 | 0.23 | | |
| MSE | | | 1.12 | | | | | | | | | | | | | |
| SED | | | 0.86 | | | | | | | | | | | | | |

Preplant N applied using UAN (32-0-0) 4/6/2016
Sidedress N applied using UAN (32-0-0)
6/15/2016

Std. dev, standard deviation

**Table 7**. Treatment structure and grain yield and grain nitrogen uptake, Lake Carl Blackwell, OK 2016

| Trt | Preplant N (kg N ha-1) | Sidedress N (kg N ha-1) | Grain Yield Mg ha -1 | | NVDI 6/16/2016 | | NVDI 6/28/2016 | | Grain N uptake kg ha-1 | | Total Nitrogen % | | NUE % | | Cummulative Heat Units | Precipitation (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Stddev | Mean | Stddev | Mean | Stddev | Mean | Stddev | Mean | Stddev | Mean | Stddev | | |
| 1 | 0 | 0 | 5.30$^{ED}$ | 1.0 | 0.85 | 0.04 | 0.82 | 0.03 | 49.0 | 11.6 | 0.99 | 0.07 | 0 | 0 | 2344.50 | 1064 |
| 2 | 17 | 0 | 7.20$^{BC}$ | 0.4 | 0.81 | 0.05 | 0.82 | 0.03 | 72.8 | 7.0 | 1.09 | 0.09 | 1.41 | 0.42 | | |
| 3 | 34 | 0 | 6.70$^{DC}$ | 0.9 | 0.81 | 0.02 | 0.82 | 0.00 | 64.4 | 11.7 | 1.03 | 0.05 | 0.46 | 0.35 | | |
| 4 | 50 | 0 | 7.80$^{BAC}$ | 0.3 | 0.81 | 0.01 | 0.82 | 0.02 | 79.6 | 5.9 | 1.11 | 0.04 | 0.61 | 0.12 | | |
| 5 | 67 | 0 | 8.90$^{BA}$ | 0.4 | 0.82 | 0.05 | 0.82 | 0.02 | 102.5 | 7.5 | 1.25 | 0.07 | 0.80 | 0.11 | | |
| 6 | 101 | 0 | 8.60$^{BA}$ | 0.6 | 0.81 | 0.04 | 0.81 | 0.02 | 94.6 | 5.2 | 1.19 | 0.04 | 0.45 | 0.05 | | |
| 7 | 0 | 34 | 5.00$^{E}$ | 0.3 | 0.82 | 0.02 | 0.78 | 0.02 | 56.3 | 5.9 | 1.21 | 0.06 | 0.21 | 0.17 | | |
| 8 | 17 | 34 | 8.00$^{BAC}$ | 0.6 | 0.81 | 0.04 | 0.83 | 0.00 | 88.2 | 8.3 | 1.20 | 0.02 | 0.78 | 0.17 | | |
| 9 | 34 | 34 | 7.30$^{BC}$ | 0.8 | 0.81 | 0.03 | 0.79 | 0.02 | 79.4 | 12.4 | 1.17 | 0.07 | 0.45 | 0.18 | | |
| 10 | 50 | 34 | 8.10$^{BAC}$ | 0.9 | 0.82 | 0.02 | 0.81 | 0.03 | 94.5 | 6.9 | 1.27 | 0.05 | 0.54 | 0.08 | | |
| 11 | 67 | 34 | 9.30$^{A}$ | 0.1 | 0.80 | 0.01 | 0.83 | 0.02 | 117.7 | 4.5 | 1.38 | 0.04 | 0.68 | 0.04 | | |
| 12 | 101 | 34 | 8.70$^{BA}$ | 0.7 | 0.83 | 0.02 | 0.81 | 0.02 | 107.9 | 10.5 | 1.34 | 0.05 | 0.44 | 0.08 | | |
| LSD | | | 0.33 | | | | | | | | | | | | | |
| SED | | | 0.47 | | | | | | | | | | | | | |

Preplant N applied using UAN (32-0-0)
4/15/2016

Sidedress N applied using UAN (32-0-0) 6/16/2016

Std. dev, standard deviation

**Table 8**. Seasonal rainfall from preplant nitrogen application to harvest, EFAW, OK, 2016.

| Month | Total Rainfall (mm) |
|---|---|
| April | 141 |
| May | 73 |
| June | 49 |
| July | 142 |
| August | 5.30 |
| Total | 411 |

**Table 9**. Seasonal rainfall from preplant nitrogen application to harvest, Lake Carl Blackwell, OK, 2016.

| Month | Total Rainfall (mm) |
|---|---|
| April | 113 |
| May | 77 |
| June | 95 |
| July | 126 |
| August | 0.00 |
| Total | 411 |

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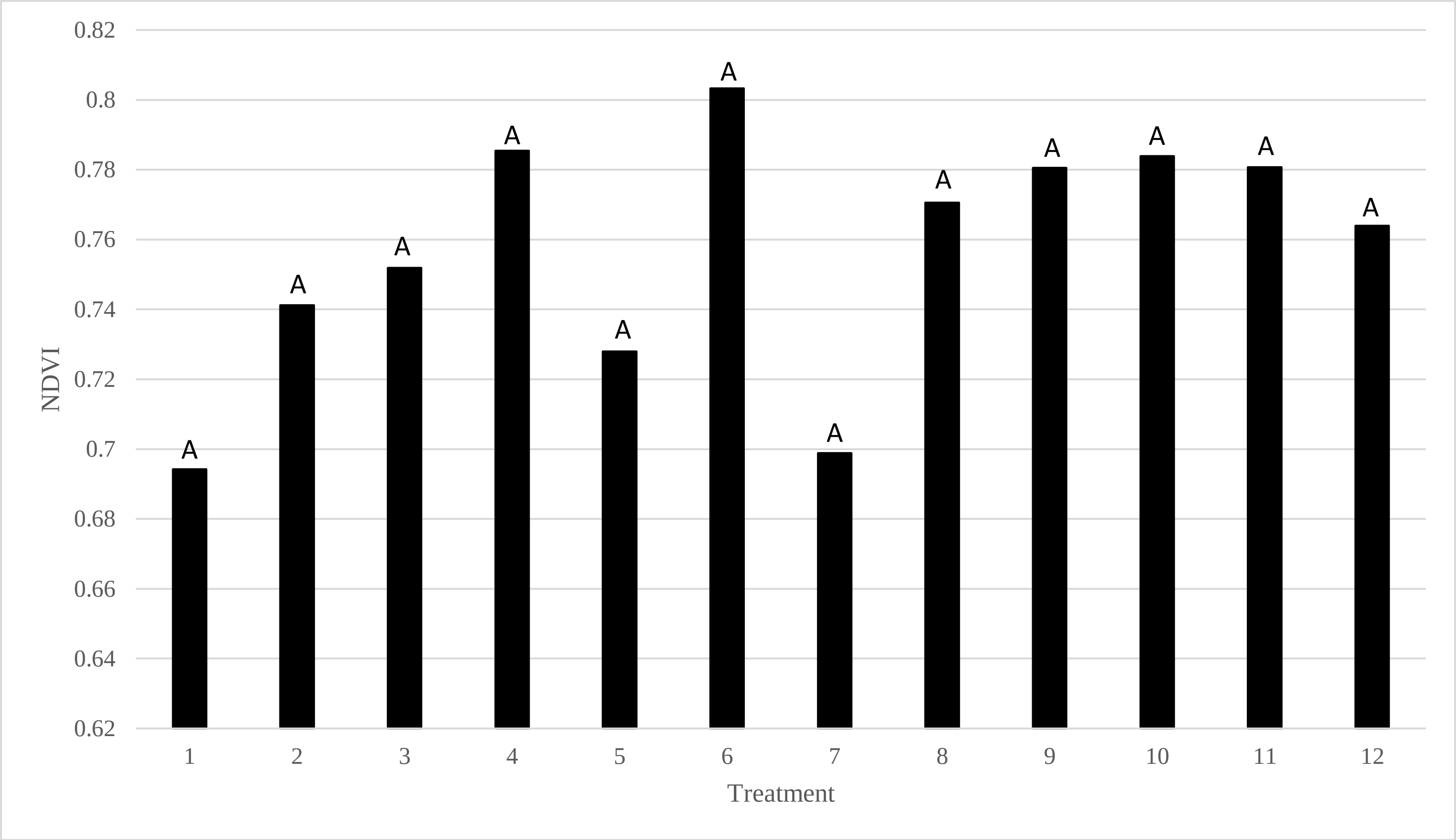
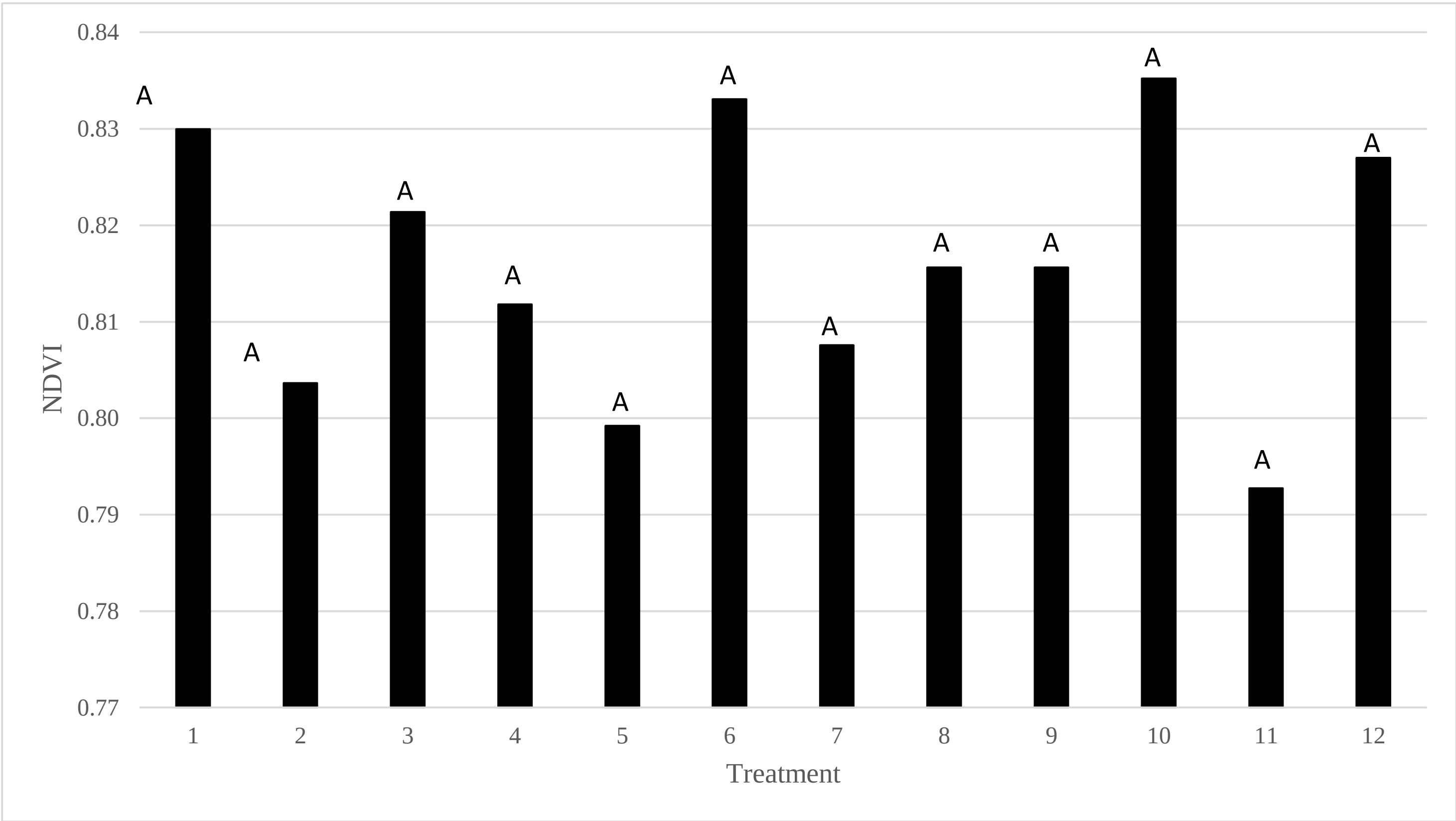
**Figure 1**. Average NDVI readings for each individual treatment at 512 total degree day heat units, EFAW, OK, 2016.



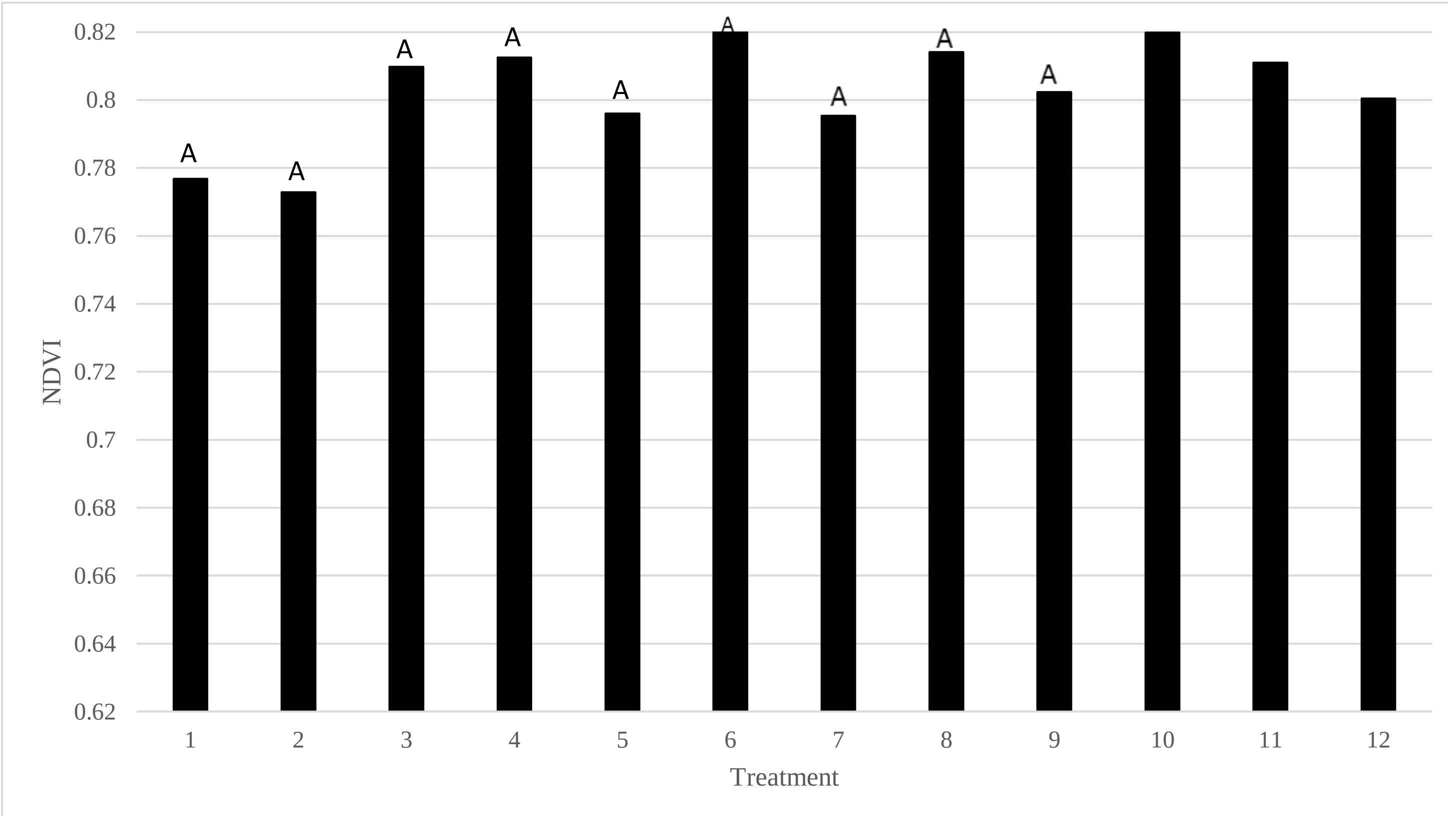

Means following by the same letter are not significantly different at the 0.05 probability level.

**Figure 2**. Average NDVI readings for each individual treatment at 732 total degree day heat units, Lake Carl Blackwell, OK, 2016.



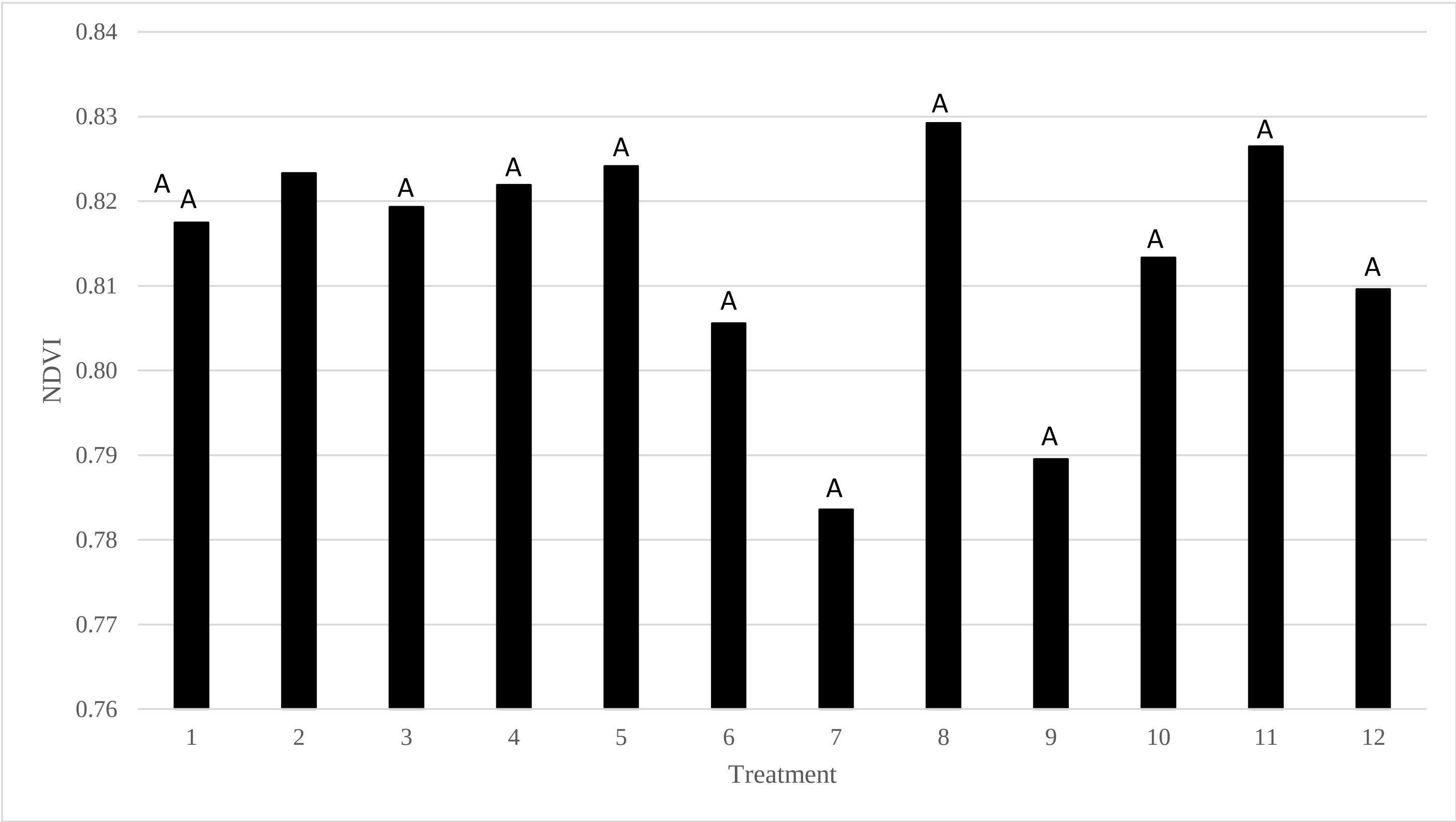

Means following by the same letter are not significantly different at the 0.05 probability level.

**Figure 3.** Average NDVI readings for each individual treatment at 1341 total degree day heat units, EFAW, OK, 2016.




Means following by the same letter are not significantly different at the 0.05 probability level.

**Figure 4**. Average NDVI readings for each individual treatment at 1080 total degree day heat units, Lake Carl Blackwell, OK, 2016.




Means following by the same letter are not significantly different at the 0.05 probability level.

**Figure 6.** Water balance from planting to harvest, EFAW, OK 2016

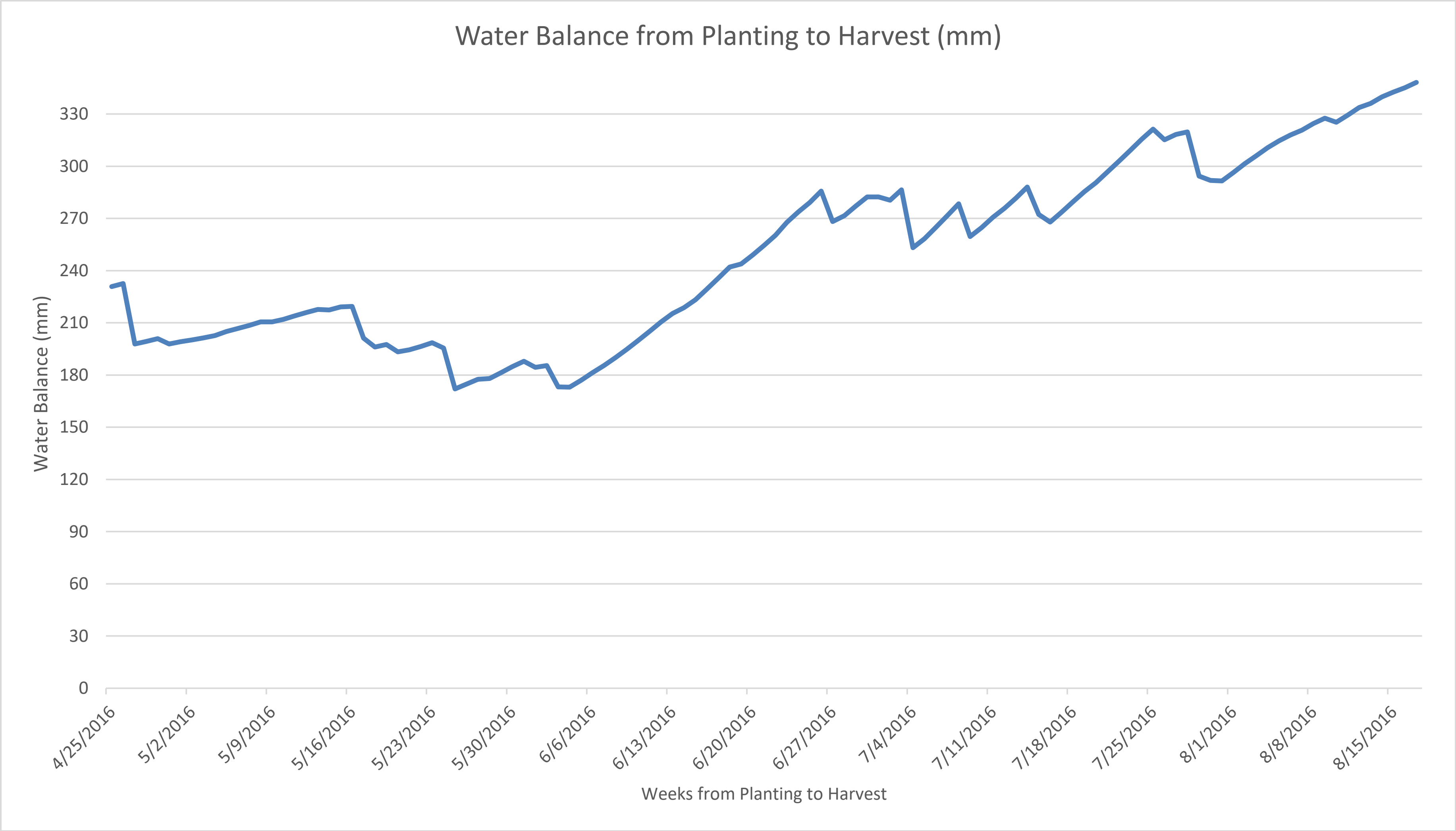
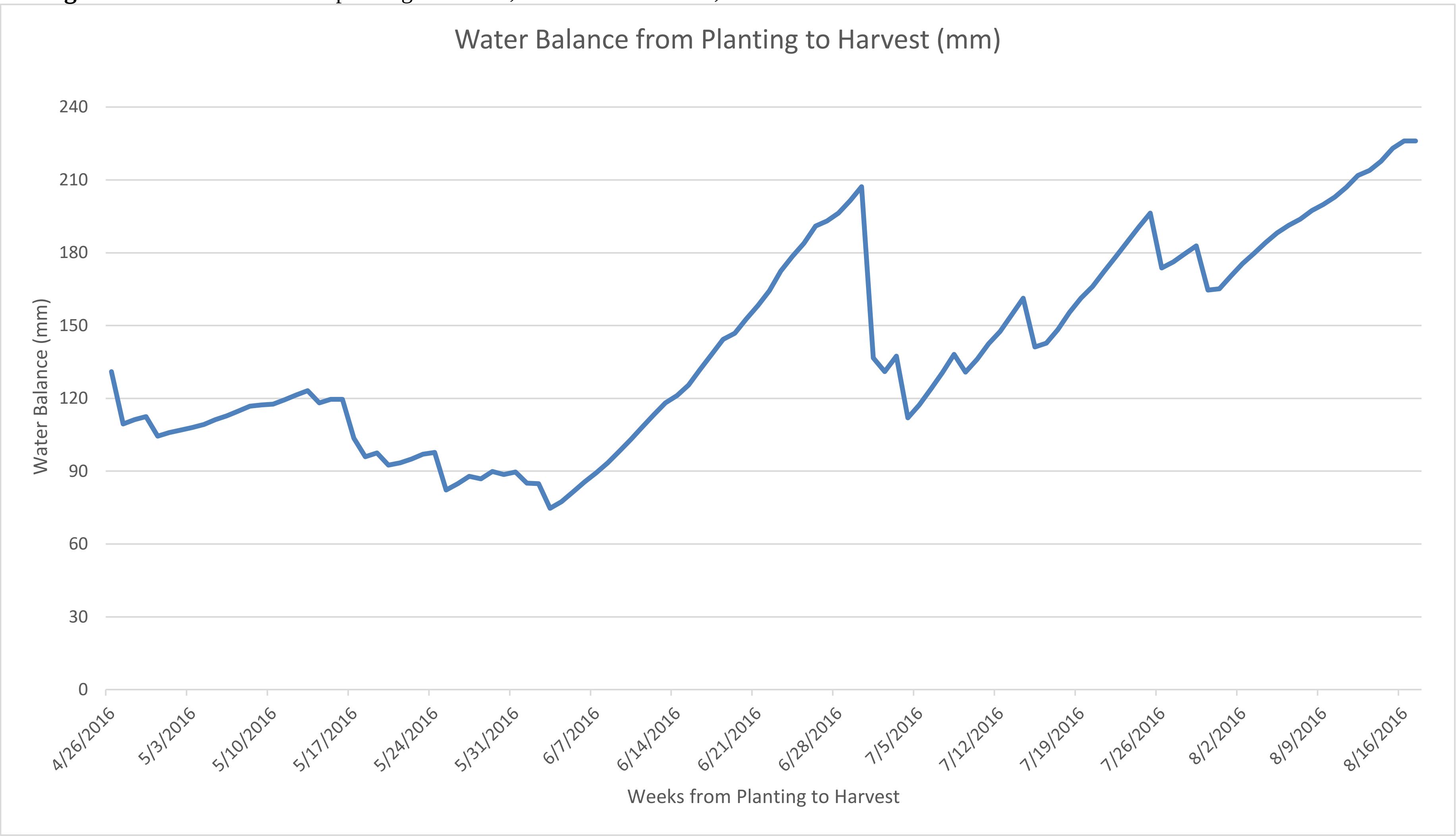


**Figure 6.** Water balance from planting to harvest, Lake Carl Blackwell, OK 2016



# APPENDICES

**Appendix 1**. Treatment structure and grain yield and grain nitrogen uptake, EFAW, OK 2016

| Trt | Preplant N (kg N ha-1) | Sidedress N (kg N ha-1) | Grain Yield Mg ha -1 | | NDVI (514 HU) | | NDVI (739 HU) | | NDVI (852 HU) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Stddev | Mean | Stddev | Mean | Stddev | Mean | Stddev |
| 1 | 0 | 0 | 3653.91 | 1741.13 | 0.35 | 0.02 | 0.53 | 0.02 | 0.75 | 0.06 |
| 2 | 7 | 0 | 3167.69 | 1883.54 | 0.36 | 0.07 | 0.50 | 0.09 | 0.67 | 0.11 |
| 3 | 14 | 0 | 3098.10 | 1021.23 | 0.40 | 0.06 | 0.55 | 0.10 | 0.78 | 0.05 |
| 4 | 27 | 0 | 3604.18 | 1542.06 | 0.38 | 0.04 | 0.54 | 0.04 | 0.77 | 0.06 |
| 5 | 41 | 0 | 3173.45 | 1564.04 | 0.39 | 0.04 | 0.59 | 0.08 | 0.81 | 0.01 |
| 6 | 54 | 0 | 5598.03 | 839.21 | 0.40 | 0.01 | 0.58 | 0.06 | 0.83 | 0.02 |
| 7 | 68 | 0 | 5272.37 | 1289.50 | 0.37 | 0.03 | 0.55 | 0.03 | 0.80 | 0.05 |
| 8 | 0 | 68 | 5505.24 | 280.43 | 0.32 | 0.00 | 0.46 | 0.04 | 0.74 | 0.05 |
| 9 | 7 | 68 | 5275.70 | 942.79 | 0.35 | 0.02 | 0.53 | 0.03 | 0.78 | 0.04 |
| 10 | 14 | 68 | 5104.40 | 2717.23 | 0.33 | 0.07 | 0.45 | 0.12 | 0.70 | 0.20 |
| 11 | 27 | 68 | 5426.11 | 1090.72 | 0.40 | 0.03 | 0.60 | 0.09 | 0.76 | 0.04 |
| 12 | 41 | 68 | 6095.86 | 251.11 | 0.39 | 0.04 | 0.56 | 0.04 | 0.77 | 0.02 |
| 13 | 54 | 68 | 5570.05 | 1443.55 | 0.39 | 0.08 | 0.57 | 0.14 | 0.78 | 0.09 |
| 14 | 68 | 68 | 6702.48 | 795.12 | 0.40 | 0.04 | 0.60 | 0.02 | 0.80 | 0.01 |

Preplant N applied using UAN (32-0-0)
4/06/2016

Sidedress N applied using UAN (32-0-0) 6/01/2016

Std. dev, standard deviation

HU, total degree day heat units

**Appendix 2**. Treatment structure and grain yield and grain nitrogen uptake, Lake Carl Blackwell 1.1, OK 2016

| Trt | Preplant N (kg N ha-1) | Sidedress N (kg N ha-1) | Grain Yield Mg ha -1 | | NDVI (468 HU) | | NDVI (597 HU) | | NDVI (835 HU) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Stddev | Mean | Stddev | Mean | Stddev | Mean | Stddev |
| 1 | 0 | 0 | 1591.25 | 749.41 | 0.38 | 0.04 | 0.83 | 0.02 | 0.72 | 0.03 |
| 2 | 7 | 0 | 2039.25 | 336.48 | 0.42 | 0.06 | 0.82 | 0.04 | 0.75 | 0.08 |
| 3 | 14 | 0 | 2336.47 | 320.72 | 0.45 | 0.04 | 0.81 | 0.03 | 0.80 | 0.09 |
| 4 | 27 | 0 | 2586.17 | 648.06 | 0.47 | 0.03 | 0.79 | 0.10 | 0.77 | 0.02 |
| 5 | 41 | 0 | 2238.27 | 299.17 | 0.46 | 0.03 | 0.82 | 0.04 | 0.77 | 0.02 |
| 6 | 54 | 0 | 2445.29 | 483.85 | 0.48 | 0.03 | 0.81 | 0.07 | 0.80 | 0.06 |
| 7 | 68 | 0 | 2232.20 | 459.96 | 0.47 | 0.07 | 0.83 | 0.01 | 0.78 | 0.05 |
| 8 | 0 | 68 | 2723.93 | 1038.65 | 0.39 | 0.06 | 0.81 | 0.04 | 0.80 | 0.10 |
| 9 | 7 | 68 | 2857.40 | 444.08 | 0.42 | 0.06 | 0.81 | 0.05 | 0.80 | 0.07 |
| 10 | 14 | 68 | 2142.05 | 590.56 | 0.43 | 0.08 | 0.85 | 0.02 | 0.79 | 0.06 |
| 11 | 27 | 68 | 3038.79 | 979.74 | 0.41 | 0.05 | 0.83 | 0.00 | 0.78 | 0.04 |
| 12 | 41 | 68 | 2954.79 | 582.20 | 0.45 | 0.04 | 0.75 | 0.03 | 0.82 | 0.08 |
| 13 | 54 | 68 | 2829.38 | 842.59 | 0.43 | 0.09 | 0.85 | 0.01 | 0.78 | 0.05 |
| 14 | 68 | 68 | 2105.47 | 758.34 | 0.45 | 0.09 | 0.80 | 0.06 | 0.78 | 0.03 |

Preplant N applied using UAN (32-0-0) 4/07/2016

Sidedress N applied using UAN (32-0-0) 5/23/2016

Std. dev, standard deviation

HU, total degree day heat units

**Appendix 3**. Treatment structure and grain yield and NDVI values, Lake Carl Blackwell 1.2, OK 2016

| Trt | Preplant N (kg N ha-1) | Sidedress N (kg N ha-1) | Grain Yield Mg ha -1 | | NDVI (468 HU) | | NDVI (597 HU) | | NDVI (835 HU) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Stddev | Mean | Stddev | Mean | Stddev | Mean | Stddev |
| 1 | 0 | 0 | 2562.45 | 584.97 | 0.33 | 0.05 | 0.71 | 0.05 | 0.75 | 0.03 |
| 2 | 7 | 0 | 2764.01 | 873.76 | 0.35 | 0.03 | 0.74 | 0.03 | 0.76 | 0.02 |
| 3 | 14 | 0 | 2789.59 | 986.00 | 0.37 | 0.02 | 0.76 | 0.02 | 0.80 | 0.05 |
| 4 | 27 | 0 | 3168.06 | 985.19 | 0.39 | 0.02 | 0.79 | 0.02 | 0.82 | 0.06 |
| 5 | 41 | 0 | 3759.46 | 662.17 | 0.37 | 0.06 | 0.79 | 0.03 | 0.78 | 0.01 |
| 6 | 54 | 0 | 4249.53 | 310.27 | 0.39 | 0.05 | 0.81 | 0.04 | 0.82 | 0.01 |
| 7 | 68 | 0 | 5372.36 | 637.95 | 0.44 | 0.03 | 0.84 | 0.02 | 0.86 | 0.02 |
| 8 | 0 | 68 | 3699.65 | 755.78 | 0.33 | 0.03 | 0.77 | 0.04 | 0.79 | 0.01 |
| 9 | 7 | 68 | 4345.60 | 583.27 | 0.39 | 0.06 | 0.78 | 0.07 | 0.81 | 0.06 |
| 10 | 14 | 68 | 4783.23 | 1198.83 | 0.40 | 0.07 | 0.82 | 0.03 | 0.81 | 0.03 |
| 11 | 27 | 68 | 5015.52 | 125.67 | 0.38 | 0.04 | 0.80 | 0.03 | 0.85 | 0.01 |
| 12 | 41 | 68 | 5277.71 | 716.39 | 0.39 | 0.05 | 0.82 | 0.03 | 0.84 | 0.02 |
| 13 | 54 | 68 | 5324.21 | 1653.56 | 0.40 | 0.05 | 0.82 | 0.04 | 0.84 | 0.02 |
| 14 | 68 | 68 | 6072.78 | 1561.35 | 0.41 | 0.05 | 0.82 | 0.03 | 0.82 | 0.03 |

Preplant N applied using UAN (32-0-0) 4/07/2016

Sidedress N applied using UAN (32-0-0) 5/23/2016

Std. dev, standard deviation

HU, total degree day heat units

# VITA

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