EFFECT OF DIFFERENT METHODS AND TIMING OF NITROGEN (N) APPLICATION ON SORGHUM (*SORGHUM BICOLOR L*) GRAIN YIELD

By

DILLON JACOB DAVIDSON

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Thesis Approved:

Dr. William Raun

Thesis Adviser

Dr. Karen R. Hickman

Dr. Dwayne Cartmell

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Name: DILLON JACOB DAVIDSON

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Abstract: Sorghum *(Sorghum bicolor)* is rapidly becoming an needed crop due to its drought tolerance. High production levels of this crop could assist in fulfilling the intense growing food demands. This study was conducted to determine the effect of different methods and timing of nitrogen (N) application on sorghum grain yield. Data was collected in 2018 at two locations in Oklahoma. Urea was used as the N source where three different rates (0, 30, 60 kg N ha^{-1}) were applied either as a pre-plant application, a side-dress application, or both. Three different N application methods (broadcast, dribble surface band, and the OSU hand planter) were used in this study to see if they had an effect on grain yields. Normalized difference vegetation index (NDVI) readings were taken biweekly throughout the growing season. When no N or low rates were applied with the seed, a loss in yields were recorded. This loss could have different causes, from soil fertility issues, to the abnormal amount of rainfall, or other environmental issues beyond human control. When comparing applied N with the seed to a surface pre-plant and midseason application, a distinct advantage was present for applying N in split applications. This work showed that as much as 30 kg N ha^{-1} can be applied in furrow with the sorghum seed without significant yield reductions

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CHAPTER I

INTRODUCTION

Grain sorghum (*Sorghum bicolor L*) plays an important role in cropping systems and local agricultural economies throughout the world. In 2017, sorghum was ranked in the top five cereal crops in the world (FAO, 2017). This species originated in Africa nearly 7,000 years ago and was introduced to the United States through the slave trade during the 1700-1800's (ICRISAT, 2005). Sorghum is among the most efficient crops in conversion of solar energy and use of water and is known as a high-energy, drought tolerant crop that is environmentally friendly. Due to sorghum's wide uses and adaptation, "sorghum is one of the really indispensable crops" required for the survival of humankind (Jack Harlan, 1971, "All About Sorghum", 2017). In the United States 2.3 million hectares of sorghum were planted with a total of 364 million bushels harvested in 2017 ("All About Sorghum", 2017).

Of the summer crops commonly grown throughout Oklahoma, grain sorghum is the most drought tolerant. According to USDA, in 2017 295,000 hectares of sorghum was harvested in Oklahoma, which is projected to rise in 2018. While sorghum is a major crop in Oklahoma, and throughout the world, acreage has dropped in recent years as

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farmers and ranchers are intensifying and diversifying their major cropping systems. There are other factors that have been influencing sorghum acreage, which include the limited options for weed control, rising cost of inputs, especially fertilizer and fuel, it is beneficial for the producer to develop fertilization practices, that can be adjusted mid-season according to changing weather and potentially enhancing the profitability for sorghum producers. With sorghum being one of the world's most vital crops, the use for the crop has expanded and has become a large fuel source for ethanol, to keep up with the continuous demand of ethanol production (Wang, D., S. Bean, J. McLaren, P. Seib, R. Madl, M. Tuinstra, and R. Zhao, 2008). It is recorded that approximately one-third of sorghum is used for ethanol in the United States, and gives ethanol producers in high drought areas a smart alternative choice to help farmers preserve the local resources (United Sorghum Checkoff Program, 2016). A bushel of grain sorghum can produce the same amount of ethanol as a bushel of corn with less water ("All About Sorghum", 2017). With the ever-evolving food market, sorghum is becoming popular to consumers who have gluten sensitivities. Through research, finding ways to improve yield of sorghum is a high priority to meet the growing demand.

Many research studies have identified that there is an increased understanding of grain sorghum yield throughout the Midwest United States, but there is a lack of research studies accessible to answer questions dealing with producing sorghum in those areas with short growing seasons. The producer plays an extensive role in making the decision of which hybrid to grow to improve the chance of the crop reaching maturity.

Thus, hybrid selection is one of most important factors affecting maturity. The number of required growing degree-days (GDD) to maturity is primarily determined by genetics (Rooney and Aydin, 1999; Quinby and Karper, 1945). Another one of the most overriding factors that affect sorghum yields globally is seeding rates as it is essential to ensure that the amount of seed being planted into the soil is appropriate.

Producers can adjust the seeding rate, row spacing, and row orientation, which can affect the time it takes for the sorghum crop to reach maturity, ultimately affecting grain yield. In rainfed conditions across the Midwest United States, Larson and Thompson (2011) found that increasing the seeding rate of sorghum decreased the time required to reach maturity. Much of this response can be explained by the negative interaction of seeding rate and row spacing of a plant (Baumhardt R.L., J.A Tolk, and S.R. Winter, 2005), with both agronomic practices controlled both by the producer and also light quality mediated by the phytochrome system affect the number of tillers a plant produces (Kasperbauer and Karlen, 1986, Skinner and Simmons, 1993). Therefore, the seeding rate and row spacing have an effect on time to maturity and is correlated to the number of tillers and their time of appearance on a sorghum plant, resulting in delayed time to maturity, giving the producer low yields.

Studies on different row spacing widths have identified a significant affect the number of tillers that plants produce. Field studies by Jones and Johnson (1991) and Staggenborg, S.A., D.L. Fjell, D.L. Devlin, W.B. Gordon, and B.H. Marsh (1999) established that as row spacing widened, the tiller number decreased dramatically due to an increase within-row plant competition, leading to early maturity. The effects of row orientation on maturity have not been studied directly, but a study from Kansas State University, Witt, M.D., R.L. Vanderlip, and L.D. Bark. (1972) concluded that row orientation did not affect evapotranspiration or light interception by the plants, suggesting that row orientation would not significantly impact the number of tillers a plant would produce, therefore not affecting the yield totals.

Nutrient management is one of the most productive ways to increase sorghum yields. Nitrogen tends to be the most limiting nutrient in crop production (Fageria and Baligar, 2005). It takes the correct timing and amount of nitrogen to maximize sorghum grain yield. A lack of these vital nutrients at the critical growth stages will negatively affect sorghum yield. Yield goals, soil test information, and average rainfall are some of the main factors that go into the determination of the amount of nitrogen needed (Baumhardt et al., 2005; Lafarge et al., 2002). These are all variables that must be considered when making an accurate recommendation for nitrogen.

Starter fertilizers, the placement of small quantities of nutrients in a concentrated zone in close proximity to the point of seed placement at the time of planting are becoming increasingly popular in today's agriculture industry (Hergert, G.W., C.S. Wortmann, R.B. Ferguson, C.A. Shapiro, and T.M. Shave (2012). Using Starter Fertilizers for Corn, Grain Sorghum, and Soybeans. NebGuide.). The main benefit of using starter fertilizer is to increase early growth and crop uniformity. Sorghum commonly responds to starter fertilizer with an increased early growth. By applying increased rates of starter fertilizer the number of field passes are reduced and it reduces soil erosion ultimately maintaining surface residue (Deibert, 1994). When the 2x2 rule is implemented, phosphorus fertilizer and band applications are used, which means a strip of fertilizer is placed 0.05 meters beside and 0.05 meters below the soil furrow (Gelderman, 2007). Although studies have shown this method to be effective with positive results, there are also setbacks. By placing the strip of fertilizer in bands beside the furrow, more residue is removed from the soil surface and it increases time and cost inputs. Given these specific setbacks, farmers are seeking methods of fertilizer application that are with the seed. According to a review by Gelderman (2007), placing the fertilizer with the seed can be more beneficial than the traditional 2x2 placement, explained above. In the case of urea, 50% or more of the nitrogen will lose its NH_3 if the fertilizer is applied to the soil surface and not incorporated (Fowler and Brydon, 1989; Hargrove et al., 1977; Raun and Johnson, 1999). When attempting to reduce these losses, applying nitrogen directly with the seed can possibly increase the nitrogen use efficiency of the soil. In this study, the importance is focused on how much nitrogen can be applied directly with the sorghum seed that will result in limited adverse effects on emergence.

Objective

The objective of this study was to determine proper timing and method of nitrogen application, specifically, three different side-dress methods were evaluated to determine effect on sorghum grain yields planted using the Oklahoma State University hand planter.

CHAPTER II

REVIEW OF LITERATURE

By being able to optimize fertilization use, it would allow for producers to assure for the stored water and yield potential for that given year, and in return, the producer might obtain from the investment in side-dressed nitrogen fertilizer. Furthermore, fertilizer rates could potentially be altered to meet the need of producing sorghum. There are several concepts that will be discussed in this chapter, including nitrogen application timing, nitrogen recommendation systems, nitrogen fertilizer placements, use of optical crop sensors, nitrogen rates needed in sorghum production, and the use of the hand planter as a side dress nitrogen applicator.

Nitrogen Timing for Sorghum Production

Having sufficient nitrogen available to the sorghum early in the growth cycle to ensure high yield potential, and making sure that there is sufficient nitrogen remaining late in the season are both essential for the best sorghum yield results. There are many causes that can result in reduced yield potential through incorrect panicle size and reduced seed numbers, but the most common cause is applying no nitrogen or very minimal nitrogen rates at planting, especially in no-till fields.

The layer of crop residue on the soil can reduce the soil temperatures, (Unger 1978; Thomas et al., 1973) and sometimes lower nutrient availability in the earlier stages of growth (Gordon and Whitney, 1995). The application of nitrogen using the dribble surface band, which places the nitrogen fertilizer on the soil surface near the bottom of the plant, within the rooting zone of the young seedlings has been shown to be efficient and beneficial to crop production (Lamond and Whitney, 1991). In a study in several areas of North Central Oklahoma, Raun (2011) reported an increase of 21% in the grain yields of sorghum by application of fertilizer nitrogen in a dribble surface band application. In a tilled scenario, dribble surface band nitrogen responses are not as common, due to the more rapid mineralization of crop residues.

The period where sorghum is at its rapid vegetative growth and nutrient uptake begins around the 30 day mark post-emergence at the six to eight leaf growth stage and continues all the way through pollination and early grain fill (Vanderlip, 1993). Side-dress application of nitrogen using the hand planter during the early periods of growth is feasible and could benefit the crop (Gordon and Whitney, 1995). Since sorghum is normally grown in low rainfall regions, this practice is becoming more popular. Although there is little research comparing the advantages to the disadvantages of using the side-dress method in sorghum, the application of nitrogen fertilizer after planting should not be ignored, specifically in no-till planting scenarios (Vanderlip, 1993). If the application of nitrogen is delayed much past the 5th phase of the growing cycle, it may no longer be as beneficial to the crop, and could damage the sorghum head (See Figure 4).

Nitrogen Recommendation Systems for sorghum

The current nitrogen recommendation for sorghum which is outlined by the University of Nebraska-Lincoln, along with a number of other nationwide systems there are several components considered to calculate an appropriate nitrogen recommendation. Those components consist of yield goal or expected yield term to determine overall nitrogen need by the crop itself, with an expected soil nitrogen supply, estimated from mineralization of soil organic matter and previous crop residue, and where soil profile nitrate-nitrogen is subtracted. The balance is the adequate nitrogen recommendation. For sorghum the nitrogen recommendation equation is:

Nitrogen needed in kg/ha= (Yield Goal Mg/ha x 25.5)-(% SOM x 22) +/- Previous Crop Adjustments – Soil Profile Nitrate-N – Manure N – Other N Adjustments

Although this approach has its advantages, the biggest disadvantage is that yield and nitrogen provided through mineralization are both strongly impacted by in-season weather. USDA National Agriculture Statistics state average yields for Oklahoma ranged from 1930-5280 kg/ha in a five year period (2010-2014). This yield variability make the determination of crop nitrogen need quite difficult, along with determining the soil nitrogen supply. The nitrogen management practices commonly used on sorghum, together with the fact that a majority of the sorghum grown in the Midwest uses the no-till production system (Kastens et al., 2006) may result in lower nitrogen use efficiency, and a resulting need for higher nitrogen applications. Nitrogen application practices for example have been shown to significantly impact nitrogen utilization and crop yield (Bandel et al., 1980; Eckert, 1987; Fox et al., 1986; Lamond, 1987; Mengel et al., 1982). For example, a portion of the broadcast surface applications of nitrogen as urea blends applied in late winter or early spring to wheat stubble, could be immobilized by soil organisms. This nitrogen may not be released in time to be readily available for the planted crop, which would result in a lower nitrogen use efficiency of sorghum and the need to apply higher rates of nitrogen.

Nitrogen Fertilizer Placement

Nitrogen fertilizers need to be applied via methods that will ensure the crop will receive a high level of nitrogen and a high nitrogen use efficiency. There are several studies (Fox and Piekielek, 1987; Fox et al.,1986; Maddux et al., 1984; Bandel et al.,1984) which have thoroughly examined the placement methods needed for no-till production. All of their findings showed that broadcast applications produced lower yields than injected with surface-banded applications. Possible nitrogen loss mechanisms noted with broadcast applications from the urea component of the solution and immobilization of the nitrogen left in the surface reside (Bandel et al., 1984). There has been significantly less research done on nitrogen fertilizer management for grain sorghum in both conventional tillage and no-till systems. However, Raun and students at Oklahoma State University (2011) have found results of higher yields with different application methods. Thus, applying the fertilizer below the soil surface should be more effective than broadcasting or surface banding, both to ensure quick availability and enhancing nitrogen use efficiency.

Use of Optical Crop Sensors for Better Yield Rates

The use of proper timing and placement of fertilizer nitrogen can enhance efficiency and increase sorghum yields if producers deliver the right amount of nitrogen needed, and account for current nitrogen supply in the soil. Determining the appropriate nitrogen need and nitrogen supply is quite difficult in any crop because of the large influence of weather on both, especially with Oklahoma droughts. With sorghum production, this is just as important as the yield, and subsequent nitrogen need can vary widely from season to season. A new and innovative tool that is slowly gaining adoption among producers to assist them in determining nitrogen need and nitrogen supply using optical crop sensors. These crop sensors were developed based on research which has shown that indices based on red/near infrared ratios can be used to estimate leaf area index, green biomass, and crop yield (Araus, 1996). In recent years, there have been advances in technology, which have resulted in instruments that use these concepts to increase nitrogen use efficiency within crops. Some of these instruments that are currently available include: the Spad Chlorophyll Meter (Konica Minolta, Inc., Tokyo, Japan) the GreenSeeker hand held optical sensor (Oklahoma State University, Stillwater, Oklahoma) and the Crop Circle ACS-210 hand held optical sensor (Holland Scientific, Lincoln, NB). Raun et al (2001, 2002) proposed the use of the optical sensors for in-season nitrogen management in winter wheat fields. The work they did using the GreenSeeker hand held optical sensor, used light emitting diodes (LED) to generate light in the red and near infrared bands (NIR). This specific method of using light in the red and near infrared bands give not only an indication of plant biomass, but also, an indication of plant greenness. All data, which helps researchers ensure that the crop is receiving the best in-season nitrogen management possible. This in-season method of estimating top-dress nitrogen rates is based on yield estimated from early-season sensor data rather than pre-season yield goals. The in-season top-dress nitrogen rate is estimated by subtracting the projected nitrogen uptake for the predicted yield in the sensor area, from the projected nitrogen uptake in the non-nitrogen limiting reference strip, and then dividing by an efficiency factor (Stone et al., 1996).

While the GreenSeeker hand held sensor is one of three active sensors currently commercially available for the on-the-go nitrogen applications in grain crops its adoption has been good, but as all devices it does have limitations. When the normalized difference vegetation index is above 0.8 saturation level, no additional application of nitrogen is needed. Detection of differences beyond that point do not make any sense.

Nitrogen Rates Needed for Sorghum Production

Nitrogen is a vital nutrient in plant production, especially in grain sorghum. Nitrogen is a key component in amino acids, which are used for the synthesis of enzymes, which make it important for rapid growth (Hirel et al., 2007). Specifically, for the production of grain sorghum, nitrogen is outlined as the most limiting nutrient (Maddux et al., 1984). Within the soil, nitrogen is present in one of three ways: nitrate, ammonium, and organic compounds. There are many external and internal nitrogen cycling processes that occur within the soil. External processes are those which add or remove nitrogen from the system either through loss pathways or depositions (Hart et al., 1994). Internal processes are those that occur within the soil itself. Such processes include: plant assimilation of nitrogen, nitrogen mineralization and nitrification (Hart et al., 1994). According to McClure from Corteva (2018), 33.6 – 67.3 kg ha^{-1} could be sufficient enough nitrogen supply in drought-like growing conditions for grain sorghum.

Productivity potential and yield goals are factors of how much nitrogen the crop needs. In 2017 the average grain yield for sorghum was 4.01 Mg ha^{-1} in Payne County, Oklahoma (Oklahoma Agricultural Statistics, 2017). When looking at Oklahoma as a state, 67.3 – 84.1 kg nitrogen ha^{-1} is needed to achieve a yield goal of 3.89 – 4.77 Mg ha^{-1} (Arnall, 2015). Yield goals as high as 5.9 – 7.41 Mg ha^{-1} require anywhere from 123.3 – 168.1 kg nitrogen ha^{-1} to achieve that optimum level of grain production (Arnall, 2015). For profitable production of sorghum, location of nitrogen application is key to determine the optimum nitrogen rates needed.

It is crucial to apply appropriate rates of nitrogen in application methods and locations where 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). Research conducted at Kansas State University, found that side dress applications should be applied around 20 days after emergence. At this stage, 33% of the total nitrogen 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 nitrogen is used during this period (KSU Production Handbook, 1998). During these growth stages, nitrogen must not be limiting. Between 30 to 40 days after emergence the potential growth of the grain head is determined (KSU Production Handbook, 1998). At this critical stage, yield potential deceases significantly if nitrogen is limited.

Use of the hand planter as a side dress Nitrogen applicator

Not long after the creation of the GreenSeeker normalized difference vegetation index sensor technology in 2001, Oklahoma State University developed a simple mechanical hand planter capable of singulating sorghum seed, now known as the Greenseeder Hand Planter. With continuing work, this hand planter has been determined to be valuable as a side dress fertilizer applicator with a simple replacement of an internal drum. Across the world, for basic insect control, chemically treated seed is a necessity, but that creates an unacceptable physical risk for men and women who are handling this seed by hand on a daily basis. By implementing the Oklahoma State University hand planter, it eliminates the farmers from handling the seed. Although there are many hand planters with similar shapes, sizes, and weights currently being used, this planter can reliably singulate various seeds, in various soil textures, moisture, and tillage systems via a single strike to the soil surface.

This planter has been tested with various seed sizes and fertilizers, resulting in improved plant spacing which in turn delivers decreased soil erosion and increased yields. The Oklahoma State University designed planter ultimately removes chemically treated seeds from the hands of small-scale farmers. This design eliminates seed-chemical-exposure and other associated health risks for these farmers, especially childbearing women who do much of this work in developing regions. Via a simple internal-drum replacement (see image 4), this planter can be adapted to place urea fertilizer below the surface reducing NH_3 losses and accommodating in-season applications of urea-nitrogen fertilizer.

Fertilizer Drum provides 1.5 grams of urea per strike per plant
(population of 70,000 seeds /ha)
=50 kg nitrogen/ha

Improved nitrogen use efficiency can lead to greater yield totals, which will ultimately boost economic impact for producers adopting this technology. In addition, this planter can also be easily adapted to plant other crops such as corn, rice, wheat, sesame, and can be used to apply any fertilizer to these crops. The distance between strikes or where the seed is placed has to be embedded within the knowledge of the producer. At present, there are over 350 Greenseeder hand planters adopted and being implemented into crop production all over the world (See Image 3).

CHAPTER III

METHODOLOGY

Materials & Methods

This study was conducted in 2018 at two locations Lake Carl Blackwell and Efaw, both research stations for Oklahoma State University near Stillwater, Oklahoma. The Lake Carl Blackwell trial is on a Port-Oscar silty clay loam (Fine, silty, mixed, thermic Cumulic Haplustoll) soil that occasionally floods (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). Composite preplant soil samples by all three replications were taken at each site with results listed in Table 1. A soil core from each treatment was taken 0.15 meters in depth.

This trial consisted of thirteen treatments with three replications. A complete block design was used for this study. Seed populations, seeding nitrogen rates, and application methods were the three independent variables used in the treatment structure, outlined in Table 2.

Field Methods

Each treatment was planted with two methods, a John Deere Max Emerege-2-7300 four-row planter, and the hand planter. Row spacing for this study was 0.76 m. Each treatment was planted with four rows in a 3.05 m by 6.10 m plot. The alleys in between each replication were 1,041.88m^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 numbers of seeds were indeed being planted. In a similar way, before planting, a dry run with the hand planter was performed to determine that it was dropping the appropriate number of seeds per strike. However, in the field setting there is always room for planter error in that it will not always drop the exact number of seeds every time, especially since the sorghum seed is very small in size. In addition, before planting, the dry fertilizer boxes were calibrated to determine the correct gearbox settings in order to apply the appropriate seeding-nitrogen rates of 30 and 60 kg nitrogen ha^{-1}. The dry fertilizer box gear settings can vary depending on a variety of variables. No supplemental fertilizers were used in addition to the urea fertilizer applied with the seed or the urea ammonium nitrate surface applied with the hand planter in half of the treatments. Appropriate herbicide and insecticide applications were made as necessary throughout the season.

Data variables collected and used for analysis were emergence percentages, normalized difference vegetative index readings, and final grain yield. Tables 4 and 5 outline the field activities performed for the 2018-growing season 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 bi-weekly until the V4 growth stage. When determining the final emergence percentage, the last stand count from the center two rows were taken. Averages were divided by the number of plants present in a single row based on the number of seeds planted per row. 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 given variables.

Throughout the growing season, normalized difference vegetation index readings (NDVI) were taken using the GreenSeeker ™ Sensor. Normalized difference vegetation index is calculated as follows:

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

Wavelengths for near infrared bands (NIR) and red are (780 nm) and (671 nm) respectively (Mullen et al., 2003). Normalized difference vegetation index readings are essential in this study as they can be used to estimate the plant biomass, which can be used as a variable of plant health and vigor. Research has shown that NDVI readings can serve as an in-season yield predictor in wheat (Raun et al., 2001). Research at Kansas State University (2012) explains that total accumulated NDVI readings rather than single readings can be used as a more reliable indicator for final yields with sorghum crops, because of the additional stability it offers. Furthermore, the study outlined that the total accumulated readings were linearly correlated with grain yields after the booting stage while biomass was linearly correlated with readings earlier in the season after tillage (Raun, W.R., G.V. Johnson. M.L. Stone, J.B. Solie, E.V. Lukina, W.E. Thomason, and J.S. Schepers, 2001).

At the end of the season, all grain yields were collected. All plots were mechanically harvested using a Kincaid 8XP plot combine. Plots are needed to be harvested sooner than later to prevent yield losses from impending deer and bird feedings. In addition, daily weather records were noted from the local Oklahoma Mesonet sites for both locations. Rainfall amounts along with average daily temperature and cumulative heat units were used in the analysis of this trial.

Each season, new ways to prevent field damage are implemented. This year the major limitations were insect/bird disease damage and weed competition. As the head of sorghum is highly attractive to birds, it makes the crop at high risk for disease. In order to reduce those chances, a piece of silver reflective tape was strung around the parameters of the plot and through the middle to deter the birds from coming into the trials. Weed competition is a problem seen in field trials all over, it is especially a problem in the Lake Carl Blackwell trials. "Johnsongrass, *Sorghum halepense*, is known to be a fast-growing perennial that can grow up to 6 feet tall. This grass is able to spread easily by a system of rhizomes which are horizontal underground roots. Leaf blades are about 1 inch wide and can grow up to 2ft long. The numerous seeds that develop in the fall are yellow to purplish, occurring in a large, spreading, open seed head" (McWhorter, C. G. 1971). This grass quickly blends in with the sorghum, and can take over the trial quickly, ultimately severely damaging sorghum yields. To limit the grass without spraying, weekly visits to the trial, where a hoe was used to eliminate the grass from trial.

CHAPTER IV

RESULTS

Efaw 2018

During the 2018 growing season, statistical differences were seen within normalized difference vegetation index readings (Table 4). On the first and third normalized difference vegetation index readings there were no significant differences, and the fourth having minimal differences, whereas on the second and fifth there were significant differences. The second normalized difference vegetation index reading, on June 28, 2018, there was a cumulative heat unit of 1332. The highest reading was treatment 2 of 0.82, which has a pre-plant rate of nitrogen at 30 kg ha^{-1} and 30 kg ha^{-1} of side-dress rate of nitrogen. The lowest being treatment 10 of 0.73, which had 0 pre-plant nitrogen, and side-dress rate of nitrogen at 30 kg ha^{-1}. The standard error of difference between two equally replicated means was 0.02, therefore there would need to be a difference of 0.04 for it to be significant, and both treatments were applied with by the dribble surface band method. The fifth normalized difference vegetation index reading, on August 07, 2018, there was a cumulative heat unit of 2399.

The highest reading was treatment 6 of 0.72, which consisted of a pre-plant rate of nitrogen at 30 kg ha^{-1} and 30 kg ha^{-1} of side-dress rate of nitrogen and was applied by broadcast. The lowest being treatment 2 of 0.57, which consisted of a pre-plant rate of nitrogen at 30 kg ha^{-1} and 30 kg ha^{-1} of side-dress rate of nitrogen and was applied by dribble surface band method. The standard error of difference between two equally replicated means was 0.02, therefore would need to have a difference greater than 0.04 for it to be significant, which it did. Grain yields ranged from 3.41 to 5.50 Mg ha^{-1}. The highest recorded yield was 5.50 Mg ha^{-1} in treatment 6, which consisted of a pre-plant rate of nitrogen at 30 kg ha^{-1} and 30 kg ha^{-1} of side-dress rate of nitrogen and was applied broadcast. The lowest recorded yield was 3.41 Mg ha^{-1} in treatment 1, which consisted of no pre-plant nitrogen, and no nitrogen side-dress . The standard error of difference between two equally replicated means was 0.57, therefore one would need to have a difference greater than 1 for it to be significant, and that was observed. A total of 329 mm of rain was received during the growing season (Figure 1). Although there were obvious differences among the treatments, grain yields remained consistent for the most part.

Statistical differences were not seen at the Efaw site during 2018 (Table 5). Few differences were noted in the normalized difference vegetation index readings. The most significant difference was in normalized difference vegetation index reading where there was a pre-plant nitrogen rate linear pattern, which means as more nitrogen was applied to the crop, increased yields were recorded. This could be due to fact that as a plant matures, and a split method of nitrogen is applied thus making differences in biomass less noticeable.

Lake Carl Blackwell 2018

In the 2018 growing season at Lake Carl Blackwell, normalized difference vegetation index values were significant, especially for early season readings. The highest average normalized difference vegetation index reading values were recorded on August 7, 2018 with 2314 cumulative heat units. As the crop matured, minor differences were detected through the normalized difference vegetation index readings. Linear trends were found for normalized difference vegetation index until 2314 cumulative heat units were reached. When transitioning with a rate of 30 kg nitrogen ha^{-1} pre-plant and 30 kg nitrogen ha^{-1} side-dress applied from dribble surface band method to broadcast, a decrease in normalized difference vegetation index values were significant until the end of the growing season. Differences between the other nitrogen rates applied among the other normalized difference vegetation index readings there were no significant differences.

Grain yields were highest at this location during the 2018-growing season. Receiving the largest in-season rainfall of 362 mm (Figure 2). Limited supplemental irrigation was added using a linear drop sprinkler system totaling 114.3 mm. Treatment 13, where there was no pre-plant nitrogen applied, and a rate of 60 kg nitrogen ha^{-1} applied as a side-dress using the Broadcast method, produced the highest yield of 7.01 kg ha^{-1}. The variation of yield was significantly different with a coefficient of variation value of 12% and yields ranging from 4.42 to 7.01 kg ha^{-1}. The side-dress nitrogen rates alone showed a significant effect on yields with the broadcast and hand planter methods at a 0.01 probability level. When evaluating yields by nitrogen rate groups, differences were recorded between applying 0 kg nitrogen ha^{-1} pre-plant, and 30 or 60 kg nitrogen ha^{-1} side-dress with the different application methods.

With overall non-significant differences within the Lake Carl Blackwell location, there were a few significant differences found within the individual normalized difference vegetation index readings. There was a significant difference in normalized difference vegetation index readings 2 and 4 when contrasting side-dress methods broadcast vs hand planter and dribble surface band methods. There was a significant difference at the 0.01 probability level in normalized difference vegetation index reading 2, meaning that there was a large difference when the 90 kg nitrogen ha^{-1} was applied broadcast rather than the other two methods. There was a significant difference at the 0.05 probability level in normalized difference vegetation index reading 4, meaning there a significant difference in the fact that the broadcast application had higher readings right after the nitrogen rates were applied. A significant difference at the 0.01 probability level in 2^{nd} normalized difference vegetation index reading when contrasting the side-dress method of dribble surface band application vs hand planter and broadcast methods. There was a pre-plant nitrogen rate linear seen in 3^{rd} normalized difference vegetation index reading, with a significant difference at the 0.05 probability level, meaning that the yields were higher when a higher rate of nitrogen was applied. There was a significant difference at the 0.05 probability level in the 5^{th} normalized difference vegetation index reading, and a side-dress nitrogen rate linear with the broadcast application method was present. Finally, there was a side-dress nitrogen rate linear with the dribble surface band application and a significant difference at the 0.05 probability level was seen in both 2nd and 3^{rd} normalized difference vegetation index readings.

CHAPTER V

DISCUSSION

Consistent differences were seen in the analysis of data across both sites evaluated in 2018. Seeding nitrogen rate and application methods were not an influencing factor in that as higher nitrogen rates were applied with the seed, there was not a significant difference in yields. A previous study where nitrogen was banded with sorghum seed resulted in 5- 42% loss in plant stand when nitrogen was applied at 0.0035 kg per meter of row (25 kg nitrogen ha^{-1}) (Smithfield. 1999). The rate of nitrogen applied in this study was 0.0035 kg per meter of row which would be comparable to a rate of 25 kg nitrogen ha^{-1}. Results from our study are not comparable as we did not see a significant difference when we applied 30 kg nitrogen ha^{-1} to 60 kg nitrogen ha^{-1} to 90 kg nitrogen ha^{-1} with the different methods of broadcast, hand planter, and dribble surface band. Where we did see some significant differences was in the split application methods of nitrogen rates.

From our data, consistent differences were not seen in yield levels by applying nitrogen with the three different methods. A possible reasoning for this finding might be because sorghum has tillering abilities. Research from Kansas State University found that sorghum has the ability to compensate for losses during early growth stages (Gelderman, 2007). Further studies have outlined that planting densities along with hybrid selection does influence 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.

Given that there were no significant differences within the yields in terms of the application methods, that is a good sign for the hand planter. That means that the hand planter that has been developed for farmers in developing countries does work, and does meet the standards that the more common applications have been meeting. Therefore, that means the hand planter would indeed be a beneficial resource for those farmers in developing countries who are trying to grow their production in a more efficient manner.

When analyzing the grain yield results, it is essential to note that total nitrogen levels needed for grain sorghum production were not applied. An adequate nitrogen rate for the Oklahoma region for sorghum production is 67 – 84 kg nitrogen ha^{-1} (Arnall, 2015). When looking at this type of study in the future, putting an additional midseason application of 90 kg nitrogen ha^{-1} along with an in furrow rate could be useful in discovering total impacts on grain yield. The nitrogen 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 study.

GreenSeeker Sensor readings showed the most significant differences across both locations during the 2018 growing season. The seeding nitrogen rate showed some effect on normalized difference vegetation index values right after the application was applied.

Sensor readings were 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 nitrogen application recommendations. As noted earlier, work by Bartholome (1989) delineated that accumulated normalized difference vegetation index readings rather than single normalized difference vegetation index 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.

CHAPTER VI

CONCLUSIONS

Higher nitrogen rates applied with sorghum seed contributed to larger yield totals. When no nitrogen or low rates were applied with the seed, a loss in yields were recorded. This loss could have different causes, from soil fertility issues, to the abnormal amount of rainfall, or other environmental issues out of human control. When comparing applied nitrogen with the seed to a surface pre-plant and midseason application, we saw that there was a slight significant different when the nitrogen applications were split. Considering the different nitrogen rates applied at the different times, with the three different methods, there must be other outlining reasons as to why there was no significant effect on yields.

Furthermore, no differences were seen in yield levels for surface applied nitrogen treatments either. This suggests that as much as 30 kg nitrogen ha^{-1} can be applied in furrow with sorghum without yield reductions. The hand planter, as used for seeding and fertilizer applications in this study, resulted in similar sorghum yields as with the other application methods. These results suggest use of the hand planter as a suitable substitute in less-developed agricultural systems. In future studies on this topic, an additional nitrogen application of 90 kg ha^{-1} may be needed in order to fulfill the crop’s nitrogen requirements for the growing season.

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LIST OF TABLES

Table 1. Pre-plant soil test characteristics at (0-0.15 m) and soil classification at Efaw, and Lake Carl Blackwell, OK. 2018.

Year	Location	pH	OM %	NH_4-N	NO_3-N	P	K
				--------------------------- mg kg^{-1}			----------------------------
2018	Efaw Rep 1	7.3	1.36	1.7	1.9	41	351
	Efaw Rep 2	7.1	1.52	4.3	20.1	40	401
	Efaw Rep 3	6.9	1.42	1.5	2.1	60	338
Classification: Norge loam (Fine-silty, mixed , active, thermic Udic Paleustoll)							
2018	Lake Carl Blackwell Rep	6.9	1.82	1.9	0.6	177	258
	Lake Carl Blackwell Rep	7.2	1.53	2.8	9.2	32	308
	Lake Carl Blackwell Rep	6.2	1.62	5.7	4.1	155	264
Classification: Port- Oscar silty clay loam (Fine-silty, mixed thermic Cumulic Haplustoll)							

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	Planting Method	Pre-plant N Method	Pre-plant N Rate kg N ha^{-1}	Side-dress N Rate kg N ha^{-1}	Mid-season N Method
1	HP		0	0	
2	HP	DSB	30	30	DSB
3	HP	DSB	60	30	DSB
4	HP	DSB	30	30	HP
5	HP	DSB	60	30	HP
6	HP	DSB	30	30	Broadcast
7	HP	DSB	60	30	Broadcast
8	HP		0	30	HP
9	HP		0	60	HP
10	HP		0	30	DSB
11	HP		0	60	DSB
12	HP		0	30	Broadcast
13	HP		0	60	Broadcast

** HP- hand planter, DSB- dribble surface band, N-nitrogen

Table 3. 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 Dat
Efaw	Norge loam	04/11/2018	04/16/2018	05/01/2018	05/14/2018 05/21/2018 05/24/2018 05/28/2018	06/12/2018 06/28/2018 07/10/2018 07/24/2018 08/07/2018	06/13/2018	09/111/2018
Lake Carl Blackwell	Port Oscar silty clay loam	04/13/2018	04/19/2018	05/02/2018	05/15/2018 05/18/2018 05/21/2018 05/25/2018	05/24/2018 06/12/2018 06/28/2018 07/10/2018 07/24/2018 08/07/2018	06/12/2018	09/17/2018

Table 4. Treatment structure, treatment means, main effect model, and single-degree-of-freedom contrasts for NDVI, and grain yield, Lake Carl Blackwell, OK, 2018.

Treatment	Pre-plant N Rate kg N ha^{-1}	Side-dress N Rate kg N ha^{-1}	Mid-season N Method	NDVI, Cumulative Heat Units 896	1289	1601	1985	2314	Grain Yield (Mg ha^{-1})
1	0	0	--	0.81	0.78	0.77	0.73	0.68	5.52
2	30	30	DSB	0.81	0.78	0.78	0.71	0.66	5.51
3	60	30	DSB	0.80	0.77	0.77	0.70	0.62	5.01
4	30	30	HP	0.80	0.77	0.66	0.71	0.67	4.69
5	60	30	HP	0.81	0.78	0.76	0.68	0.66	5.48
6	30	30	Broadcast	0.79	0.77	0.76	0.71	0.65	4.42
7	60	30	Broadcast	0.79	0.77	0.76	0.71	0.67	6.00
8	0	30	HP	0.79	0.76	0.74	0.73	0.67	5.94
9	0	60	HP	0.79	0.77	0.75	0.72	0.76	6.90
10	0	30	DSB	0.78	0.75	0.74	0.73	0.67	5.13
11	0	60	DSB	0.78	0.76	0.74	0.73	0.68	6.32
12	0	30	Broadcast	0.79	0.78	0.74	0.70	0.67	6.09
13	0	60	Broadcast	0.79	0.78	0.76	0.72	0.67	7.01
SED				0.02	0.01	0.16	0.13	0.04	0.56
CV				3	1	3	2	7	12
Statistical Analysis									
Pre-plant: Side-dress Method DSB vs (HP&BC)				ns	ns	ns	ns	ns	ns
Pre-plant: Side-dress Method HP vs (DSB&BC)				ns	ns	ns	ns	ns	ns
Pre-plant: Side-dress Method BC vs (HP&DSB)				ns	ns	ns	ns	ns	ns
Side-dress Method DSB vs (HP&BC)				ns	**	ns	ns	ns	ns
Side-dress Method HP vs (DSB&BC)				ns	ns	ns	ns	ns	ns
Side-dress Method BC vs (HP&DSB)				ns	**	ns	*	ns	ns
Pre-plant nitrogen rate Linear				ns	ns	*	ns	ns	ns
Side-dress nitrogen rate Linear (HP)				ns	ns	ns	ns	ns	ns
Side-dress nitrogen rate Linear (BC)				ns	ns	ns	ns	ns	*
Side-dress nitrogen rate Linear (DSB)				ns	*	*	ns	ns	ns

SED – standard error of the difference between two equally replicated means, CV – coefficient of variation
ns, *, **, not significant, and significant at the 0.05 and 0.01 probability levels respectively, DSB- dribble surface band, HP- hand planter, BC- broadcast

Table 5. Treatment structure, treatment means, main effect model, and single-degree-of-freedom contrasts for NDVI readings, and grain yield, Efaw, OK, 2018.

Treatment	Rate kg N ha^{-1}	Side-dress N Rate kg N ha^{-1}	Mid-season N Method	NDVI, Cumulative Heat Units 927	1332	1659	2057	2399	Grain Yield (Mg ha^{-1})
1	0	0	--	0.80	0.79	0.73	0.62	0.60	3.41
2	30	30	DSB	0.86	0.82	0.76	0.65	0.57	4.81
3	60	30	DSB	0.79	0.81	0.72	0.66	0.60	4.68
4	30	30	HP	0.78	0.81	0.73	0.65	0.61	4.78
5	60	30	HP	0.80	0.81	0.75	0.65	0.58	5.07
6	30	30	Broadcast	0.81	0.81	0.73	0.65	0.72	5.50
7	60	30	Broadcast	0.82	0.80	0.73	0.67	0.60	5.22
8	0	30	HP	0.82	0.79	0.74	0.68	0.61	4.98
9	0	60	HP	0.81	0.80	0.74	0.66	0.63	4.36
10	0	30	DSB	0.82	0.73	0.74	0.64	0.62	5.12
11	0	60	DSB	0.79	0.81	0.73	0.66	0.63	4.26
12	0	30	Broadcast	0.76	0.79	0.72	0.64	0.60	4.44
13	0	60	Broadcast	0.77	0.78	0.74	0.64	0.60	4.50
SED				0.04	0.02	0.02	0.03	0.02	0.57
CV				6	3	3	5	5	21
Statistical Analysis									
Pre-plant: Side-dress Method DSB vs (HP&BC)				ns	ns	ns	ns	ns	ns
Pre-plant: Side-dress Method HP vs (DSB&BC)				ns	ns	ns	ns	ns	ns
Pre-plant: Side-dress Method BC vs (HP&DSB)				ns	ns	ns	ns	ns	ns
Side-dress Method DSB vs (HP&BC)				ns	ns	ns	ns	ns	ns
Side-dress Method HP vs (DSB&BC)				ns	ns	ns	ns	ns	ns
Side-dress Method BC vs (HP&DSB)				ns	ns	ns	ns	ns	ns
Pre-plant nitrogen rate Linear				ns	**	ns	ns	ns	ns
Side-dress nitrogen rate Linear (HP)				ns	ns	ns	ns	ns	ns
Side-dress nitrogen rate Linear (BC)				ns	ns	ns	ns	ns	ns
Side-dress nitrogen rate Linear (DSB)				ns	ns	ns	ns	ns	ns

SED – standard error of the difference between two equally replicated means, CV – coefficient of variation
ns, *, **, not significant, and significant at the 0.05 and 0.01 probability levels respectively, DSB- dribble surface band, HP- hand planter, BC- broadcast

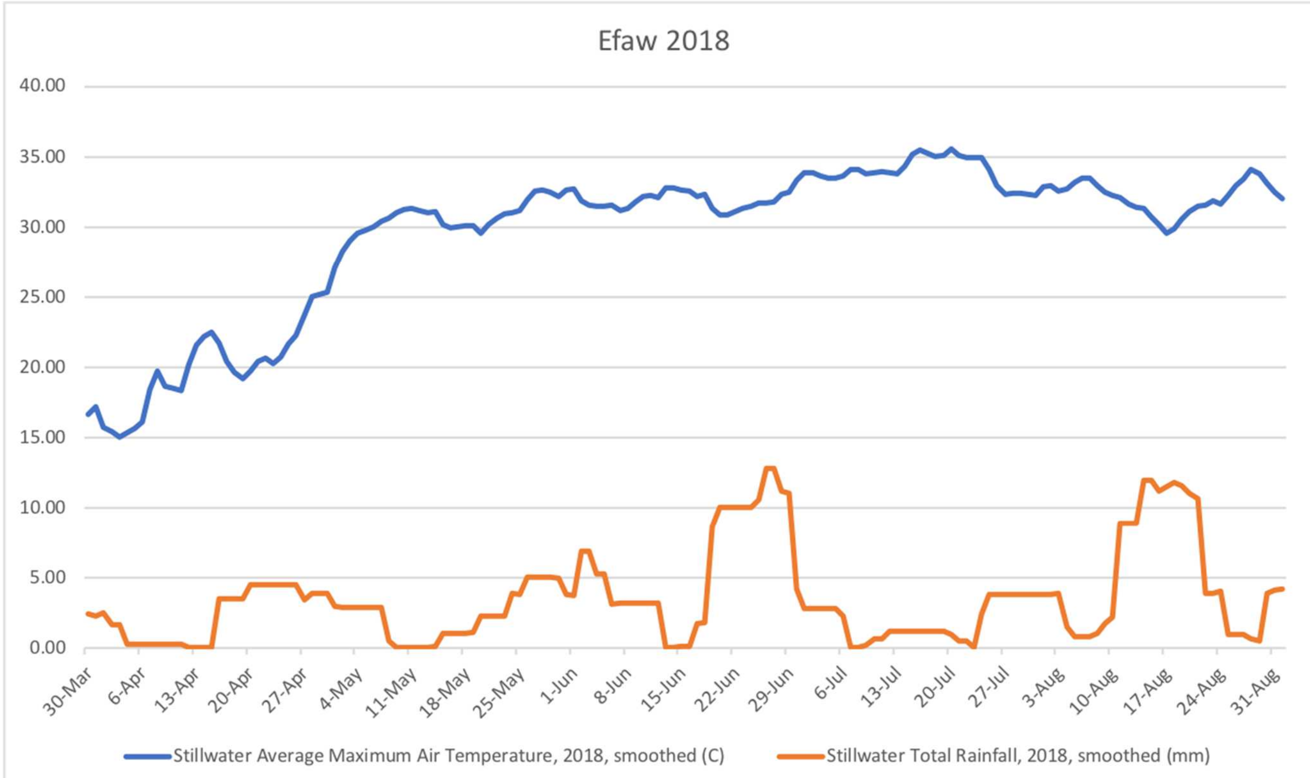

FIGURE 1. Weather Data, Efaw, OK. 2018. Source: http://mesonet.org/

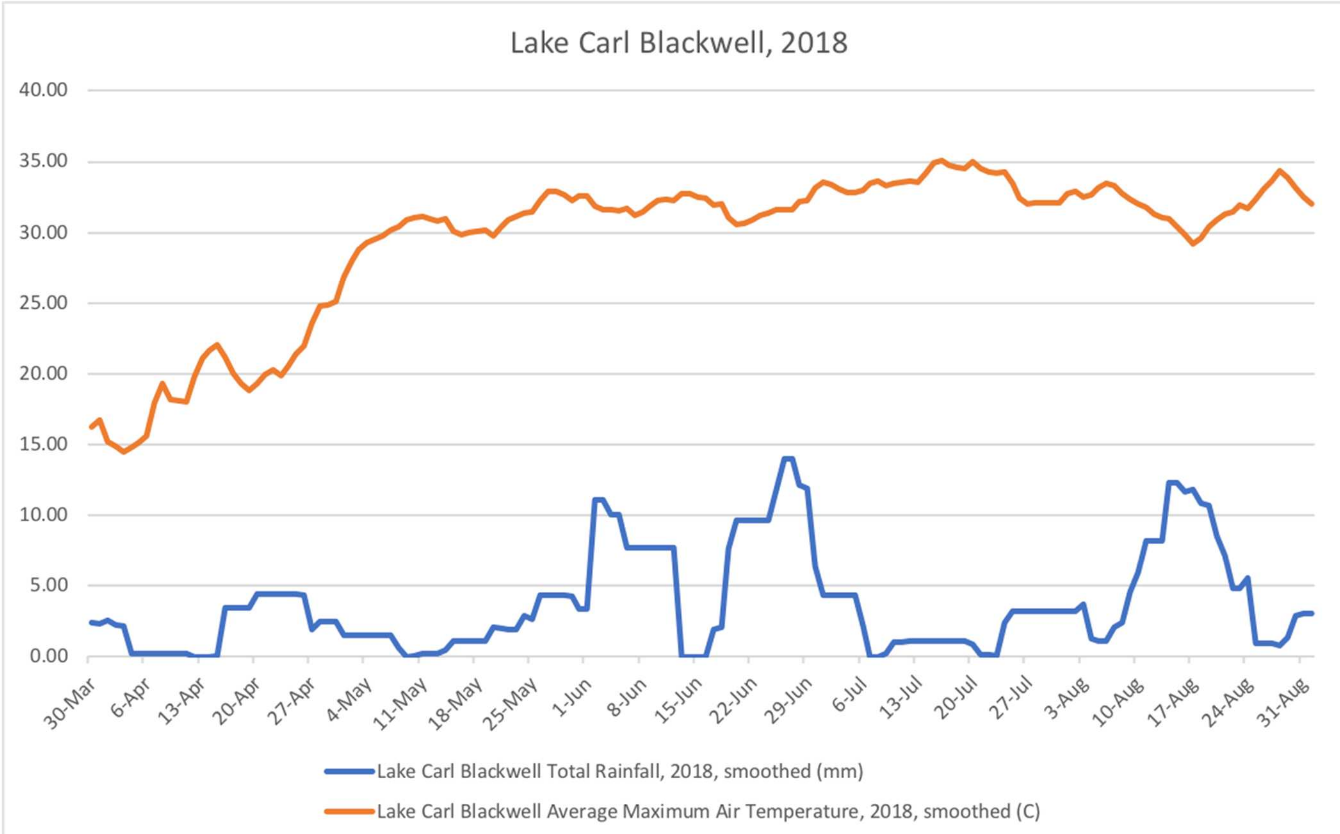

FIGURE 2. Weather Data, Lake Carl Blackwell, OK. 2018. Source: http://mesonet.org/

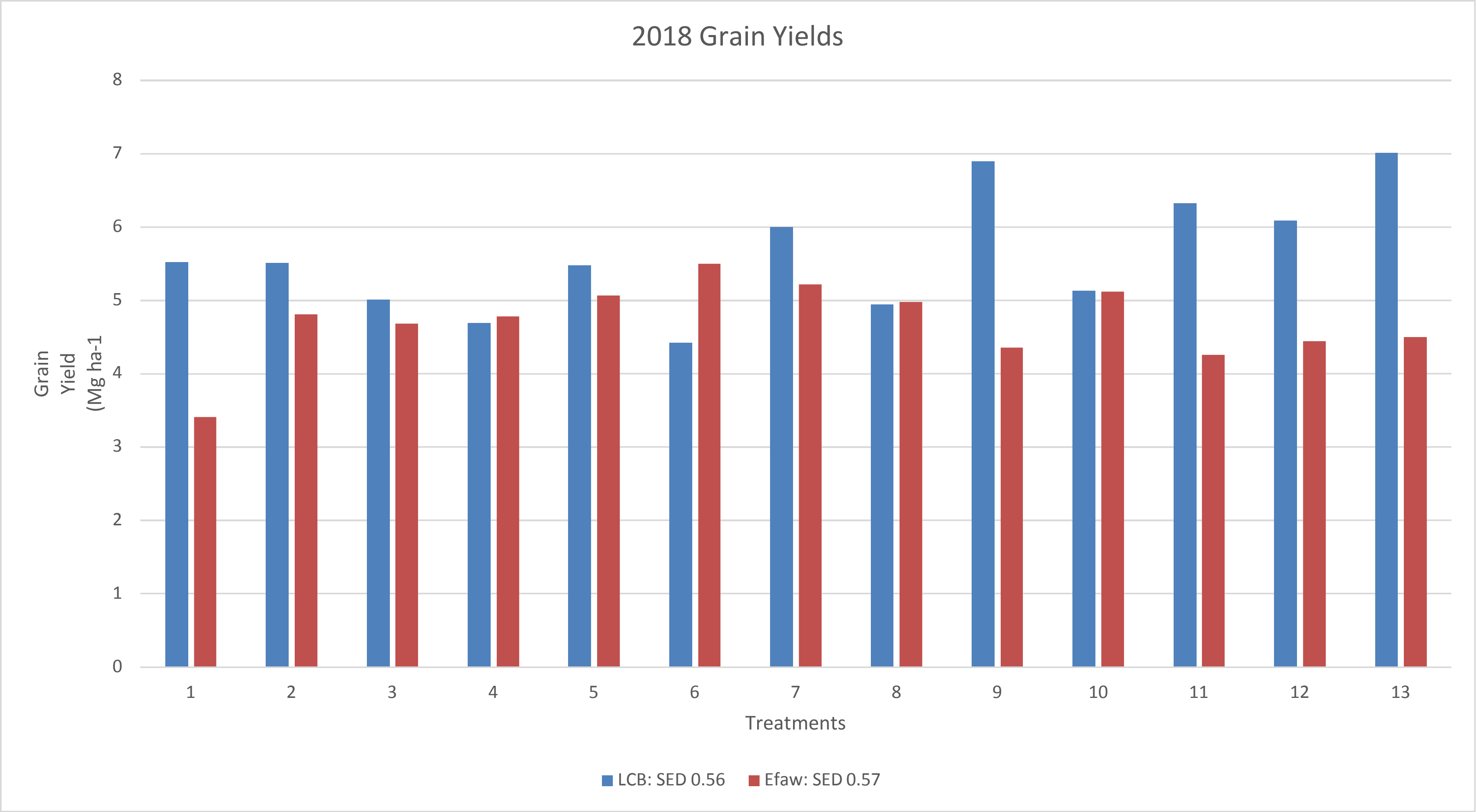

FIGURE 3. 2018 Yield Data, Efaw and Lake Carl Blackwell (LCB), Stillwater, Oklahoma. Yield Results for 2018 where there was a Standard Error of Difference (LCB): 0.56 Mg ha^{-1}, Standard Error of Difference (Efaw): 0.57 Mg ha^{-1}

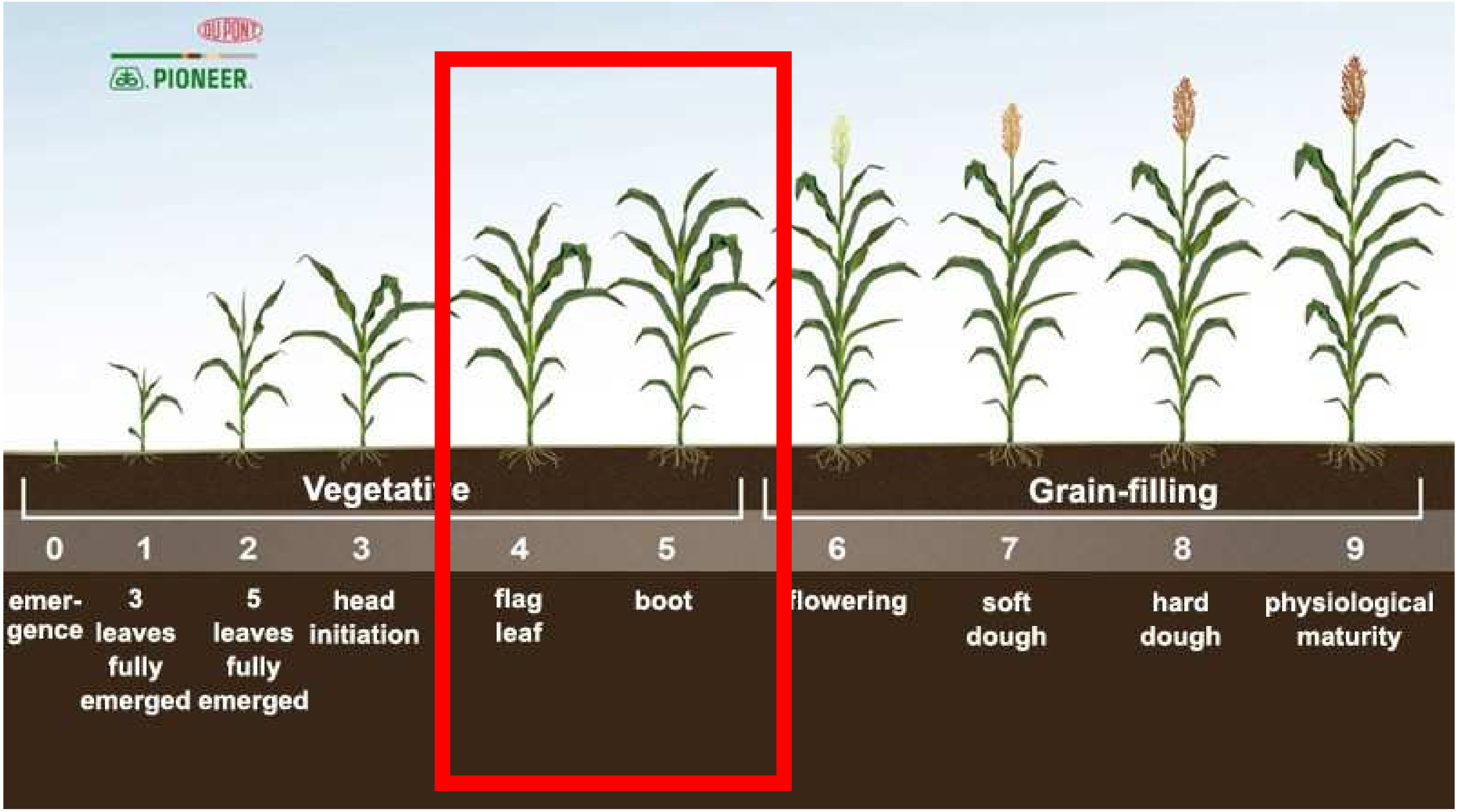

FIGURE 4. The growth stages of sorghum, and a visual outline (red box) of when mid-season nitrogen should be applied. Source: https://www.pioneer.com/CMRoot/Pioneer/US/Non_Searchable/agronomy/cropfocus_pdf/grain_sorghum_mgmt.pdF

APPENDICES

IMAGE 1- Mid-season growth stage, Efaw, 2018.

IMAGE 2. A closeup of the hand planter head, to illustrate urea nitrogen application during a strike to the soil. Source: http://www.nue.okstate.edu/Hand_Planter.htm

IMAGE 3. A An example of the hand planter being adopted by farmers in East Africa. Source: http://www.nue.okstate.edu/Hand_Planter.htm

IMAGE 4. This is an example of a hand contaminated with treated seed. The red color is from one product, and the blue color is from another product. Farmers using the chuzo carry the seed and do not wear gloves, the use of the hand planter would eliminate this problem. (photo courtesy of Edgar Ascencio).

VITA

Dillon Jacob Davidson

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF DIFFERENT METHODS AND TIMING OF NITROGEN (N) APPLCATION ON SORGHUM (*SORGHUM BICOLOR L*) GRAIN YIELD

Major Field: International Agriculture

Biographical:

Education:

Completed the requirements for the Master of Science in International Agricultural Trade and Development at Oklahoma State University, Stillwater, Oklahoma in May 2019.

Completed the requirements for the Bachelor of Science in International Agricultural Business at Wilmington College, Wilmington, Ohio in May 2017.

Experience: I have experience in research and teaching as a Graduate Teaching Assistant at Oklahoma State University. During graduate school, I served as an intern for Oklahoma Department of Agriculture as an International Marketing Intern. Prior to graduate school, I served as an sustainability and urban farming intern in Washington, D.C. as well as serving as a program volunteer in rural Tanzania, working on farming and fertilizer techniques.

Professional Memberships: Agriculture Future of America, National FFA Alumni Association, Young Agricultural Professionals, American Farm Bureau