EFFECT OF APPLYING NITROGEN WITH

SORGHUM SEED (*SORGHUM BICOLOR*) ON

EMERGENCE AND FINAL GRAIN YIELD

By

ELIZABETH MARY EICKHOFF

Bachelor of Science in Agronomy and Agricultural
Business
Northwest Missouri State University
Maryville, MO
2017

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2018

EFFECT OF APPLYING NITROGEN WITH

SORGHUM SEED *(SORGHUM BICOLOR)* ON

EMERGENCE AND FINAL GRAIN YIELD

Thesis Approved:

Dr. William Raun

Thesis Adviser

Dr. Hailin Zhang

Dr. Misha Manuchehri

Name: ELIZABETH MARY EICKHOFF

Date of Degree: DECEMBER, 2018

Title of Study: EFFECT OF APPLYING NITROGEN WITH SORGHUM SEED (SORGHUM BICOLOR) ON EMERGENCE AND FINAL GRAIN YIELD

Major Field: PLANT AND SOIL SCIENCE

Abstract: Sorghum *(Sorghum bicolor)* is becoming an important crop due to its drought tolerance. High production levels of this crop could aid in fulfilling growing food demands. This study was conducted to determine the amount of nitrogen (N) fertilizer that could be applied in furrow with sorghum seed while minimizing decreases in crop emergence and maximizing grain yield. Data was collected in 2017 at two locations and in 2018 at three locations in Oklahoma. Emergence counts were taken frequently to evaluate plant stands and yield was collected at harvest. Urea was used as the N source where four different rates (0, 10, 20, 30 kg N ha^{-1}) were applied at three seeding rates (101,222, 177,700, 216,330 seeds ha^{-1}). Soil moisture levels were monitored at planting due to its influencing effect on the level of salt damage to developing seedlings. In 2017, high rainfall within two days after planting had a prominent impact on the minimal salt injury observed in the emergence values compared to 2018. On average, applying 30 kg N ha^{-1} with the seed resulted in emergence losses of 51%, where 20 kg N ha^{-1} and 10 kg N ha^{-1} resulted in losses of 38% and 29% respectively. The check treatments where 0 kg N ha^{-1} was applied with the seed resulted in an average 13% loss in emergence. Even though major decreases in emergence were noted, seeding-N-rate did not have a significant effect on yield levels. It is recommended that less than 10 kg N ha^{-1} be applied with sorghum seed to minimize emergence loss.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Sorghum ranks as one of the top five cereal crops in the world (FAO, 2014). World production of sorghum totaled 68 million tonnes that were harvested from 45 million ha in 2014 (FAO, 2014). This cereal originated in Africa as much as 7,000 years ago and was introduced to the United States through the slave trade during the 1700-1800's (ICRISAT, 2005). Sorghum's high efficiency of water use makes it a well-suited crop for multiple environments ("All About Sorghum", 2016). In the United States 2.7 million ha of sorghum were planted with a total of 12 million tones harvested in 2016 ("All About Sorghum", 2016).

Sorghum is one of the world's most vital crops because of its sustainability with drought tolerance and its variety of uses to meet the needs of a growing world. In recent years it has expanded and has become a fuel source for ethanol, to keep up with the ever expanding ethanol production (Wang et. al. 2008). The same amount of ethanol can be produced from one bushel of sorghum compared to other oil crops; the difference being sorghum only uses one third of the water ("Sorghum 101", 2016). With the changing food markets in the United States, sorghum is also becoming a desirable product for individuals with gluten sensitivities because it is a gluten free crop ("Sorghum 101", 2016). Improving the yield of sorghum is a constant goal in order to meet these growing demands.

One of the predominant factors that affect sorghum yields is seeding rates, which vary depending on the environment in which it is grown. Many specialists recommend the use of a narrow row spacing such as 50.8 cm rows (Moldenhauer et al., 1957: Bond et al., 1964). This helps to control weed pressure by achieving a quicker canopy closure, which also helps to reduce soil moisture evaporation (Moldenhauer et al., 1957; Bond et al., 1964). Appropriate seeding rates are needed to achieve maximum yield. Nonetheless, a higher seeding rate could cause increased competition negatively affecting yield (Snider et al., 2011).

Improving sorghum yield begins with nutrient management. Nitrogen (N) is generally the most limiting nutrient in crop production (Fageria and Baligar, 2005). The correct amount of N must be applied at the right times to maximize yield. A shortage of nutrients at critical growth stages will adversely affect crop yield. The amount of N needed is dependent upon several factors such as yield goal, soil test information, and average rainfall. All these variables must be considered when making an accurate recommendation.

Starter fertilizers are becoming increasingly popular in today's agriculture industry (Deibert, 1994). Applying higher rates of starter fertilizer can reduce the number of field passes and help reduce soil erosion and maintain surface residue (Deibert, 1994). Often for phosphorus (P) fertilizer, band applications are used following the 2x2 rule; meaning placing a strip of fertilizer, 2 inches beside and 2 inches below the seed furrow (Gelderman, 2007). Although this has proven to be an effective practice, there are also disadvantages. By placing fertilizer in bands beside the furrow, more residue is removed from the surface and it adds more time and cost. It is because of these disadvantages that farmers are looking towards placing fertilizer with the seed (Gelderman, 2007). According to Gelderman's review (2007), placing fertilizer with the seed can be just as beneficial if not better than the traditional 2x2 placement (Gordon and Whitney, 2000; Ham et al., 1973; Nelson and Randall, 1968). If urea is applied to the soil surface and not incorporated, 40% or more of the nitrogen can be lost as NH_3 (Fowler and Brydon, 1989; Hargrove et al., 1977; Raun and Johnson, 1999). To reduce these losses, applying N with the seed can possibly improve nitrogen use efficiency (NUE). The important question is how much N can be applied with sorghum seed that results in limited adverse effects on emergence. A similar study in maize where different rates and sources of N were applied with the seed, Raun et al. (1986), reported that N source did not affect seed germination but amounts of N fertilizer can. Furthermore, it was concluded that the salt index method was effective in determining the adverse effects of the rate and source of fertilizer placed with corn seed.

Objective

The objective of this study is to evaluate the impact of different rates of N applied with sorghum seed at planting on seedling emergence, and final grain yield at different planting rates.

CHAPTER II

REVIEW OF LITERATURE

Optimum Seeding Rates of Sorghum

Seeding rates can vary for grain sorghum production depending on rainfall and soil type. In South Texas, work by Stichler et al. (1997) recommended seeding rates of 74,100 to 247,000 plants per ha depending on moisture availability. The average annual rainfall for Stillwater, OK is 94.72 cm (37 in) according to (U.S. Climate Data). Work from Kansas State University recommended seeding rates of 172,900 plants per ha in areas receiving more than 81.28 cm of annual rainfall (Shroyer et al. 1996). In addition, Snider et al. (2011) showed that seeding rates of 116,000 seeds per ha resulted in optimum productivity. Furthermore, in the same study it was found that increasing population rates above 116,000 seeds per ha did not change biomass production and at times decreased overall yield. Therefore, 116,000 seeds per ha could be considered a target rate for photoperiod-sensitive sorghum in a non-irrigated environment (Snider et al. 2011). Stichler et al. (1997) found that only 75% of the seeds planted survived and emerged, which needs to be considered in order to achieve the desired stand.

Row spacing is an additional factor in determining optimum planting rates for grain sorghum production. Narrow row spacing is desirable for production as it promotes soil moisture conservation while also reducing erosion (Moldenhauer et al., 1957). Narrow row spacings are also reported to result in faster canopy closure which can reduce weed control expenses (Moldenhauer et al., 1957). According to Bond et al. (1964), soil moisture was a key factor in whether narrower rows produced more grain than wide row production. In their study, 101.6 cm rows produced a higher yield compared to 50.8 cm rows when moisture reserves were 12.7 cm or less. When moisture levels are higher however, the narrower row spacing produced higher yield (Bond et al., 1964). Alternatively, Snider et al. (2011) reported increased yields with narrower row spacing at each of their locations for the years studied. A possible reason for this is increased light interception (Steiner, 1986). Decreased plant competition within the row could also contribute to an increase in grain yield (De Bruin and Pederson, 2008).

Nitrogen Rates Needed for Grain Sorghum Production

For grain sorghum production, N is the most limiting nutrient (Fageria and Baligar, 2005). Nitrogen is a vital nutrient in plant production. Nitrogen is an important component in amino acids which are utilized for the synthesis of enzymes making it important for plant growth (Hirel et al., 2007). In the soil, N presents in one of three forms: organic compounds, ammonium, and nitrate (Mosaic Crop Nutrition, 2016). Several internal and external N cycling processes occur within the soil. External processes are those which add or remove N from the system either through loss pathways or depositions (Hart et al., 1994). Internal processes are those that occur within the soil body itself. Such processes include: plant assimilation of N, N mineralization and nitrification (Hart et al., 1994). Most of the soil N is often in organic forms which are not readily available for plant uptake (Stevenson, 1982). Previous studies have shown that a "priming effect" can be observed in soils by when fertilizer N is added. Work by Westerman and Kurtz (1973) showed that additions of N fertilizer can increase soil N uptake by as much as 45% in some cases. The reason behind this is that the added N promotes more soil microbial activity which leads to higher N mineralization rates. Although small amounts of organic compounds will be converted to available N by soil microorganisms, it is important that adequate N rates are applied through fertilizer to meet the demands of the crop. When looking at N rates for grain sorghum, they can vary greatly depending on anticipated rainfall and productivity potential (McClure, 2018). According to McClure from DuPont Pioneer (2018), 33.6 - 67.3 kg ha^{-1} could be sufficient enough N supply in drought-like growing conditions for grain sorghum.

Nitrogen needs of the crop are tied to yield goals and productivity potential. In 2016 the average grain yield for sorghum was 4.08 Mg ha^{-1} (65 bu ac^{-1}) in Payne County Oklahoma (Oklahoma Agricultural Statistics, 2016). When looking at the Oklahoma region, 67.3 - 84.1 kg N ha^{-1} is needed to achieve a yield goal of 3.89 - 4.77 Mg ha^{-1} (62 - 76 bu ac^{-1}) (Arnall, 2015). Yield goals as high as 5.9 - 7.41 Mg ha^{-1} (94 - 118 bu ac^{-1}) require anywhere from 123.3 - 168.1 kg N ha^{-1} to achieve that level of grain production (Arnall, 2015). Location is key to determine optimum N rates needed for profitable production.

Not only is it important to apply the correct rates of N, it also is critical that it is applied in a way in which it can be readily available to the plant when needed. The rapid growth stage in sorghum occurs between 21-40 days after planting (KSU Production Handbook, 1998). According to research from Kansas State University, sidedress applications should be applied about 20 days after emergence. During this stage 33% of the total N required by the plant is utilized (KSU Production Handbook, 1998). Early bloom stage occurs next at 41-60 days after emergence in which 32% of the total N is used during this this period (KSU Production Handbook, 1998). Nitrogen must not be limiting during these growth stages. Between 30 to 40 days after emergence the potential growth of the grain head is determined (KSU Production Handbook, 1998). If N is limited at this critical stage, yield potential decreases.

Applying Nitrogen with the Seed

Applying starter fertilizers at planting is becoming more of a common practice today to boost yields (Deibert, 1994). Research has looked at different placement options when applying starter fertilizer at the beginning of the growing season. Placing fertilizer in furrow can be referred to as 'pop up' fertilizer and is intended to help boost early plant growth by providing available nutrients immediately in the seedling zone (Niehues et al., 2004). Applying higher rates of N with the seed can reduce the number of field passes and promote conservation tillage practices which benefit soil water management (Deibert, 1994). Starter fertilizer applications are often found to be more beneficial in a no-till production system compared to conventional tillage systems (Mengel et al., 1982).

A previous study concerning different placements of starter fertilizer applications in maize showed increases in yield when starter fertilizers of N, P, and K were applied. This study noted significant grain yield increases in all methods of placement evaluated which included direct seed contact, over row dribble, and subsurface band. However, when N was placed in furrow, yield increases were only noted where less than 22 kg N ha^{-1} was applied (Niehues et al., 2004). Applications above 22 kg N ha^{-1} also significantly decreased plant stands. Work by Gordon and Whitney (1995) with grain sorghum N and P combination fertilizers showed that plant growth and grain yield can be improved by using N and P starter fertilizers at various rate combinations. However, the placement method in this study was a 2 x 2, meaning banding below the surface at 2 inches below and 2 inches to the side of the seed furrow.

The major concern of applying N with the seed is reducing germination and emergence levels. Salt injury to plants occurs when fertilizers dissolve in the soil thus increasing the soil's salt concentration (University of Illinois, 2010). A higher salt concentration in the soil causes a higher osmotic potential which makes it difficult for the seeds to take in water from the soil (University of Illinois, 2010). Salt index measurements can provide the producer with a way to compare fertilizer products in order to determine which ones might be more problematic in terms of salt injury to the seed (University of Illinois, 2010). The salt index of urea is 74.4 whereas anhydrous ammonia has an index of 47.1 (University of Illinois, 2010). Subsequently, urea has a significantly higher risk of seedling injury. It is important to recognize there are multiple factors that can affect how much salt injury will occur to the seed and one cannot just base injury level on the salt index. Factors such as soil moisture, the fertilizer's location relative to the seed, crop type, and soil texture all influence the degree of injury to the seedling (University of Illinois, 2010). In addition to salt injury, applying N with the seed can also adversely affect germination through ammonia toxicity (Diebert, 1994). Anhydrous ammonia would be most harmful to seed germination with urea being a close second because when urea is applied, it quickly hydrolyzes to ammonium carbonate.

Urea is a beneficial fertilizer for N but it can have adverse effects on seed germination and early plant growth (Bremner and Krogmeier, 1989). Work by Bremner and Krogmeier, (1989) showed that the adverse effects on plant growth from urea are due to the ammonia formed through the hydrolysis of urea rather than impurities found in urea fertilizer. When 1.0 mg N g^{-1} of soil was added in the form of urea, germination was 0% in each of the crops that were studied (Bremner and Krogmeier, 1989). Reducing the N level to 0.5 mg g^{-1} of soil, germination was significantly improved to a percentage of 63-85 depending on the crop.

Previous studies have evaluated the appropriate in furrow N rates that can be applied with different crops that results in minimal germination reductions. For small grain production, a general rule for applying N with the seed is not to apply more than 22.4 to 33.6 kg N plus K_2O ha^{-1} so that damage to the seed is minimal (Deibert, 1994). Information from Texas A&M University cautions not to use over 5.6 kg N ha^{-1} to avoid salt injury on the developing sorghum seedlings (Stichler et al., 1997). Under irrigated conditions, or locations with high average rainfall, up to 11.2 kg N per ha^{-1} may be applied with minimal injury (Stichler et al., 1997). A soybean study found that rates of 3.4 kg ha^{-1} of UAN applied in furrow significantly decreased emergence rates on a silty loam soil (Hoeft et al., 2008). Furthermore, that study confirmed an inverse relationship between salt index and emergence. Work by Raun et al. (1986) found moisture at planting to be an influencing factor in the crop's germination percentage when applying fertilizer with maize seed. In their experiment the fertilizer rates of 0, 6, 11.2, 16.8, 22.4 kg ha^{-1} (0, 5, 10, 15, and 20 lb ac^{-1}) were used. Four different fertilizer sources were used as well. It was found that fertilizer source made little to no difference in the effect on germination of maize but rates made noticeable differences. Fertilizer rates that exceed 7.8 kg salt ($N + K_2O$) ha^{-1} (7 lb ac^{-1}) with the seed will most likely cause intolerable losses in maize stands (Raun et al., 1986). The common recommendation of applying 5.6 to 7.8 kg salt ha^{-1} (5 to 7 lb ac^{-1}) will present low risk of seedling injury (Raun et al., 1986).

Other research has looked at ways to reduce salt injury to cereal crops by adding small amounts of urease inhibitors to the fertilizer placed with the seed. Work by Bremner and Krogmeier (1988) showed that the adverse effects of urea on seedling emergence can be reduced and even eliminated by adding different urease inhibitors. Results with sorghum in this study showed that the addition of N-(diaminophosphinyl) benzamide was the superior inhibitor in that it eliminated germination decreases (Bremner and Krogmeier, 1988). They also noted that soil type can be a major factor in how beneficial an inhibitor is.

CHAPTER III

METHODOLOGY

Materials & Methods

This study was established at two locations in 2017 and three locations in 2018. Locations during 2017 season were Lake Carl Blackwell (LCB) and Efaw, both research stations for Oklahoma State University near Stillwater, OK. Those same sites were used in 2018 with the addition of Hennessey, OK as the third site. The LCB trial site is on a Port-Oscar silty clay loam (Fine, silty, mixed, thermic Cumulic Haplustoll) soil that is occasionally flooded (Payne County Soil Survey, 2018). The Efaw location is on a Norge loam (Fine-silty, mixed, thermic Udic Paleustoll) soil (Payne County Soil Survey, 2018). Soil classification at the Hennessey, OK location is a Bethany silt loam (Fine, mixed, thermic Pachic Paleustolls) (Kingfisher County Soil Survey, 2018). Composite preplant soil samples by replication were taken at each site with results listed in Table 1. Cores were taken fifteen cm deep with fifteen cores per replication for all site years.

This trial consisted of fourteen treatments with three replications. A randomized complete block design was used for this study. Population rate and seeding N rate were the two independent variables used in the treatment structure outlined in Table 2. Three populations were used along with three different N rates. Two additional treatments were added that contained no urea application with the seed (13 and 14). Treatment 13 had a preplant application with 30 kg N ha^{-1} applied in a dribble surface band using UAN as the source. Treatment 14 was a midseason application with 30 kg N ha^{-1} applied in a dribble surface band using UAN as the source. The purpose of these extra two treatments was to allow for cross comparison of different timing of application and or placement of N with the seed compared to surface applied.

Field Methods

Trials were planted using a John Deere Max Emerge 2 7300 four row planter. Row spacing for this study was 76 cm (30 in). Each treatment was planted with four rows in a 3.05 m by 6.10 m (10 by 20 ft) plot. Alleys in between replications measured 3.05 m (10 ft). Total trial area including all fourteen treatments with three replications was 1,041.88 m^2 (11,200 ft^2).

Appropriate gear settings were used to achieve the different population rates. Before planting, a dry run with the planter was performed to determine that the planter was dropping the appropriate amount of seeds. Seeds were collected in a pan while the tractor was stationary to verify the correct number of seeds were indeed being planted. However, in the field setting there is always some room for planter error in that it will not always drop the exact number of seeds every time especially since sorghum seed is very small. Also, prior to planting, the dry fertilizer boxes were calibrated to determine the correct gear box settings in order to applying the seeding-N-rates of 10, 20, and 30 kg N ha^{-1}. The dry fertilizer box gear settings can vary depending on a number of factors, therefore calibrations were performed each season to ensure accuracy. No supplemental fertilizers were used in addition to the urea fertilizer applied with the seed or the UAN surface applied in the two additional treatments. Appropriate herbicide and insecticide applications were made as needed.

Data variables collected and used for analysis were emergence, Normalized Difference Vegetative Index (NDVI) readings, and final grain yield. Tables 3 and 4 outline the field activities preformed for the 2017 and 2018 growing seasons, respectively. All data collected were obtained from the middle two rows of each individual plot. To evaluate the impact of in-furrow urea, emergence counts were taken frequently until the V4 growth stage. When determining the final emergence percentage, the last stand count of the center two rows taken was averaged and divided by the number of plants that were planted in a single row based on the set population rate per ha. This was used to determine the emergence percentage of sorghum and to decipher statistical differences between the different rates of urea placed with the seed and/or how the population rates interacted with those variables.

Throughout the growing season, Normalized Difference Vegetative Index (NDVI) readings were taken using the GreenSeeker^{TM} sensor. NDVI is calculated as:

$$NDVI= [(NIR-Red) / (NIR+Red)]$$

Wavelengths for NIR and Red are (780 nm) and (671 nm) respectively (Mullen et al., 2003). NDVI readings are important to this study in that they can be used to estimate plant biomass which can be used as an indicator of plant health and vigor. It has also been shown that NDVI readings can serve as an in-season yield predictor in wheat (Raun et al., 2001). Work by Bartholome (1989) explains that accumulated NDVI readings rather than a single NDVI reading can be used as a better indicator for final yield with millet and sorghum crops because of the added stability it provides. Furthermore, the author reported that accumulated NDVI readings were linearly correlated with grain yields after the booting stage while biomass was linearly correlated with such readings earlier in the season after tillering (Bartholome, 1989).

At the end of the season grain yield was collected. During 2017 all plots were mechanically harvested using a Kincaid 8XP plot combine. In 2018 all plots were hand harvested and then put through the combine for threshing. This was done due to inclement weather conditions in the field. Plots needed to be harvested sooner to prevent yield losses from impending deer and bird feedings. Daily weather records were noted from the local Oklahoma Mesonet sites for all locations. Rainfall amounts along with average daily temperature and cumulative heat units (HU) were used in the analysis of this trial.

CHAPTER IV

RESULTS

EFAW 2017

During the 2017 growing season, statistical differences were seen in emergence and NDVI readings (Table 5). When calculating emergence percentage a few treatments resulted in greater than 100% emergence. This is a result of possible planter errors where a few extra seeds were dropped and/or human error in taking stand counts. When looking at the main effects the rate of N applied with the seed was a significant factor in emergence. Furthermore, a negative linear trend was noted where increasing N rate decreased emergence (Table 5). Emergence decreased linearly as population increased within each N rate. Reasons for this could be increased plant competition for sunlight, water, nutrients, etc. Significant emergence reduction was seen while comparing 20 kg N ha^{-1} to 30 kg N ha^{-1}. Reduced emergence was encountered when N was applied with the seed in comparison to preplant N and midseason N treatments (13 & 14). As much as 26% loss in emergence was noted in treatment 11 compared to 13 and 14. Figure 1, illustrates the negative trend in emergence as higher N rates were applied with the seed.

NDVI readings throughout the season showed obvious differences but that were not significant in terms of the seeding-N-rate. However, plant population was significant in the resulting NDVI readings. This was explained by the fact that a higher plant population leads to increased biomass production and resulting NDVI. By running contrasts, a linear trend in population with N rate was evident in all readings excluding the final reading of the season.

Grain yields were very low this year and ranged from 0.01 to 0.15 Mg ha^{-1}. The highest recorded yield was 0.15 Mg ha^{-1} in treatment 13. Water stress was a factor contributing to the low yields. A total of 319 mm (12.56 in) of rainfall was recorded during the growing season. Total average rainfall during the same period for Stillwater, OK from 2003-2017 is 286 mm (11.26 in). Although decent rainfall was received, the timing was not ideal. Extended periods of drought combined with high temperature during the critical time of flowering and grain fill severely affected yields (Figure 2). To try and alleviate some environmental stress, limited supplemental irrigation was used by placing drip tape down the center between two rows. In total 61 mm (2.4 in) of water was applied over the season through drip tape irrigation. In addition to climate stress, bird and deer feedings were negative factors resulting in lower grain yield. However, no significance was observed for any factor in this study for final grain yield. Important to note is that even though as much as 32% of plant stand were lost compared to the check when 30 kg N ha^{-1} was applied with the seed, no significant differences in yield were observed.

Lake Carl Blackwell 2017

Statistical differences were not seen at the LCB site during 2017 (Table 6). Few differences were noted in emergence when using the SED value of 15.6. However, the presence of high CV values diminished interpretation of results. When looking at the main effects, neither seeding N rate, plant population, or the interaction of those two variables was significant in affecting emergence. Significance was not found in single-degree-of-freedom-contrasts either. Figure 3 depicts the variability noted in the recorded emergence at this location based on the treatment structure. No definite trends were observed at this location. High rainfall in the early season contributed to ponding in some plots resulting in data variability.

Over the entire season NDVI readings were not significant except when used for plant population differences. Plant population was an influencing factor in early sensor readings. Closer to plant maturity, the reading values showed a lower CV where not as many differences are apparent. This could be due to fact that as a plant matures, it loses vigor in vegetation thus making differences in biomass less noticeable. Linear contrasts showed significance for all NDVI readings evaluated, meaning that in general as population increases with N rate, NDVI values increase as well.

Grain yields at LCB ranged from 0.28 – 0.64 Mg ha^{-1} with the highest recorded yield when a seeding rate of 216, 330 seed ha^{-1} was used and a N rate of 10 kg N ha^{-1} was applied with the seed. No significant differences were detected at this location. Rainfall during the growing season totaled 262 mm (10.3 in). Some yield loss at this site is attributed to the lack of timely rains during grain fill periods (Figure 4). Bird damage was also seen in this trial.

EFAW 2018

Significant differences were found in emergence at the Efaw site in 2018 (Table 7). The independent variables of seeding N rate and plant population were significant at this site. The interaction of the two variables however, had no effect on emergence. Linear trends within both plant population and seeding N rate were observed. On average, for every additional 10 kg N ha^{-1} that was applied, a loss of 16% in emergence was observed. Compared to the check treatments where no N was applied with the seed, applying 30 kg N ha^{-1} reduced emergence by an average of 46%. The negative trend in plant emergence can be seen in Figure 1 as the seeding N rate is increased. Major stand loses were also noted when comparing treatments where 177,700 seed ha^{-1} was used with either 30 kg N ha^{-1} was applied with the seed versus 30 kg N ha^{-1} being applied surface either preplant or midseason. 11 vs 13 and 11 vs 14. This difference represents the effects of placing a high rate of urea with the seed against surface applying UAN. Both single-degree-of-freedom-contrasts comparing these treatments were significant at the 0.01 probability level. No noticeable differences were recorded when comparing treatments 13 and 14 where the preplant vs midseason applications were evaluated.

Several significant differences were noted for NDVI readings throughout the growing season. The highest NDVI value was recorded at 1147 cumulative heat units (HU), representing a peak in plant biomass. Both main effect models for seeding N rate and plant population were significant, although the interaction of those variables was not found to be an influencing factor. From running single-degree-of-freedom contrasts, it was noted that both main effects have a linear trend. The linear trend for plant population was positive, noting the values increase as plant population increased with N rate. On the other hand, a negative linear trend was noted with seeding N rate which corroborates with the same trend seen for emergence. Same as with emergence, differences were noted between the timing and/or placement compared to treatments 11, 13, and 14.

During the 2018 season, grain yields were noticeably higher than 2017. A total of 329 mm (12.97 in) of rain was received during the growing season (Figure 5). Yields ranged from an average of 2.63 to 4.03 Mg ha^{-1} where the highest yield was seen in treatment 7 where 20 kg N ha^{-1} was applied at a population of 101,222 seeds ha^{-1}. Although numerous distinctions between treatments were noted for all other variables, yield remained constant. The seeding N rate and plant population variables did not play a factor in the resultant yield levels. When looking through Table 4 it was noted that even though 49% of total population was lost by applying 30 kg N ha^{-1} with the seed compared to the 0 kg N ha^{-1} rate, yield levels remained the same. This was an important finding considering how producers view the different risks of applying N early, and with the seed, with waiting to apply N later in the season. The contrast of treatments 11, 13, and 14 where N was applied either with the seed or on the surface was not significance.

Lake Carl Blackwell 2018

For the 2018 season at LCB significant differences between treatments were found in all data variables collected. Differences in emergence where most prominent in the resulting data outlined in Table 8. The independent variables of seeding N rate and plant population were significant, but the interaction was not. In addition, both independent variables had a negative linear trend. On average a 10 kg N ha^{-1} rate applied with the seed decreased emergence by 24%, applying 20 kg further reduced it by 4%, and finally the rate of 30 kg decreased this value by an additional 12% (Figure 3). From contrasts, these differences in emergence by increased seeding N rates were all statistically significant. Furthermore, the 'timing' contrast showed notable decreases in emergence when N was applied with the seed rather than when it was surface applied.

Sensor readings for LCB 2018 were significant, especially with the early season values. Plant population and seeding N rate were both significant factors in the main effects model for the first two early season readings. The highest average NDVI values were recorded at 980 cumulative HU (6/15/2018). As the crop progressed, less differences were detected in NDVI. Linear trends were found in NDVI until 1262 cumulative heat units were reached. When transitioning from a rate of 10 to 20 kg N ha^{-1} applied with the seed, reduction in NDVI values were significant up until the later season readings. Differences between the other N rates applied were not significant overall. Additionally, the 'timing' contrast showed notable decreases in NDVI when N was applied with seed rather than when it was surface applied. However, differences between 30 kg N ha^{-1} applied with the seed and 30 kg N ha^{-1} surface applied midseason were not as noticeable later in the season.

Grain yield levels were highest at this location during 2018. LCB received the most in season rainfall totaling 361.96 mm (14.25 in) (Figure 6). Limited supplemental irrigation was added using a linear drop sprinkler system totaling 114.3 mm (4.5 in). Treatment 12, where the highest N rate with the seed was applied at the largest population, produced the highest yield of 8.15 Mg ha^{-1}. The variation of yield was notably lower at this site year compared to others at a CV value of 11%. Yields ranged from 5.74 to 8.15 Mg ha^{-1}. The seeding N rate showed a significant effect on yield at the 0.01 probability level. Other treatment variables were not influencing factors. A linear trend was significant in yield for the seeding N rate variable. When evaluating yields by N rate groups, significance was only seen between applying 0 and 10 kg N ha^{-1}. Yields increased by adding 10 kg N ha^{-1} with the seed compared to no N with the seed. The timing contrast showed no significant differences in yield.

Hennessey 2018

Significant differences between treatments were found for emergence, and NDVI readings (Table 9). In the main effects model, seeding N rate and plant population were highly significant as well as the interaction of those variables. Negative linear trends for both factors in this study were significant at the 0.01 probability level. Comparing the different N rate levels using contrasts showed significance for all comparisons. The largest decrease in emergence was seen at the first N rate level with 26% loss. Larger reductions in emergence were noted as N rate increased with up to 49% loss when 30 kg N ha^{-1} was applied. Figure 3 illustrates the negative trend in emergence as higher N rates were applied.

The placement of N was found to be significant as well when comparing treatments 11 to 13 and 14. Decreases in emergence were minimized when N was surface applied compared to applying it with the seed.

NDVI sensor readings showed significant differences from early to midseason readings. Seeding N rate had a significant effect on NDVI until 1685 cumulative HU were achieved. Plant population only had an influencing effect on sensor readings between 920 and 1322 cumulative HU. The seeding N rate was highly significant when comparing all N rates used at the 622 cumulative HU reading. Linear trends with seeding N rate and plant population were found for the early to midseason readings. At 622 cumulative HU, NDVI reading values decreased as more N was applied with the seed. For the first three readings, placement was noted to be significant in that NDVI values were higher when N was surface applied compared to N applied with the seed. Towards the end of the season distinctions between the preplant and midseason treatments were found (13 and 14). The midseason treatment resulted in higher NDVI values compared to preplant. The timely application of N midseason contributed to this higher value.

Yield levels for Hennessey in 2018 ranged from 2.71 to 4.13 Mg ha^{-1}. Treatment 14 where a midseason N application was made, resulted in the highest yield. Rainfall totaled 304.07 mm (11.97 in) (Figure 8). No significance was detected when analyzing the independent variable effects on yield. However, one significant difference between the rate of 10 vs 20 kg N ha^{-1} applied with the seed was noted. The treatments where 20 kg N ha^{-1} was applied resulted in a 0.8 Mg ha^{-1} increase in yield compared to the 10 kg N ha^{-1} treatments. Interestingly, the increase of 0.8 Mg ha^{-1} occurred even though plant stands were reduced an additional 15% by applying 10 kg N ha^{-1} more. Placement of N with the seed compared to on the surface had no significant differences in the resulting yield.

CHAPTER V

DISSCUSSION

Consistencies were seen in the analysis of emergence data across all site years evaluated. Seeding N rate was an influencing factor in that as higher N rates were applied with the seed, emergence decreased in a linear fashion. Previous published work where N, P, and K were banded with corn seed resulted in 3- 30% loss in plant stand where N was applied at 2.5 g per meter of row (15 kg N ha^{-1}) (Bates. 1971). The rate of N applied in this study was 2.5 g per meter of row which would be comparable to a rate of 15 kg N ha^{-1}. Results from our study are comparable as average losses of up to 38 and 51% were noted when 20 and 30 kg N ha^{-1} was applied with sorghum seed respectively. Applying 10 kg N ha^{-1} with the seed resulted in average stand losses of 29%. Comparing these losses back to the check treatments is important. Even when no N is applied with the seed, an average of 13% stand loss is expected due to non-germinating seeds and other environmental stressors. In all sites the highest reduction in emergence occurred when 30 kg N ha^{-1} was applied with the seed. Higher losses in emergence were observed during the 2018 growing season compared to 2017. This might be due to heavy rain received within two days after planting in 2017 which aided in dissolving and dispersing the urea in furrow thus reducing the seedling salt injury. Four out of the five site years showed a significant decrease in emergence when comparing applying N with the seed vs. surface applications.

Although as much as 70% emergence reduction can occur with an application of 30 kg N ha^{-1} with the seed, no significant loses in yield were recorded at any location and at the same time, no increases were observed either. From this data, consistent advantages and/or disadvantages were not seen in yield levels by applying N with the seed. A possible reasoning for this finding might be because sorghum has tillering abilities. Research from Texas A&M found that sorghum has the ability to tiller and compensate for some losses in stand during early growth stages (Gerik et al., n.a.). Further work has shown that planting densities along with hybrid selection influence that production of tillers. Planting rates where less than three plants per row-foot were used, tillering was promoted and densities of four or more plants per row-foot hindered tillering production (Gerik et al., n.a). Even though additional tillers may be produced in reduced stand occurrences, grain heads may not form on all tillers. Previous published work has shown that production of grain forming tillers significantly declines at population densities greater than 2.5 plants m^{-2} (Gerik and Neely, 1987). For the three populations used in our study, the densities were 10.2, 17.6 and 21.6 plants m^2. Tillering was still noted in the field experiments, but the grain produced from those tillers alone were not quantified. Also, when analyzing the grain yield results, it is important to note that total N levels needed for grain sorghum production were not applied. An adequate N rate for the Oklahoma region for sorghum production is 67 – 84 kg N ha^{-1} (Arnall, 2015). In this study the maximum N rate applied was 30 kg, less than half of the plant's requirements. No additional midseason applications were made in this work because the objective was to strictly observe the results of applying in furrow rates of N. When looking at this topic in the future, putting an additional midseason application of 50 or 60 kg along with an in furrow rate could be useful in discovering total impacts on grain yield. The N rates applied in this study could simply be too low in order to see treatment differences in yield. Additionally, bird and deer feedings did reduce yields to some degree in this trial.

Sensor readings showed variable results across all locations during both seasons. The seeding N rate showed some effect on NDVI values in 2018 but not in 2017. Plant population however, did significantly influence NDVI values at all sites with higher significance noted in earlier season readings. Sensor readings are most valuable for giving an indication of plant health and vigor. They also serve as a variable in early season yield prediction calculators which are used to make better in season N application recommendations. As noted earlier, work by Bartholome (1989) delineated that accumulated NDVI readings rather than single NDVI readings can be used as a better indicator for final yield with millet and sorghum crops because of the added stability it provides. This is consistent with findings in this study. When using the regression model looking at all site years evaluated, no significance was seen in the R^2 values.

CHAPTER VI

CONCLUSIONS

Higher N rates applied with sorghum seed contributed to larger losses in plant emergence. When no N was applied with the seed, an average 13% loss in emergence was noted in this study. This loss is attributed to the hybrid germination percentage and other environmental factors. As much as 70% of stand can be lost by applying 30 kg N ha^{-1} with the seed with an average loss of 51% recorded. Up to 64% losses can occur when 20 kg N ha^{-1} is applied; however, on average only 38% reduction in emergence was recorded at this rate. A rate of 10 kg N ha^{-1} with the seed resulted in an average 29% loss in stand. When comparing applied N with the seed to a surface preplant and midseason application, little to no reduction in emergence was recorded. Considering all of the significant stand losses that were recorded in the treatments where N was applied with the seed, the seeding-N-rate did not have a significant effect on yields. Furthermore, no differences were seen in yield levels of the surface applied N treatments either. This suggests that as much as 30 kg N ha^{-1} can be applied in furrow with sorghum without significant yield reductions, however drastic stand losses will occur. In future studies on this topic, an additional N application may be needed in order to fulfill the crop's N requirements for the growing season. Once that is met, differences in yield could become more evident.

REFERENCES

All About Sorghum. United Sorghum Checkoff. Available at: http://www.sorghumcheckoff.com/all-about-sorghum. (Accessed: 26th May 2017)

Arnall, B. 4 Keys to Reaching Grain Sorghum's Yield Potential [Web log post]. Retrieved July 17, 2017, from https://osunpk.com/2015/03/18/4-keys-to-reaching-grain-sorghums-yield-potential/

Bates, T. E. 1971. Response of Corn to Small Amounts of Fertilizer Placed with the Seed: II. Summary of 22 Field Trials1. *Agronomy Journal* 63:369-371.

Bartholome, E. 1988. Radiometric measurements and crop yield forecasting: Some observations over millet and sorghum experimental plots in Mali. *International Journal of Remote Sensing* 9:1539–1552.

Bond, J. J., T.J. Army, and O.R. Lehman. 1964. Row spacing, plant populations and moisture supply as factors in dryland grain sorghum production. *Agronomy Journal*, *56*: 3-6.

Bremner, J. M., and M. J. Krogmeier. 1989. Evidence that the adverse effect of urea fertilizer on seed germination in soil is due to ammonia formed through hydrolysis of urea by soil urease. *Proceedings of the National Academy of Sciences*, *86:* 8185-8188.

Bremner, J.M, and M. J. Krogmeier. 1988. Elimination of the adverse effects of urea fertilizer on seed germination, seedling growth, and early plant growth in soil. *Proceedings of the National Academy of Sciences 85 (13); 4601-4604.*

Cooperative Extension Service, Kansas State University. 1998. Grain Sorghum Production Handbook, Manhattan, Kansas.

Data, U.C. (n.d.). Temperature – Precipitation- Sunshine - Snowfall. Retrieved November 18, 2018, from https://www.usclimatedata.com

de Bruin, J.L., P. Pederson. 2008. Effect of row spacing and seeding rate on soybean yield. *Agronomy Journal*, 100: 704-710.

Deibert, E. J. 1994. Fertilizer application with small grain seed at planting. EB-62. NDSU Ext. Service, Fargo, ND

Fageria, N. K., and V.C. Baligar. 2005. Enhancing nitrogen use efficiency in crop plants. *Advances in Agronomy*, 88: 97-185.

Food and Agricultural Organization (FAO) (2014). FAOSTAT. http://faostat.fao.org/faostat

Fowler, D.B., and J. Brydon. 1989. No-till winter wheat production on the Canadian prairies; Placement of urea and ammonium nitrate fertilizers. *Agronomy Journal*, 81: 518-524.

Gelderman, R. H. 2007. Fertilizer Placement with Seed–A Decision Aide. *Proceedings of the North Central Extension–Industry Soil Fertility Conference, Des Moines, IA* (pp. 14-15).

Gerik, T. J., and C. L. Neely. 1987. Plant Density Effects on Main Culm and Tiller Development of Grain Sorghum1. *Crop Science* 27:1225-1230.

Gerik, T., Bean, B., & Vanderlip, R. (n.d.). Sorghum Growth and Development - Texas A&M University. Retrieved from http://publications.tamu.edu/CORN_SORGHUM/PUB_Sorghum Growth and Development.pdf

Gordon, W. B., and D. A. Whitney. 1995. No-Tillage Grain Sorghum Response to Starter Nitrogen-Phosphorus Combinations. Journal of Production Agriculture 8:369-373

Gordon, W. B., and D. Whitney. 2000. Nutrient management in reduced tillage systems. In Great Plains Soil Fertility Conf. Proc. A.J. Schlegel (ed.). p.302-307. Denver Co. Mar 7-8, 2000. KSU, Manhattan, KS.

Ham, G.E., W.W. Nelson, S.D. Evans, and R.D. Frazier. 1973. Influence of fertilizer placement on yield response of soybeans. *Agronomy Journal*, 65:81-84.

Hargrove, W.L., D.E. Kissel, and L.B. Fenn. 1977. Field measurements of ammonia volatilization from surface applications of ammonium salts to a calcareous soil. *Agronomy Journal*, 69: 473-476.

Hart, S. C., Stark, J. M., Davidson, E. A., & Firestone, M. K. (1994). Nitrogen mineralization, immobilization, and nitrification. *Methods of Soil Analysis: Part 2—Microbiological and Biochemical Properties*, (methodsofsoilan2), 985-1018.

Hirel, B., Le Gouis, J., Ney, B., Gallais, A. "The challenge of improving nitrogen use efficiency in crop plants: towards a more central role for genetic variability and quantitative genetics within integrated approaches, *Journal of Experimental Botany*, Volume 58, Issue 9, 1 July 2007, Pages 2369–2387

Hoeft, R.G., L. M. Walsh & E. A. Liegel (1975) Effect of seed□placed fertilizer on the emergence (germination) of soybeans (*Glycine max* L.) and snapbeans (*Phaseolus vulgaris* L.), *Communications in Soil Science and Plant Analysis* 6:6, 655-664

University of Illinois (2010) How Much Salt is in the Fertilizer? *The Bulletin*. Retrieved June 6, 2017, from http://bulletin.ipm.illinois.edu/print.php?id=1305

ICRISAT 2005. Sorghum report. Patancheru India. http://www.icrisat.org/text/research/grep/homepage/sorghum/sorghumhomepage.htm

McClure, B. (2018). Sorghum Fertility Management. Retrieved July 06, 2017, from https://www.pioneer.com/home/site/us/agronomy/library/sorghum-fertility-management/

Mengel, D.B., D.W. Nelson, and D.M. Huber. 1982. Placement of nitrogen fertilizers for no-till and conventional till corn. *Agronomy Journal* 74:515–518.

Moldenhauer, W. C., and W. Lipscomb. 1957. Narrow row sorghum for soil, water conservation. *Southwestern Crop and Stock* 11: 12.

Mosaic Crop Nutrition. 2016. Nitrogen. Retrieved July 06, 2017, from http://www.cropnutrition.com/efu-nitrogen

Mullen, R.W., K.W. Freeman, W.R. Raun, G.V. Johnson, M.L. Stone, and J.B. Solie. 2003. Identifying an in-season response index and the potential to increase wheat yield with nitrogen. *Agronomy Journal* 95:347-351.

Nelson, W.W., and G. Randall. 1968. Effect of fertilizer placement methods on the early growth and grain yield of corn. *Agronomy Journal Abstracts*, November 10-15. p.107.

Niehues, B. J., R. E. Lamond, C. B. Godsey, and C. J. Olsen. 2004. Starter Nitrogen Fertilizer Management for Continuous No-Till Corn Production Contribution no. 04-099-J, K-State Research and Extension. *Agronomy Journal* 96:1412-1418.

"Sorghum 101" Retrieved July 17, 2017, from http://sorghumgrowers.com/sorghum-101/

Raun, W. R., J. B. Solie, G. V. Johnson, M. L. Stone, E. V. Lukina, W. E. Thomason, and J. S. Schepers. 2001. In-Season Prediction of Potential Grain Yield in Winter Wheat Using Canopy Reflectance Contribution of the Oklahoma Agriculture Experiment Station *Agronomy Journal* 93:131-138.

Raun, W. R., and G.V. Johnson. 1999. Improving nitrogen use efficiency for cereal production. *Agronomy Journal*, 91: 357-363.

Raun, W. R., D.H. Sander, and R.A. Olson. 1986. Emergence of corn as affected by source and rate of solution fertilizers applied with the seed. *Journal of Fertilizer Issues* 3:18-24.

Shroyer, J. P., C. Thompson, R. Brown, P.D. Ohlenbach, D.L. Fjell, S. Staggenborg, and G.L. Kilgore. 1996. Kansas crop planting guide. L□818. Manhattan, Kansas: Kansas State University Cooperative Extension Service.

Snider, J. L., R.L. Raper, and E.B. Schwab. 2012. The effect of row spacing and seeding rate on biomass production and plant stand characteristics of non-irrigated photoperiod-sensitive sorghum (Sorghum bicolor (L.) Moench). *Industrial Crops and Products*, 37: 527-535.

Steiner, J.L. 1986. Dryland grain sorghum water use, light interception, and growth responses to planting geometry. *Agronomy Journal*, 78: 720-726.

Stevenson F.J. 1982. Origin and distribution of nitrogen in soil. In: Stevenson FJ (ed) Nitrogen in agricultural soils. *American Society of Agronomy*, pp 1–42

Stichler, C., M.L. McFarland, and C.G. Coffman, 1997. Irrigated and Dryland Grain Sorghum Production, South and Southwest Texas. Texas Agricultural Extension Service, Texas A & M University System. P. (n.d.). Sorghum 101. Retrieved June 26, 2017, from http://sorghumgrowers.com/sorghum-101/

United States, USDA, Oklahoma Field Office. *Oklahoma Agricultural Statistics 2016.* (p. 35).

USDA., Web Soil Survey. 2016. Available at: https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx (Accessed: August 14, 2017)

Wang, D., S. Bean, J. McLaren, P. Seib, R. Madl, M. Tuinstra, and R. Zhao. 2008. Grain sorghum is a viable feedstock for ethanol production. *Journal of Industrial Microbiology and Biotechnology*, 35: 313-320.

Westerman, R. L., and L. T. Kurtz. 1973. Priming Effect of 15N-Labeled Fertilizers on Soil Nitrogen in Field Experiments1. *Soil Science Society of America Journal*, 37:725-727.

LIST OF TABLES

Table 1. Preplant soil test characteristics at (0-15 cm) and soil classification at Efaw, Lake Carl Blackwell, and Hennessey, OK. 2017 & 2018.

Year	Location	pH	OM %	NH_4-N	NO_3-N	P	K
				--------------------------	mg kg^{-1}	----------------------------	
2017	Efaw	5.8	1.9	1.1	1.5	29.6	185.6
2018	Efaw	6.1	1.4	10.0	0.5	17.2	132.2
Classification: Norge loam (Fine-silty, mixed , active, thermic Udic Paleustoll)							
2017	Lake Carl Blackwell	6.0	1.8	1.0	1.8	24.0	153.9
2018	Lake Carl Blackwell	6.9	1.4	21.7	3.7	27.0	137.2
Classification: Port- Oscar silty clay loam (Fine-silty, mixed thermic Cumulic Haplustoll)							
2018	Hennessey	5.9	2.1	16.1	2.8	92.8	397.8
Classification: Bethany silt loam (Fine, mixed, superactive, thermic Pachic Paleustolls)							

pH – 1:1 soil:water, NH_4-N and NO_3-N – 2M KCL extract, P and K – Mehlich III extraction

Table 2. Treatment Structure

Treatment	Seed Planting Population ha^{-1}	N Rate with Seed kg N ha^{-1}	Pre-plant N Rate kg N ha^{-1}	Mid-season N Rate kg N ha^{-1}
1	101,222	0	0	0
2	148,923	0	0	0
3	201,667	0	0	0
4	101,222	10	0	0
5	148,923	10	0	0
6	201,667	10	0	0
7	101,222	20	0	0
8	148,923	20	0	0
9	201,667	20	0	0
10	101,222	30	0	0
11	148,923	30	0	0
12	201,667	30	0	0
13	148,923	0	30	0
14	148,923	0	0	30

Table 3. Field Activities 2017

Location	Soil Type	Soil Samples Taken	Pre-plant N Application	Planting Date	Stand Counts Taken	NDVI Sensing Dates	Mid-Season N Application	Harvest Date
Efaw	Norge loam	06/02/2017	06/02/2017	06/02/2017	06/07/2017 06/09/2017 06/13/2017 06/14/2017 06/16/2017 06/19/2017 06/21/2017 07/10/2017	06/16/2017 06/21/2017 07/06/2017 07/14/2017 07/18/2017 07/21/2017 07/25/2017 08/02/2017 08/10/2017 08/15/2017	07/14/2017	08/31/2017
Lake Carl Blackwell	Port- Oscar silty clay loam	06/02/2017	06/02/2017	06/02/2017	06/07/2017 06/09/2017 06/13/2017 06/14/2017 06/16/2017 06/19/2017 06/21/2017 07/07/2017	06/16/2017 06/21/2017 07/07/2017 07/14/2017 07/18/2017 07/21/2017 07/25/2017 08/02/2017 08/10/2017	07/14/2017	09/01/2017

Table 4. Field Activities 2018

Location	Soil Type	Soil Samples Taken	Pre-plant N Application	Planting Date	Stand Counts Taken	NDVI Sensing Dates	Mid-Season N Application	Harvest Date
Efaw	Norge loam	04/11/2018	04/19/2018	04/30/2018	05/15/2018 05/22/2018 05/25/2018 05/29/2018	05/27/2018 06/01/2018 06/06/2018 06/12/2018 06/15/2018 06/20/2018 07/03/2018	06/11/2018	08/03/2018
Lake Carl Blackwell	Port- Oscar silty clay loam	04/13/2018	04/19/2018	04/30/2018	05/14/2018 05/22/2018 05/25/2018	05/27/2018 06/01/2018 06/06/2018 06/12/2018 06/15/2018 06/27/2018 07/03/2018	06/11/2018	08/03/2018
Hennessey	Bethany silt loam	05/04/2018	05/04/2018	05/04/2018	05/17/2018 05/23/2018 06/01/2018	06/01/2018 06/05/2018 06/13/2018 06/19/2018 06/28/2018 07/03/2018	06/13/2018	08/03/2018

Table 5. Treatment structure, treatment means, main effect model, and single-degree-of-freedom contrasts for emergence, NDVI, and grain yield, Efaw, OK, 2017.

Treatment	Seed N Rate (kg N ha^{-1})	Plant Population (ha^{-1})	Emergence (%)	NDVI, Cumulative HU 318	786	1125	1334	1721	Grain Yield (Mg ha^{-1})
1	0	101,222	115	0.22	0.65	0.75	0.72	0.66	0.02
2	0	177,700	98	0.23	0.74	0.82	0.76	0.67	0.05
3	0	216,330	89	0.24	0.75	0.83	0.77	0.65	0.04
4	10	101,222	107	0.23	0.69	0.77	0.73	0.68	0.01
5	10	177,700	87	0.24	0.72	0.80	0.75	0.67	0.03
6	10	216,330	96	0.24	0.80	0.86	0.80	0.71	0.05
7	20	101,222	117	0.22	0.68	0.74	0.71	0.68	0.06
8	20	177,700	75	0.23	0.73	0.79	0.75	0.69	0.11
9	20	216,330	84	0.23	0.74	0.82	0.77	0.66	0.04
10	30	101,222	66	0.21	0.60	0.67	0.64	0.63	0.04
11	30	177,700	66	0.23	0.72	0.80	0.76	0.69	0.04
12	30	216,330	74	0.22	0.73	0.81	0.76	0.69	0.06
13	30•	177,700	90	0.24	0.76	0.83	0.76	0.69	0.15
14	30••	177,700	92	0.21	0.69	0.79	0.77	0.73	0.04
SED			9.03	0.01	0.03	0.02	0.01	0.02	0.06
CV			12	6	5	4	2	3	131
Main Effect									
Seeding N Rate			**	ns	ns	ns	ns	ns	ns
Plant Population			ns	*	**	**	**	ns	ns
Seeding N Rate*Plant Population			ns	ns	ns	ns	*	ns	ns
Contrasts									
N Rate with Seed Linear			**	ns	ns	**	**	ns	ns
Population within N Rate Linear			**	*	**	**	**	ns	ns
N Rate 0 vs 10			ns	ns	ns	ns	ns	*	ns
N Rate 10 vs 20			ns	ns	ns	ns	ns	ns	ns
N Rate 20 vs 30			**	ns	ns	ns	*	ns	ns
Timing Trt (11vs.13) (11vs.14) (13vs.14)			*,**,ns	ns,ns,*	ns,ns,*	ns,ns,ns	ns,ns,ns	ns,ns,ns	ns, ns, ns

•Preplant N application only, ••Midseason N application only, SED – standard error of the difference between two equally replicated means, CV – coefficient of variation, Main Effect excludes treatments 13 & 14 where N was not applied with the seed, ns, *, **, not significant, and significant at the 0.05 and 0.01 probability levels respectively

Table 6. Treatment structure, treatment means, main effect model, and single-degree-of-freedom contrasts for emergence, NDVI, and grain yield, Lake Carl Blackwell, OK, 2017.

Treatment	Seed N Rate (kg N ha^{-1})	Plant Population (ha^{-1})	Emergence (%)	NDVI, Cumulative HU 323	792	1091	1290	1489	Grain Yield (Mg ha^{-1})
1	0	101,222	84	0.18	0.53	0.71	0.71	0.69	0.59
2	0	177,700	69	0.18	0.54	0.66	0.65	0.63	0.45
3	0	216,330	102	0.19	0.63	0.68	0.66	0.64	0.28
4	10	101,222	94	0.17	0.40	0.57	0.61	0.63	0.43
5	10	177,700	85	0.19	0.70	0.77	0.74	0.71	0.56
6	10	216,330	54	0.19	0.60	0.76	0.76	0.72	0.64
7	20	101,222	66	0.18	0.45	0.61	0.63	0.65	0.51
8	20	177,700	67	0.18	0.59	0.69	0.68	0.65	0.28
9	20	216,330	81	0.19	0.70	0.81	0.78	0.72	0.56
10	30	101,222	72	0.18	0.46	0.61	0.62	0.62	0.53
11	30	177,700	77	0.19	0.63	0.75	0.74	0.70	0.54
12	30	216,330	45	0.18	0.55	0.70	0.68	0.70	0.40
13	30•	177,700	69	0.18	0.49	0.62	0.65	0.66	0.33
14	30••	177,700	69	0.18	0.58	0.73	0.72	0.67	0.58
SED			15.57	0.01	0.10	0.08	0.06	0.04	0.16
CV			26	5	21	14	11	7	41
Main Effect									
Seeding N Rate			ns	ns	ns	ns	ns	ns	ns
Plant Population			ns	**	**	*	ns	ns	ns
Seeding N Rate*Plant Population			ns	ns	ns	ns	ns	ns	ns
Contrasts									
N Rate with Seed Linear			ns	ns	ns	ns	ns	ns	ns
Population Linear within N Rate			ns	**	**	*	*	*	ns
N Rate 0 vs 10			ns	ns	ns	ns	ns	ns	ns
N Rate 10 vs 20			ns	ns	ns	ns	ns	ns	ns
N Rate 20 vs 30			ns	ns	ns	ns	ns	ns	ns
Timing Trt (11vs.13) (11vs.14) (13vs.14)			ns,ns,ns	ns,ns,ns	ns,ns,ns	ns,ns,ns	ns,ns,ns	ns,ns,ns	ns,ns,ns

•Preplant N application only, ••Midseason N application only, SED – standard error of the difference between two equally replicated means, CV – coefficient of variation, Main Effect excludes treatments 13 & 14 where N was not applied with the seed,
ns, *, **, not significant, and significant at the 0.05 and 0.01 probability levels respectively

Table 7. Treatment structure, treatment means, main effect model, and single-degree-of-freedom contrasts for emergence, NDVI, and grain yield, Efaw, OK, 2018.

Treatment	Seed N Rate (kg N ha^{-1})	Plant Population (ha^{-1})	Emergence (%)	NDVI, Cumulative HU 557	786	927	1147	1472	Grain Yield (Mg ha^{-1})
1	0	101,222	95	0.28	0.56	0.78	0.80	0.73	3.28
2	0	177,700	78	0.32	0.59	0.80	0.81	0.72	3.34
3	0	216,330	85	0.36	0.70	0.84	0.84	0.76	3.05
4	10	101,222	74	0.28	0.53	0.74	0.78	0.73	3.06
5	10	177,700	64	0.32	0.63	0.81	0.81	0.73	2.70
6	10	216,330	59	0.32	0.64	0.81	0.80	0.72	2.63
7	20	101,222	62	0.25	0.47	0.67	0.74	0.72	4.03
8	20	177,700	50	0.30	0.52	0.74	0.76	0.71	3.02
9	20	216,330	46	0.30	0.60	0.78	0.79	0.75	3.18
10	30	101,222	44	0.23	0.40	0.61	0.68	0.68	3.28
11	30	177,700	30	0.25	0.44	0.63	0.69	0.68	3.49
12	30	216,330	38	0.27	0.50	0.66	0.72	0.69	3.70
13	30•	177,700	82	0.36	0.69	0.86	0.84	0.75	3.54
14	30••	177,700	78	0.34	0.65	0.82	0.81	0.76	3.00
SED			5.26	0.01	0.04	0.03	0.02	0.02	0.58
CV			10	5	8	5	4	3	22
Main Effect									
Seeding N Rate			**	**	**	**	**	**	ns
Plant Population			**	**	**	**	*	ns	ns
Seeding N Rate*Plant Population			ns	ns	ns	ns	ns	ns	ns
Contrasts									
N Rate with Seed Linear			**	**	**	**	**	**	ns
Population Linear within N Rate			**	**	**	**	**	ns	ns
N Rate 0 vs 10			**	*	ns	ns	ns	ns	ns
N Rate 10 vs 20			**	**	**	**	*	ns	ns
N Rate 20 vs 30			**	**	**	**	**	**	ns
Timing Trt (11vs.13) (11vs.14) (13vs.14)			**,**,ns	**,**,ns	**,**,ns	**,**,ns	**,**,ns	**,**,ns	ns,ns,ns

•Preplant N application only, ••Midseason N application only, SED – standard error of the difference between two equally replicated means, CV – coefficient of variation, Main Effect excludes treatments 13 & 14 where N was not applied with the seed,
ns, *, **, not significant, and significant at the 0.05 and 0.01 probability levels respectively

Table 8. Treatment structure, treatment means, main effect model, and single-degree-of-freedom contrasts for emergence, NDVI, and grain yield, Lake Carl Blackwell, OK, 2018.

Treatment	Seed N Rate (kg N ha^{-1})	Plant Population (ha^{-1})	Emergence (%)	NDVI, Cumulative HU 522	652	980	1262	1425	Grain Yield (Mg ha^{-1})
1	0	101,222	94	0.37	0.72	0.80	0.76	0.73	6.02
2	0	177,700	74	0.45	0.78	0.82	0.77	0.73	5.74
3	0	216,330	78	0.53	0.82	0.83	0.78	0.75	6.24
4	10	101,222	67	0.35	0.67	0.79	0.78	0.76	7.63
5	10	177,700	60	0.46	0.79	0.83	0.79	0.76	6.89
6	10	216,330	47	0.45	0.79	0.82	0.78	0.74	6.29
7	20	101,222	66	0.33	0.64	0.79	0.77	0.75	6.94
8	20	177,700	50	0.38	0.70	0.78	0.77	0.74	6.83
9	20	216,330	47	0.39	0.70	0.80	0.78	0.74	7.04
10	30	101,222	52	0.32	0.60	0.76	0.76	0.73	7.05
11	30	177,700	38	0.35	0.64	0.76	0.77	0.74	6.77
12	30	216,330	38	0.35	0.68	0.78	0.77	0.74	8.15
13	30•	177,700	68	0.45	0.79	0.84	0.80	0.77	7.84
14	30••	177,700	70	0.42	0.74	0.80	0.79	0.76	7.00
SED			5.05	0.03	0.05	0.02	0.01	0.01	0.60
CV			10	9	8	3	2	2	11
Main Effect									
Seeding N Rate			**	**	**	**	ns	ns	**
Plant Population			**	**	**	ns	ns	ns	ns
Seeding N Rate*Plant Population			ns	ns	ns	ns	ns	ns	ns
Contrasts									
N Rate with Seed Linear			**	**	**	**	ns	ns	**
Population Linear within N Rate			**	**	**	*	ns	ns	ns
N Rate 0 vs 10			**	ns	ns	ns	*	*	*
N Rate 10 vs 20			*	**	*	*	ns	ns	ns
N Rate 20 vs 30			**	ns	ns	*	ns	ns	ns
Timing Trt (11vs.13) (11vs.14) (13vs.14)			**,**,ns	**,*,ns	**,*,ns	**,*,*	*,ns,ns	*,ns,ns	ns,ns,ns

•Preplant N application only, ••Midseason N application only, SED – standard error of the difference between two equally replicated means, CV – coefficient of variation, Main Effect excludes treatments 13 & 14 where N was not applied with the seed,
ns, *, **, not significant, and significant at the 0.05 and 0.01 probability levels respectively

Table 9. Treatment structure, treatment means, main effect model, and single-degree-of-freedom contrasts for emergence, NDVI, and grain yield, Hennessey, OK, 2018.

Treatment	Seed N Rate (kg N ha^{-1})	Plant Population (ha^{-1})	Emergence (%)	NDVI, Cumulative HU 622	920	1322	1685	1920	Grain Yield (Mg ha^{-1})
1	0	101,222	96	0.65	0.78	0.77	0.73	0.52	3.10
2	0	177,700	78	0.68	0.80	0.78	0.67	0.52	3.11
3	0	216,330	76	0.70	0.81	0.80	0.65	0.54	2.71
4	10	101,222	67	0.63	0.77	0.75	0.62	0.51	2.85
5	10	177,700	47	0.62	0.78	0.77	0.64	0.51	2.81
6	10	216,330	56	0.66	0.80	0.78	0.62	0.49	2.79
7	20	101,222	52	0.57	0.71	0.73	0.62	0.50	3.40
8	20	177,700	39	0.59	0.75	0.76	0.65	0.53	3.46
9	20	216,330	36	0.58	0.77	0.77	0.65	0.50	3.98
10	30	101,222	34	0.49	0.65	0.70	0.63	0.52	3.43
11	30	177,700	36	0.53	0.71	0.72	0.62	0.49	3.02
12	30	216,330	33	0.54	0.67	0.73	0.64	0.54	3.75
13	30•	177,700	72	0.70	0.83	0.80	0.67	0.53	3.35
14	30••	177,700	76	0.68	0.82	0.82	0.73	0.58	4.13
SED			4.75	0.03	0.02	0.02	0.02	0.02	0.58
CV			10	5.74	4	3	5	4	22
Main Effect									
Seeding N Rate			**	**	**	**	ns	ns	ns
Plant Population			**	ns	*	*	ns	ns	ns
Seeding N Rate*Plant Population			*	ns	ns	ns	ns	*	ns
Contrasts									
N Rate with Seed Linear			**	**	**	**	ns	ns	ns
Population Linear within N Rate			**	*	**	**	ns	ns	ns
N Rate 0 vs 10			**	*	ns	ns	ns	ns	ns
N Rate 10 vs 20			**	**	*	ns	ns	ns	*
N Rate 20 vs 30			**	**	**	**	ns	ns	ns
Timing Trt (11vs.13) (1 vs.14) (13vs.14)			**,**,ns	**,**,ns	**,**,ns	**,**,ns	ns,**,*	ns,**,**	ns,ns,ns

•Preplant N application only, ••Midseason N application only, SED – standard error of the difference between two equally replicated means, CV – coefficient of variation, Main Effect excludes treatments 13 & 14 where N was not applied with the seed,
ns, *, **, not significant, and significant at the 0.05 and 0.01 probability levels respectively

LIST OF FIGURES

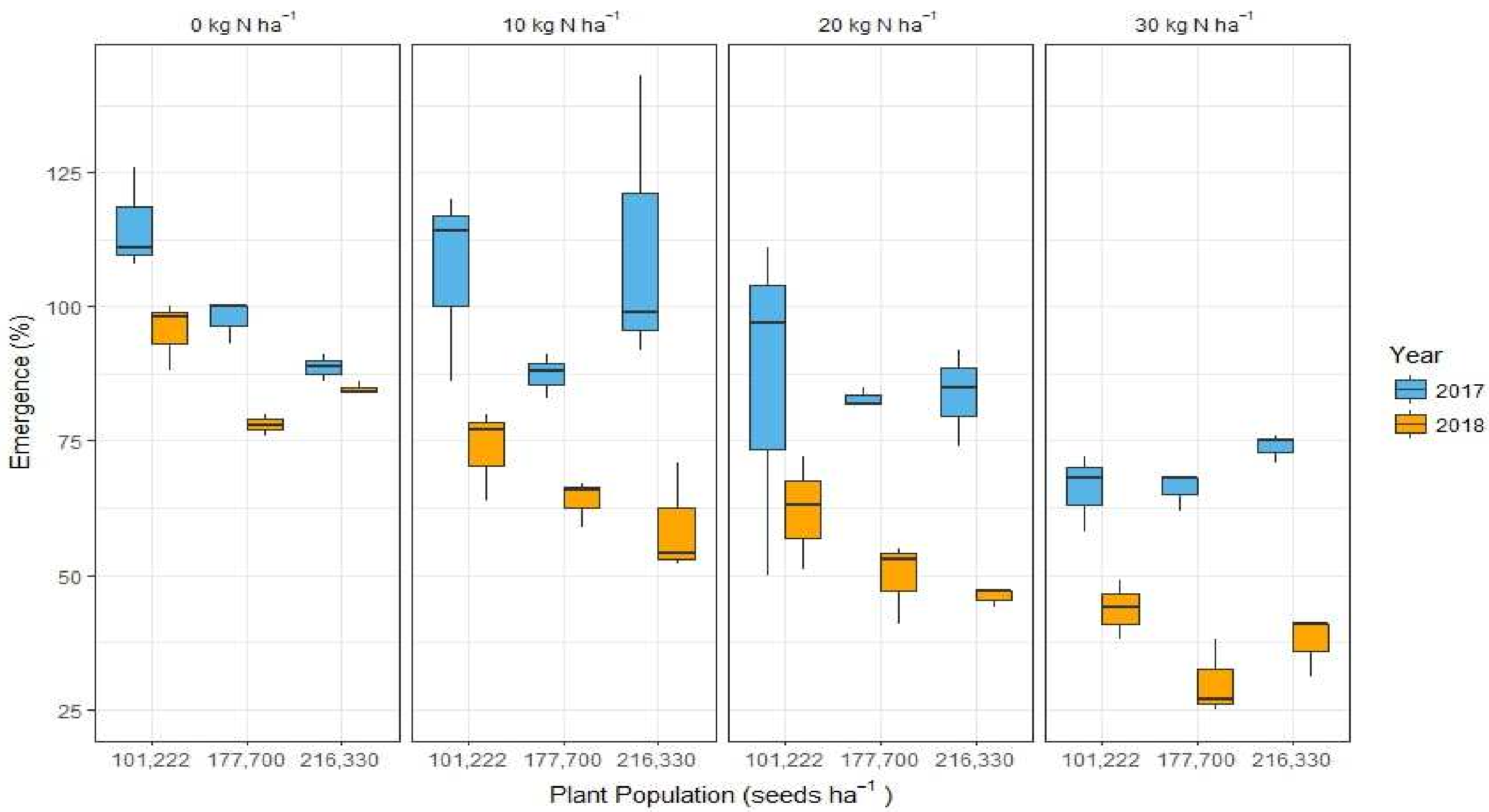

Figure 1. Emergence Percentage by Population Rate and Seeding-N-Rate, Efaw, OK. 2017 & 2018.

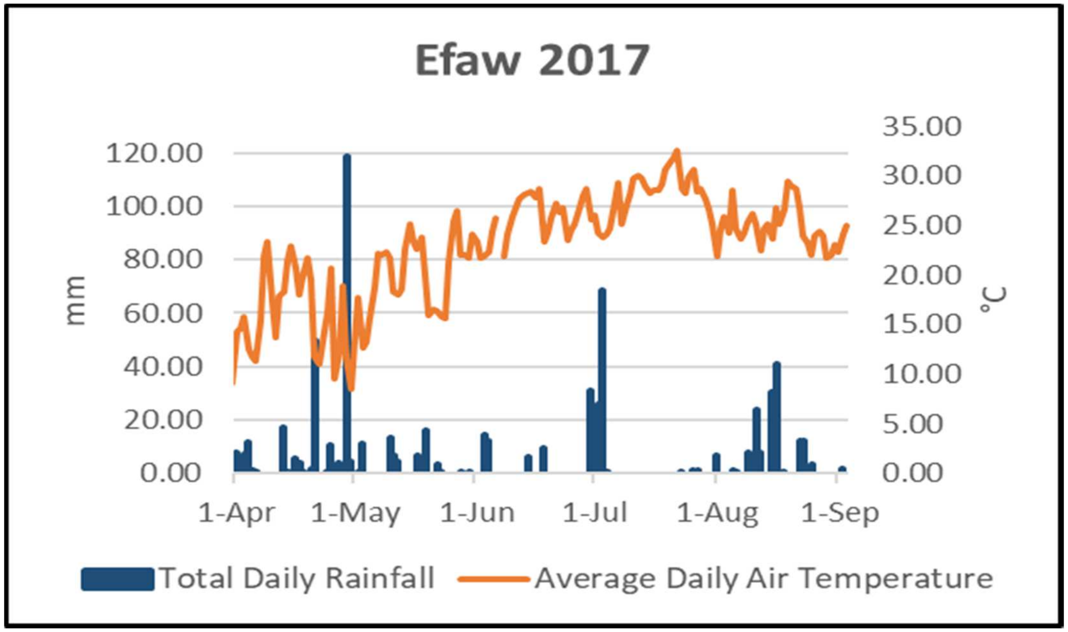

Figure 2. Weather Data, Efaw, OK. 2017.

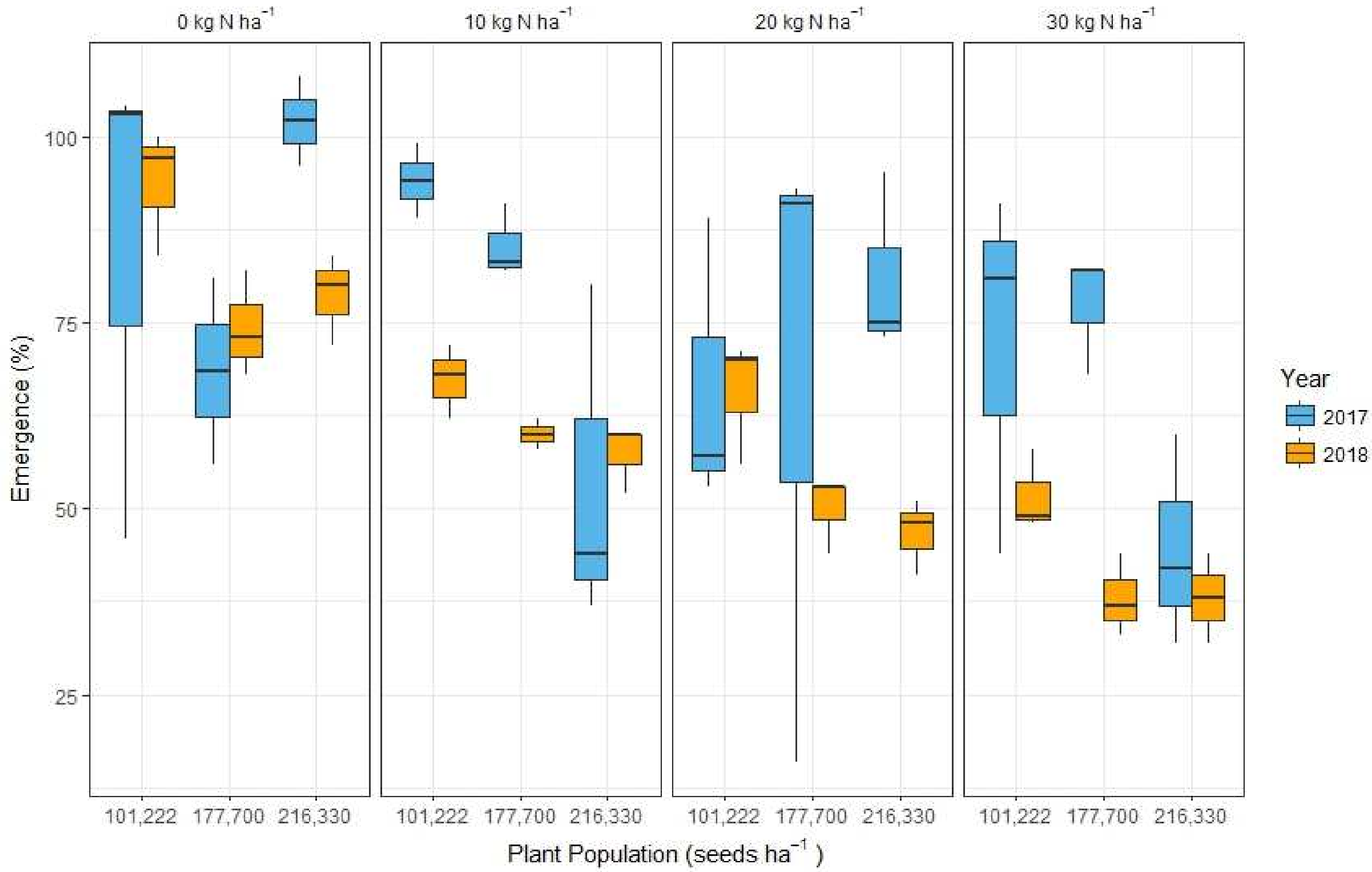

Figure 3. Emergence Percentage by Population Rate and Seeding-N-Rate, Lake Carl Blackwell, OK. 2017 & 2018.

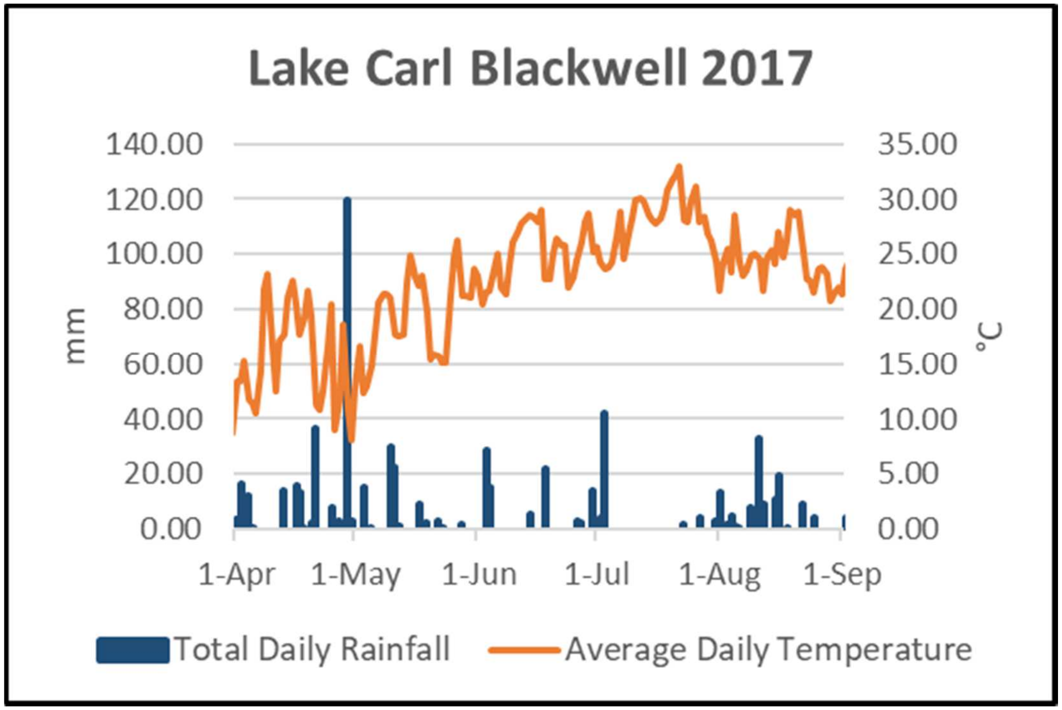

Figure 4. Weather Data, Lake Carl Blackwell, OK. 2017.

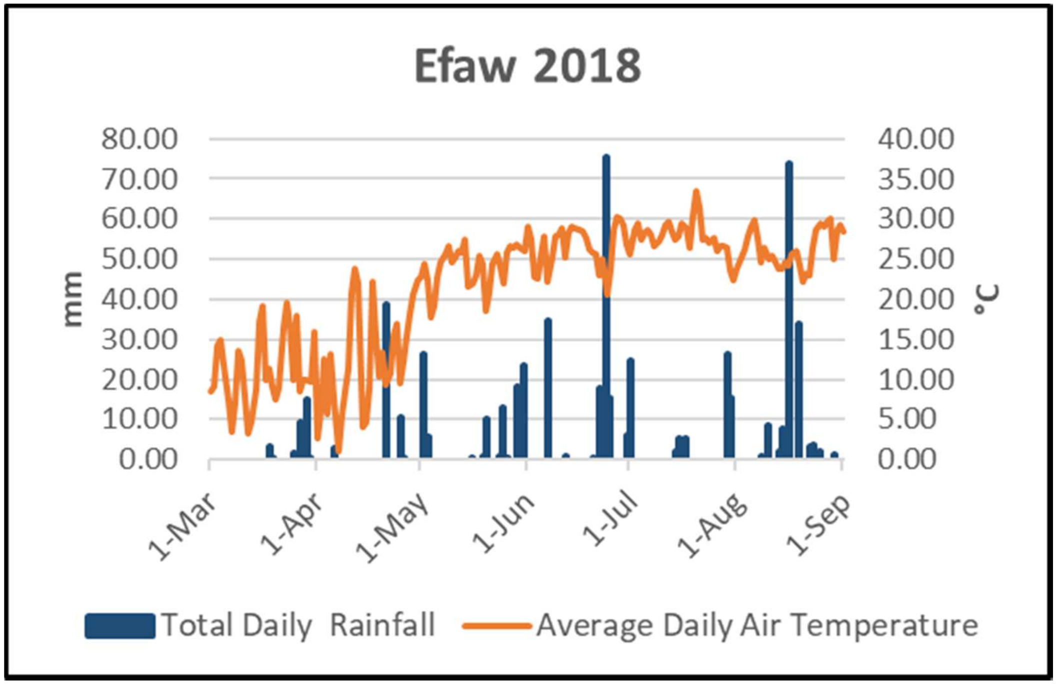

Figure 5. Weather Data, Efaw, OK. 2018.

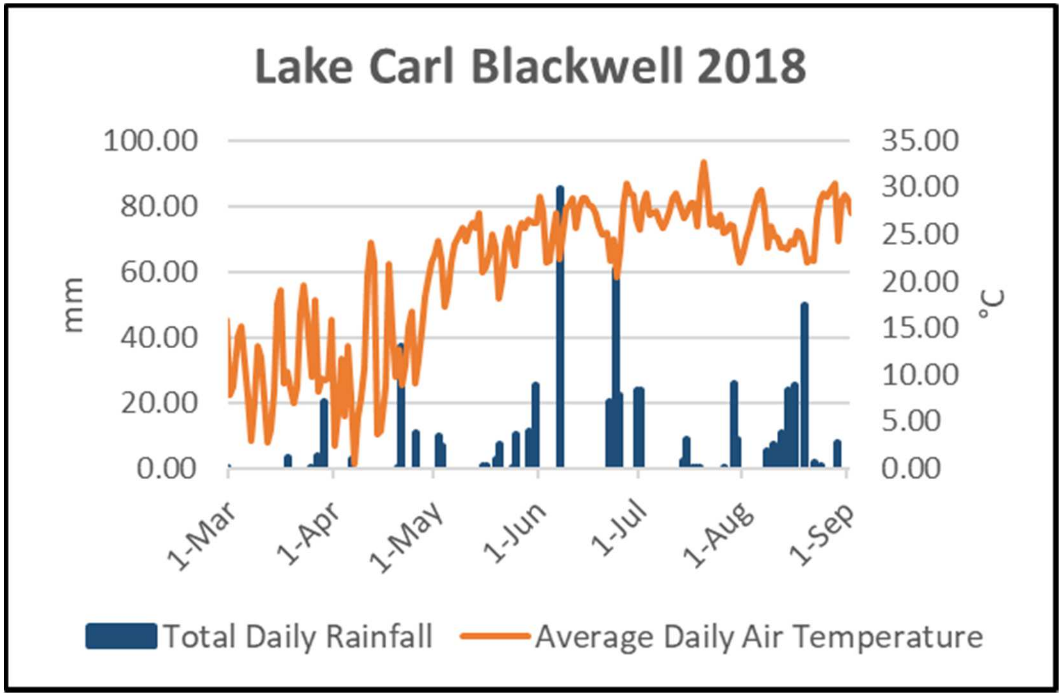

Figure 6. Weather Data, Lake Carl Blackwell, OK. 2018.

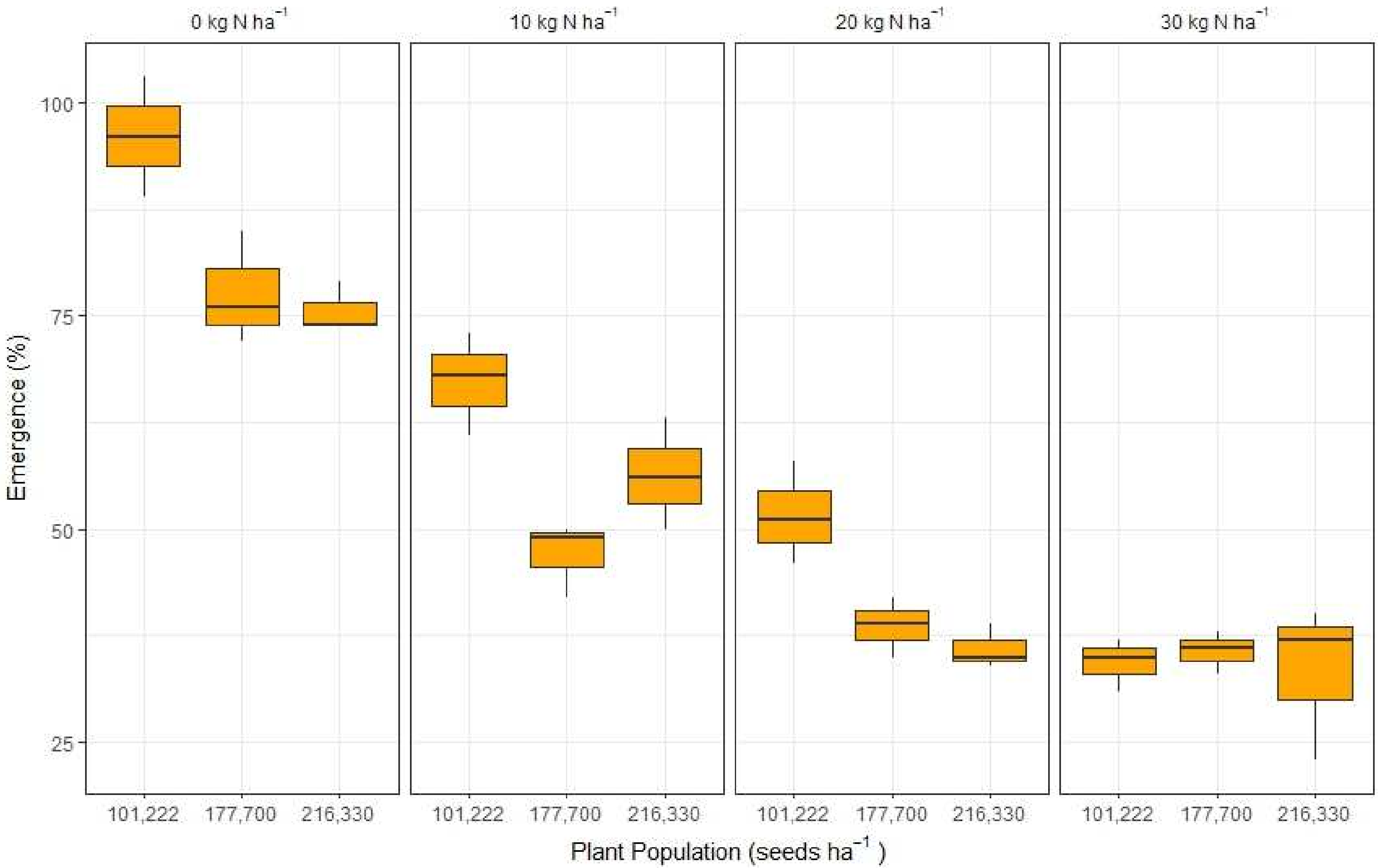

Figure 7. Emergence Percentage by Population Rate and Seeding-N-Rate, Hennessey, OK. 2018.

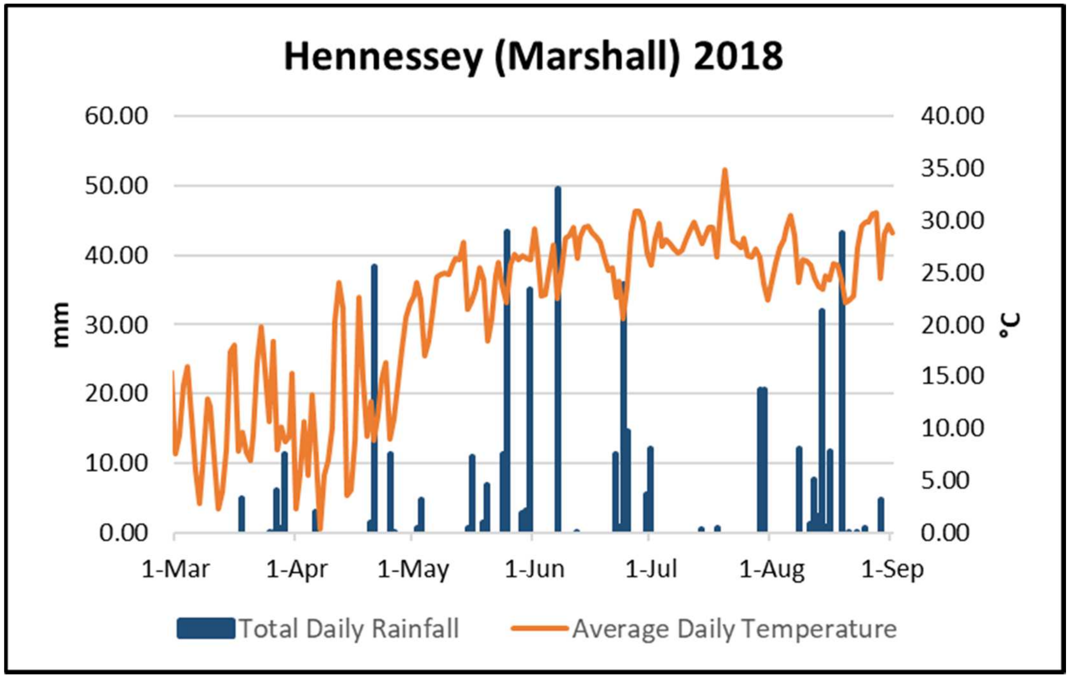

Figure 8. Weather Data, Hennessey, OK. 2018.

APPENDICES

Image 1. Emergence at Lake Carl Blackwell, OK, 2018.

Image 2. Lake Carl Blackwell, OK, 2018

Image 3. Efaw location, Stillwater, OK, 2017.

VITA

Elizabeth Mary Eickhoff

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF APPLYING NITROGEN WITH SORGHUM SEED (*SORGHUM BICOLOR*) ON EMERGENCE AND FINAL GRAIN YIELD

Major Field: Plant & Soil Sciences

Biographical:

Education:

Completed the requirements for the Master of Science in Plant and Soil Sciences at Oklahoma State University, Stillwater, Oklahoma in December 2018.

Completed the requirements for the Bachelor of Science in Agronomy and Agricultural Business at Northwest Missouri State University, Maryville, Missouri in April 2017.

Experience: I have research experience as a Graduate Research Assistant at Oklahoma State University. Prior to graduate school I served as a Crop Scout for two years evaluating crop fields for pest pressures and making management recommendations accordingly.

Professional Memberships: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America