OPTIMUM TIME AND RATE OF FERTILIZER NITROGEN FOR WHEAT (TRITICUM AESTIVUM) AND MAIZE (ZEA MAYS L.) GRAIN YIELD

By

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OPTIMUM TIME AND RATE OF FERTILIZER

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AND MAIZE (ZEA MAYS L.) GRAIN YIELD

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Title of Study: OPTIMUM TIME AND RATE OF FERTILIZER NITROGEN FOR WHEAT (TRITICUM AESTIVUM) AND MAIZE (ZEA MAYS L.) GRAIN YIELD

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Abstract (Corn): Corn yield can be related directly to the crop's nitrogen use efficiency (NUE). A study was conducted in 2017 at two locations, Lake Carl Blackwell (LCB) and EFAW both located near Stillwater, OK. This experiment was conducted under dryland and irrigated conditions. All trials employed randomized complete block experimental designs with three replications. Nitrogen (N) applications included pre-plant, sidedress and a combination of preplant and sidedress N applied. Normalized difference vegetation index (NDVI) data was collected using an active GreenSeeker sensor to confirm N response. Results of this experiment confirmed the initial hypothesis that single N application before planting or sidedress were not as effective as split applications. Split fertilizer application delivered increased corn grain yields. To obtain maximum yields in irrigated corn, the optimum N application consisted of a sidedress rate of 134 kg N ha^{-1}. The rainfed site showed a similar pattern requiring 134 kg N ha^{-1} sidedress. Low NUE for dryland corn can be attributed to the lack of appropriate water at essential times during the growing season. A pattern or trend was observed in this data suggesting the need for sidedress N applications in either dryland or irrigated environments. The crop can regulate and use N as needed, but is benefitted by having a single application to obtain maximum yield.

Abstract (Winter Wheat): Wheat yields to a certain extent tied to the expected nitrogen use efficiency (NUE). A total of five field experiments were conducted from 2017 to 2018 all under dryland conditions. The experimental design was a completely randomized block with three replications and twelve treatments. At these five locations, nitrogen (N) was applied pre-plant, sidedress, and/or split. Normalized difference vegetation index (NDVI) data was collected using a GreenSeeker sensor to validate N response. Results of this experiment confirmed the initial hypothesis that single applications pre or sidedress were not as effective as split applications. Estimated NUE values were higher for the split N applications when compared to N applied either all preplant or all sidedress. The highest yielding treatment consisted of 67 kg N ha^{-1} applied pre-plant, followed by a sidedress application of 67 kg N ha^{-1}. Low NUE for pre-plant only and for the sidedress only applications can be attributed to sporadic moisture availability at essential times during the growing season. Split N applications consistently delivered increased yields and elevated NUE.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The economics of farming continue to become more variable every year. Farmers change practices when improved methods are proven through concrete research. The most consistently responsive and most limiting nutrient for plants is nitrogen (N). It is becoming more critical to refine the optimum N rate for cropping systems. Every year the cost of fertilizer continues to rise making it more important for producers to apply correct N rates that ultimately result in better profitability. Ground water pollution is also becoming a concerning problem resulting from inefficient fertilizer applications. Consistent yield increases are needed worldwide in order to fulfill food demands for 7.3 billion people, which is growing, to 9.7 by 2050. Applying appropriate N rates can ultimately improve producer's profitability, decrease fertilizer contamination in water supplies, and increase yields to meet growing food demands.

Producers strive to achieve the highest yields while still maintaining crop quality in order to be profitable. In 2015, the United States produced 345 billion kg of maize (USDA, 2016). In 2017, Oklahoma planted a total of 141,639 ha of maize, of which 123,429 ha were harvested for grain. The average yield per ha for 2017 in Oklahoma was 8,097 kg (USDA, 2017).

Oklahoma's number one annually produced crop is wheat. In 2017, over 1.8 million ha of wheat were planted in Oklahoma. Of the total area planted, 1.2 million ha were harvested

(USDA, 2017). The United States as a whole planted a total of 20.5 million ha to wheat in 2016. The total production of the US that year was 22.3 billion Mg of wheat (USDA, 2017).

Objective

To determine the optimum preplant N rate in maize (Zea mays L.) and wheat (TRITICUM AESTIVUM L.) combined with topdress N to maintain yield and improve NUE.

CHAPTER II

REVIEW OF LITERATURE

Nitrogen Rates Needed for Maize and Wheat Production

Maize

The value of knowing the optimum pre plant N rate can be found in the reduction of cost for the producer, reduction in harm to the environment, the safe and effective production of crops. In order to determine needed N rates for corn production several factors must be considered. Expected yield, soil N levels and organic matter all factor into the needed N rate (Shapiro et al. 2008). Work by Stanford also expresses the need for mineralized N information and the predicted efficiency of plant available N when it replenishes itself (Stanford, 1973). Nitrogen being the most influential nutrient for maize it is often used in excess and thus can become a pollutant to ground water via NO_3 leaching (Andraski, 2000). Application of N should be prescribed based on those factors that contribute to improving its efficiency. Water is the most limiting factor in the production of maize (Freeman et al., 2007). The soil texture should be included into the equation as it has a significant role in N use efficiency. In fine textured soils, the maize's response to added N was significantly greater as compared to medium textured soil (Tremblay, 2012). Additionally, it was found in this study that timely N applications along with needed rainfall amounts can contribute to a greater N response.

The effect of water stress in maize is clear when observing maize under irrigation where water is not the most limiting factor. The most significant period of yield loss due to stress is during the period of growth when grain filling occurs in maize. A study conducted by Eck, H. V. (1984.) found that yields were reduced by 1.2% per day during the grain filling period if the maize was under a length of stress. This study also found that when given an adequate amount of N, grain yields were slightly increased when the plant was under stress. However, when the plant was stress free, grain yield increased greatly when given an adequate amount of N.

Worldwide producers have the same issue with application Nitrogen and utilizing the applied amount to its poteintial. According to Raun and Johnson (1999.), the worldwide production of cereal grains has an NUE of 33%. A study conducted by Ladha and Pathak (2005.) currently the world utilizes 60% of the total global N fertilizers on three crops: maize, rice, and wheat. Globally, the farmer practice applications of N are usually large and effective for maintaining maximum yields, such practices lower the NUE greatly. Better methods for applying N can be found in utilizing modern technology. A study conducted by Raun and Solie (2002.) found that mid-season sensor based application rates improved NUE by >15%. To improve the NUE worldwide, application methods must also be adjusted as well. According to Mahler and Koehler (1994.) splitting the timing of the N application showed greater increase of NUE up 61% in winter wheat.

Nitrogen rates needed for maize production can vary from location to location. Rainfall is a critical influencing factor to the N rate needed as it directly affects the potential yield levels of which N rates are dependent upon. According to the University of Nebraska, 135 to 207 kg N ha^{-1} are needed to produce 5.6 to 9.4 Mg ha^{-1} where little to N is present in the soil and organic matter is at 1% (Shapiro et al., 2008). Other work from Iowa State University recommends that rates of 168 to 224 kg N ha^{-1} be applied in a continuous corn rotation (Blackmer, 1997). However, in a corn soybean rotation 112 to 168 kg N ha^{-1} are recommended (Blackmer, 1997). N rates needed for maize production in Oklahoma can range from 56 to 101 kg N ha^{-1} to achieve yields of 3.1 to 5.5 Mg ha^{-1} (Zhang, 2006).

Wheat

The competition to produce large quantities of crops like wheat worldwide has increased, in doing so the N use efficiency has decreased. Larger amounts of N are being applied to obtain higher yields which have resulted in higher water pollution levels worldwide. The United States ranks fourth in total production levels of wheat (FAO, 2016). China is the top producing country of wheat with 131 million tonnes produced in 2016 (FAO, 2016).

Wheat is most responsive to N compared to other nutrients, however the response is variable due to environmental factors (Nagelkirk, 2016). A study of optimum N application in winter wheat in China found that increasing N rates led to increasing N losses. When applying an optimum N rate of 96 kg N ha^{-1} an average loss of 15 kg N ha^{-1} was observed. This was significantly less compared to the farmer practice where more than 100 kg N ha^{-1} was lost form the system (CUI, 2006). There are 120 million tons of synthetic N applied to cropland worldwide every year. The problem being that more than half of this is not being utilized by the crops, instead it is washing from the fields into rivers and streams (Pearce, 2018). The low efficiency of N application is a major cause of pollution to water. A review by Spalding and Exner (1992) explains that regions where well drained soils were predominately crop land systems, it was found that groundwater nitrate-N levels exceed the safe level of 10 mg/L. Increased use of tile drainage in the corn belt states has reduced groundwater contamination levels (Spalding and Exner, 1992).

Work from Purdue University recommends topdress N rates of 34 to 67 kg N ha^{-1} depending on soil type for expected yield levels of 3.0 to 3.6 Mg ha^{-1} (Mansfield and Hawkins, 1992). For wheat yields of 2.0 to 2.7 Mg ha^{-1} a N rate of 36 to 63 kg N ha^{-1} is recommended for production in Kansas (Leikam et al., 2003). General recommended N rates in Oklahoma range from 67 to 140 kg N ha^{-1} for yield levels of 2.0 to 4.0 Mg ha^{-1} respectively (Zhang, 2006).

Timing of N applications in winter wheat can have an influential effect of wheat yields. A study conducted by Mahler et al. (1994) evaluated the effect of different N sources and timing of applications on winter wheat production. Results from this experiment showed that split applications of N between fall and spring resulted in the highest grain yield and NUE and no significant differences were noted in final results between N sources used (Mahler et al., 1994). Previous published work that evaluated the effect of N source noted that ammonium nitrate and urea were equally effective in providing N to the wheat crop and the interaction of timing and source were not significant as well (Christensen and Meints, 1982). Another study showed that grain yields were optimized by applying topdress N in early January based on the quadratic yield response model (Boman et al. 1995).

Application of Sensor Based Technology

Sensor based technology is becoming a new standard tool when making in-season N application recommendations for various crops. If yield can be predicted while still in the growing season, topdress N rates can be more accurately applied. Sensor based readings rely on using what is known as the Normalized Difference Vegetative Index (NDVI). Such readings use different bands of light to give an estimation of plant vigor and biomass production. NDVI is calculated as: NDVI=[(NIR-Red)/(NIR+Red)]. Wavelengths for NIR and Red are (780 nm) and

(671nm) respectively (Mullen et al., 2003). Raun et al. (2001) noted that NDVI readings can serve as an in-season yield predictor for wheat.

CHAPTER III

MATERIALS AND METHODS

Materials

Maize

This study was established at two locations for the 2017 and 2018 growing seasons. The trials were conducted at two different Oklahoma State University research stations. One trial was located at OSU's Efaw Station in Stillwater, OK and the other was located at OSU's Lake Carl Blackwell (LCB) station near Orlando, OK. The 2017 and 2018 Efaw locations were on a Norge Loam soil. In 2017, LCB's soil type was a Pulaski, fine sandy loam, 0-1% slope, occasionally flooded. The 2018 LCB test plot was located on a Port-Oscar Complex, 0-1% slope, occasionally flooded. The variety used for both trials was a Pioneer P0636AM Maize Hybrid. The 2017 Efaw and LCB locations were both planted on April 13, 2017 with a population of 64,220 seeds/ha^{-1}. The 2018 Efaw location was planted on April 4, 2018 with a population of 55,575 seeds/ha^{-1}. The 2018 LCB location was planted on May 1, 2018 with a population of 55,575 seeds/ha^{-1}. Composite soil samples by replication were taken prior to planting. Cores were taken 15 centimeters deep with fifteen cores per replication at both sites.

This trial was a randomized complete block design consisting of 13 treatments with 3 replications (Tables 1). The treatment structure of this study focused on the rate of N applied pre and post with one check that did not receive any N. Preplant treatment rates of UAN (28-0-0) applied were 17, 34, 50, 67, 101, 134 kg ha^{-1}. Treatments 1 through 13 received rates of UAN applied to all treatments. Treatment 1 was a check with no N applied pre or sidedress. Treatments 2 through 5 included varying rates of N applied preplant. Treatments 6 through 9 included varying rates of N applied pre and sidedress. Treatments 10-13 were varying rates of N applied sidedress only. Urea Ammonium Nitrate (UAN) was used for both preplant and sidedress applications for this study. Sidedress applications were applied at the V6 growth stage. Maize trials had 3 replications, with 3 by 6 m plots and a 3m alley between each replication.

Soil samples taken pre plant for all corn trials (Table 3). The site with the highest pH was 2017 Efaw, it is also the site with the highest OM%. Lake Carl Blackwell 2017, had the lowest OM%, it is tilled conventionally every year. EFAW 2018 had the highest amount of K in the soil. Lake Carl Blackwell 2018, had the highest amount N present in the soil, it also had the second highest pH. Nutrients present in the soil were with in the 80-100% sufficiency level.

Wheat

This study was established at four locations five site years for the 2016 – 2017 and 2017-2018 growing seasons. These trials were conducted at four different Oklahoma State University research stations. The trials were located in Perkins OK, Stillwater OK, Hennessey OK, and Lahoma OK. The Perkins trial site was on Konawa and Teller fine sandy loam, Fine-loamy. The Lahoma 2016-2017 and 2018-2019 location was on a Grant silt loam, fine-silty, mixed, superactive, thermic, Udic Argiustoll. The Efaw trial was on a Norge Loam,1-5% slope. The Hennessey trial was located on a Bethany silt loam, 0-1% slope.

The variety used for both years was OSU's 'Iba'. The 2016 Perkins location was planted on October 1, 2016 at a seeding rate of 84 kg ha^{-1}. The 2016 Lahoma location was planted on October 18, 2016 at a seeding rate of 78 kg ha^{-1}. The 2017 Efaw location was planted on October 20, 2017 at a seeding rate of 84 kg ha^{-1}. The 2017 Hennessey location was planted on October 20, 2017 at a seeding rate of 84 kg ha^{-1}. The 2017 Lahoma location was planted on October 12, 2017 at a seeding rate of 78 kg ha^{-1}. Composite soil sampling consisted of fifteen cores per replication at a depth of 15 cm at both sites. These samples will be analyzed for essential nutrients, pH, and buffer index. The main nutrient we particularly are looking at is N already in the soil.

The trial was a randomized complete block design that consisted of 12 treatments and 3 replications (Table 2). The variables in this trial included rate of N applied pre plant and topdress. This study used UAN (28-0-0) as its source of N. Treatment 1 was a check with no N applied. Treatments 2, 3, 4, 5, 6 received N applied preplant at rates of 17, 34, 50, 67, 101 kg ha^{-1}, respectively. Treatments 7 and 12 received N topdress at rates of 34 and 67 kg ha^{-1}. Treatments 8,9,11 received pre-plant N at rates of 34, 67, 101 kg ha^{-1} with an additional 34 kg ha^{-1} topdress. Treatment 10 received 67 kg ha^{-1} as a pre-plant with an additional 67 kg ha^{-1} topdress. Urea Ammonium Nitrate (UAN) was used for both preplant and sidedress applications for this study. Topdress applications were applied at the Feekes 5 growth stage. Wheat trials had 3 replications, with 3 by 6 m plots and a 3m alley between each replication.

Soil samples taken pre plant for all wheat trials (Table 3). The site with the highest pH was 2017 Perkins, however it is also the site with the lowest OM%. Lahoma 2017, had the lowest top N, it is tilled conventionally every year. Lahoma 2018 had the second highest amount of K in the soil. Hennesey 2018, had the lowest pH at 5.4, it also had a low amount of top N residual left, however the amounts of P&K where high. Hennesey 2018 yielded the highest of all site years.

Efaw 2018, had the second lowest pH at 5.5, relatively high amounts of top N residual in the soil, it also had the highest soil OM%. Nutrients present in the soil were with in the 80-100% sufficiency level.

Field Methodology

Maize

For all trials, commercial pesticides were used to reduce the potential damage of insects and weeds. A John Deere four row MaxEmerge planter was used for maize trials. Conventional till sites were chisel plowed before planting for preparation of the seedbed. A Greenseeker hand held NDVI sensor was used for maize trials. The NDVI data were then used to predict biomass, throughout the growing season and to predict final grain yield. For maize trials NDVI was collected from V3 through V10. Maize sites were harvested with a Kincaid 8XP self-propelled combine. Grain yields were collected at harvest, subsampled, dried for 24 hours, ground and analyzed for total N content.

Wheat

For all trials, commercial pesticides were used to reduce the potential damage of insects and weeds. A Great Plains and a John Deere no-till drill were used for wheat. Conventional till sites were chisel plowed before planting for preparation of the seedbed. A Greenseeker hand held NDVI sensor was used for wheat trials. This NDVI data was then used to predict biomass, throughout the growing season and to predict grain yield potential. In wheat trials, NDVI data was collected from F2 to F6. All sites were harvested with a Kincaid 8XP self-propelled combine. Grain yields were collected at harvest, subsampled, dried for 24 hours, ground and analyzed for total N content.

CHAPTER IV

RESULTS AND DISCUSSION

Maize

EFAW 2017

Sensor based NDVI data was acquired at the V5 (613 HU) and V10 (1,115 HU) growth stages (Table 1). Treatment differences for this NDVI data were not observed. Single-degree-of-freedom-contrasts also showed no differences in the NDVI data. Treatment differences for final grain yield were detected. When looking at the contrasts for application rates and timing, a significant increase in yield was observed (significant N Rate Linear contrast, treatments 1 through 5). Yield data acquired at harvest ranged from 2.32 to 5.30 Mg ha^{-1} with an average of 4.03 Mg ha^{-1}. The grain yield for treatment 13 (all N applied sidedress) tended to be higher but was not significantly different than treatments 10, 11, and 12. Looking at the linear contrast for treatments 1-5, preplant N applications increased yields from 2.32 to 4.21 Mg ha^{-1}. At the same preplant N rates (34, and 67 kg N ha^{-1}) yields increased significantly when sidedress N was applied (2 and 3 versus 7 and 9). The contrast model showed that preplant N when applied with an additional application at a later date proved to be highly significant. Comparing preplant N alone against side-dress N alone we see a significant difference, and where the side-dress application increased yields.

No statistical differences were observed for the contrast of preplant N alone vs topdress N applied alone at equal rates of N (101-0 vs 0-101 and 134-0 vs 0-134). No statistical differences were found when comparing pre plant N to a split N application consisting of a preplant and side-dress application where equal amounts of N were applied (101-0 vs 50-50).

Lake Carl Blackwell 2017

Statistical differences were observed among NDVI data collected in season and yield data collected at harvest (Table 2). Sensor NDVI data was collected at the V3 (570 HU) and V4 (833HU) growth stages. In season data and single-degree-of-freedom-contrasts revealed that preplant N treatments (1 through 5) increased yields from 0.67 to 2.68 Mg ha^{-1}, and preplant with additional sidedress N treatments (6 through 9) increased yields from 1.21 to 2.46 Mg ha^{-1}, and that were highly significant. Sensor based readings observed that preplant N versus sidedress N proved to be highly significant among treatments. The sensor data showed that when comparing split applications of N versus sidedress only, these values were clearly different. Treatments that had NDVI readings collected at the V3 stage showed differences between 4 and 12, 5 versus 13 and 4 versus 8. The yield data collected for Lake Carl Blackwell 2017 was rather low in comparison to other site years collected. Yield data collected ranged from 0.61 Mg ha^{-1} to 3.02 Mg ha^{-1} with an average of 1.73 Mg ha^{-1}. The grain yield for treatment 13 (all N applied sidedress) tended to be higher but was not significantly different than treatments 10, 11, and 12. When looking at the contrasts for application rates and timing, a significant yield increase was observed for the N rate linear contrast (Treatments 1 through 5). At the same preplant N rates (34, and 67 kg N ha^{-1}) yields increased significantly when sidedress N was applied (2 and 3 versus 7 and 9). Looking at the single degree of freedom contrasts for treatments 4 versus 12, there was a significant difference observed when comparing preplant and sidedress application at equal rates of N (101 – 0 vs. 0 – 101). No statistical difference was found when comparing pre plant N to a split application of N consisting of a preplant and side-dress application when equal amounts of N were applied (101-0 vs 50-50).

EFAW 2018

Sensor based NDVI data was only collected once at this site and this taking place at the V6 growth state (944 HU, Table 3). Yield data collected at harvest ranged from 1.73 Mg ha^{-1} to 7.24 Mg ha^{-1} with an average of 5.14 Mg ha^{-1}. Via a single-degree-of-freedom contrast for preplant N (treatments 1 through 5) yields increased from 1.73 to 3.58 Mg ha^{-1}, and treatments 6 through 9 showed an increase in yield from 4.81 to 7.24 Mg ha^{-1}. Sensor based readings observed that preplant N versus side-dress N proved to be highly significant among treatments. The sensor data highlighted the difference between split applications of N versus a side-dress application alone as it proved to be highly significant in comparison. When comparing treatments, at the V6 stage, NDVI readings for 4 and 12, and 5 compared to 13 were significant. No statistical difference was found when comparing treatments 4 and 8, and pre plant N to a split application N consisting of a preplant and side-dress application at equal rates of N (101-0 vs 50-50). The grain yield for treatment 9 (N applied preplant 67 and sidedress 67) tended to be higher, but was not significantly different than treatments 6, 7, and 8. Looking at the linear contrast for treatments 1-5, preplant N applications increased yields from 1.73 to 3.58 Mg ha^{-1}. Sidedress treatments (1, 10 through 13) quadratic contrasts proved to be highly significant. Looking further into the data for treatments 1, and 6 through 9, the yield data was able to differentiate that preplant N applied with an additional application at a later date proved to be highly significant. Contrasting treatments (5 versus 13), there was a significant difference comparing preplant and sidedress application when equal amounts of N (134 – 0 vs. 0 – 134) were applied. No statistical differences were found when comparing preplant N to a split application N consisting of a preplant and side-dress application, when equal amounts of N were applied (101-0 vs. 0-101) and (101-0 vs 50-50).

Lake Carl Blackwell 2018

Significant treatment differences for NDVI and yield were observed (Table 4). Sensor NDVI was data collected at the V4 (716 HU), V5 (838 HU) and V6 (1,087 HU) growth stages. Yield data was collected at harvest and ranged from 5.19 Mg ha^{-1} to 9.64 Mg ha^{-1} with an average of 7.20 Mg ha^{-1}. Observing the NDVI data collected at the V4 growth stage showed that the side-dress treatments (1, 10 through 13) were significantly higher. There was also a significant difference present when comparing treatments 5 and 13. Furthermore, when N was applied sidedress at a rate of 101 kg N ha^{-1}, yields were higher than that recorded for N applied preplant at this same rate (4 versus 12). This same difference was not seen when the higher rate of 134 kg N ha^{-1} was applied. Single-degree-of-freedom-contrasts showed no differences in the V5 and V6 NDVI data. Although yield levels were much higher at this site, treatment differences were more difficult to detect, likely due to increased variability expressed in the trial coefficient of variation (26%). Limited differences were detected at this site, however the contrast for sidedress only encumbering treatments 10 through 13 was highly significant. This was also noted for the combination of preplant and sidedress N, represented by treatments 1, and 6 through 9. No other contrasts were found to be significant for grain yield.

Wheat

Lahoma 2017

Statistical differences were observed among NDVI data collected in season and yield data collected at harvest (Table 2). Sensor NDVI data was collected at 96 and 99 GDDs. In season data and single-degree-of-freedom-contrasts revealed that preplant N treatments (1 through 6) increased yields from 1.33 to 2.35 Mg ha^{-1}, and NDVI readings from preplant with additional topdress N treatments (7 through 9, 11) proved to be significant. Sensor based readings observed that preplant N with an additional 34 kg ha^{-1} N proved to be highly significant among treatments.

Treatment (6 versus 9) were different. Yield data collected at Lahoma ranged from 1.10 Mg ha^{-1} to 3.19 Mg ha^{-1} with an average of 1.73 Mg ha^{-1}. The grain yield for treatment 11 (total N applied 135 kg ha^{-1}) tended to be higher but was not significantly different compared to treatments 7, 8, and 9. When looking at the contrasts for application rates and timing, a significant yield increase was observed for the N rate linear contrast (Treatments 1 through 6). At the same preplant N rates (34, and 67 kg N ha-1) yields increased significantly when topdress N was applied (6 versus 11). No statistical difference was found when comparing pre plant N to split applied N consisting of a preplant and topdress application when equal amounts of N were applied (67-0 vs 34-34) (101-0 vs 67-34).

Perkins 2017

Sensor based NDVI data was only collected once at this site and this taking place at 125 GGDs (Table 3). The yield data collected for Perkins 2017 was rather low in comparison to other site years collected. Yield data collected at harvest ranged from 0.50 Mg ha^{-1} to 1.54 Mg ha^{-1} with an average of 1.02 Mg ha^{-1}. When looking at the contrasts for preplant application rates, a significant yield increase was observed for the N Rate Linear contrast, showing increased yields from 0.50 to 1.14 Mg ha^{-1} (treatments 1 through 6). In season data and single-degree-of-freedom-contrasts revealed that preplant with additional topdress N treatments (10 and 11) proved to be better. Looking at preplant with an additional 34 kg N ha^{-1} we see that NDVI and yield data were highly significant. Sensor NDVI readings yield data from a linear contrast of preplant with additional topdress N treatments (7 through 9, 11) were significant. Comparing preplant N alone against side-dress N alone yields we see a significant difference among (5 vs 12) (67-0 and 0-67) and treatments (6 vs 11) (101-0 vs 101-34). No statistical differences were observed for the contrast of preplant N alone vs topdress N applied alone at equal rates of N (101-0 vs 0-101 and 134-0 vs 0-134). No statistical difference was found when comparing pre plant N to a split N application consisting of a preplant and topdress application when equal amounts of N were applied (34-34 vs 0-67), (67-0 vs 34-34) and (101-0 vs 67-34).

EFAW 2018

Statistical differences were insignificant for the most part at this site year. Sensor NDVI data was collected at 88 and 102 GDDs. In season data proved to be significant at the 102 GDD for the N Rate quadratic contrast (1 through 6). This location showed limited response, and where yields ranged from 3.11 to 3.88 Mg ha^{-1} with an average of 3.54 Mg ha^{-1}(Table 3).

Hennessey 2018

Sensor based NDVI data was collected more at this location and was acquired at 67, 85, 97, and 111 GGDs, Table 4). In season data from all four readings and yield proved to be highly significant for treatments (1 through 6) which revealed that preplant N treatments increased yields from 2.98 to 4.10 Mg ha^{-1}. All NDVI readings from preplant with additional topdress N treatments (7 through 9, 11) were significant. When looking at a linear contrast for preplant with an additional 34 kg N ha^{-1} we see that NDVI and yield data were highly significant. Comparing preplant N alone against topdress N alone, NDVI readings were significantly different (5 vs 12) (67-0 and 0-67) and treatments (6 vs 11) (101-0 vs 101-34) and (8 vs 12). Mid-season statistical differences were observed for the contrast of timing treatments (5 vs 8) (67-0 vs 34-34) and (6 vs 9) (101-0 vs 67–34) preplant Yield data when preplant vs topdress N applied alone at equal rates of N (67-0 vs 0-67) were statistically different.

Lahoma 2018

Statistical differences were observed for NDVI data collected in season and yield data collected at harvest (Table 5). NDVI data was collected at 94 GDDs. In season data and single-degree-of-freedom-contrasts revealed that preplant N treatments (7 through 12) were significant.

Sensor NDVI readings from preplant with additional topdress N treatments (7, 8, 9, and 11) proved to be highly significant. Yield data collected at Lahoma ranged from 1.37 Mg ha^{-1} to 1.87 Mg ha^{-1} with an average of 1.64 Mg ha^{-1}. Grain yield for treatment 11 (total N applied 135 kg ha^{-1}) tended to be higher but was not significantly different than treatments (7, 8, and 9). When looking at contrasts between timings, the yield data showed that there was a significant difference between treatments 6 and 11 (101-0 vs 101-34). This difference shows that when an additional application of 34 kg ha^{-1} was made to the original preplant of 101 kg ha^{-1} the yield increased. For the other timing treatments, no significant results were shown in yield or NDVI.

CHAPTER V

CONCLUSIONS

Maize and Wheat 2017 and 2018

The purpose of this maize study over four site years was to evaluate the effect of nitrogen when applied at different rates and different times. The hypothesis was that sidedress applications of N would increase the amount of N available to the plants throughout the growing season and would in turn increase yield. The benefit of sidedress only N applications for both dryland and irrigated trials were observed at two locations along with an average yield increase. The maize crop can regulate and use N as needed, but is benefitted by having a supply from that single sidesress application to obtain maximum yield. For the wheat experiments, the initial hypothesis was confirmed that single applications pre or sidedress were not as effective as split applications in terms of wheat grain yield. Estimated NUE values were higher for the split N applications when compared to N applied either all preplant or all sidedress. Split N applications consistently delivered increased yields and elevated NUE.

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APPENDICES

Table 1. Treatment structure, for maize, EFAW and Lake Carl Blackwell, 2017, EFAW and Lake Carl Blackwell 2018.

Treatment	Preplant N (kg N ha^{-1})	Sidedress N (kg N ha^{-1})	Total, N (kg N ha^{-1})
1	0	0	0
2	34	0	34
3	67	0	67
4	101	0	101
5	134	0	134
6	17	17	34
7	34	34	68
8	50	50	100
9	67	67	134
10	0	34	34
11	0	67	67
12	0	101	101
13	0	134	134

Table 2. Treatment structure, for wheat experiments, Lahoma and Perkins, 2016-2017, EFAW, Hennessey and Lahoma 2017

Treatment	Preplant N (kg N ha^{-1})	Sidedress N (kg N ha^{-1})	Total, N (kg N ha^{-1})
1	0	0	0
2	17	0	17
3	34	0	34
4	50	0	50
5	67	0	67
6	101	0	101
7	0	34	34
8	34	34	68
9	67	34	101
10	67	67	134
11	101	34	135
12	0	67	67

Table 3. Preplant soil test analysis for all maize locations, 0-15 cm depth.

Year	Location	Crop	pH	NO_3 (mg kg $^{-1}$)	P (mg kg $^{-1}$)	K (mg kg $^{-1}$)	OM (%)
2017	Efaw	Corn	6.8	0.6	14.8	121.5	1.7
2017	LCB	Corn	5.8	0.5	28.8	108.0	1.0
2018	Efaw	Corn	5.9	0.7	12.3	156.9	1.4
2018	LCB	Corn	6.7	4.6	22.9	133.8	1.5

Table 4. Preplant soil test analysis for all wheat locations, 0-15 cm depth.

Year	Location	Crop	pH	NO_3 (mg kg $^{-1}$)	P (mg kg $^{-1}$)	K (mg kg $^{-1}$)	OM (%)
2017	Perkins	Wheat	7.1	1.8	10.3	133.2	1.2
2017	Lahoma	Wheat	6.3	0.2	10.2	221.0	1.5
2018	Lahoma	Wheat	5.9	5.5	11.7	244.3	1.5
2018	Hennessey	Wheat	5.4	0.7	96.7	367.0	1.5
2018	Efaw	Wheat	5.5	14.7	24.5	209.5	1.6

Table 5. Treatment structure means, and single-degree-of-freedom contrasts for NDVI, and corn grain yield, Efaw, OK, 2017.						
Treatment	Preplant N Rate (kg N ha^{-1})	Sidedress N Rate (kg N ha^{-1})	NDVI, Cumulative HU		Grain Yield (Mg ha^{-1})	(kg N ha^{-1}/ Mg ha^{-1})
			613	1,115		
1	0	0	0.38	0.66	2.32	0.0
2	34	0	0.41	0.67	2.99	11.4
3	67	0	0.45	0.70	3.79	17.7
4	101	0	0.37	0.70	4.04	25.0
5	134	0	0.40	0.67	4.21	31.8
6	17	17	0.42	0.65	3.01	11.3
7	34	34	0.40	0.70	3.75	18.1
8	50	50	0.45	0.69	4.95	20.2
9	67	67	0.41	0.73	5.19	25.8
10	0	34	0.40	0.70	3.83	8.9
11	0	67	0.39	0.67	4.39	15.3
12	0	101	0.42	0.69	4.68	21.6
13	0	134	0.41	0.69	5.30	25.3
SED			0.04	0.05	0.58	
CV,%			14	9	17	
Contrast						
PreplantN Rate Linear (1-5)			ns	ns	**	
PreplantN Rate Quadratic (1-5)			ns	ns	ns	
Sidedress N Linear (1, 10-13)			ns	ns	**	
Sidedress N Quadratic (1, 10-13)			ns	ns	ns	
Preplant + Sidedress N Linear (1,6-9)			ns	ns	**	
Preplant + Sidedress N Quadratic (1,6-9)			ns	ns	ns	
Preplant vs Preplant + Sidedress N rates (2-5 vs 6-9)			ns	ns	ns	
PreplantN vs SidedressN (2-5 vs 10-13)			ns	ns	*	
Preplant + Side-dress vs Side-dress N Rates (6-9 vs 10-13)			ns	ns	ns	
Timing Treatments (4 vs.12) (5 vs.13) (4 vs.8)			ns,ns,ns	ns,ns,ns	ns, ns, ns	
Preplant, versus Preplant + Sidedress (2,3 vs 7,9)			ns	ns	*	
Preplant versus sidedress (2,3,4,5 vs 10,11,12,13)			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						

Table 6. Treatment structure means, and single-degree-of-freedom contrasts for NDVI, and corn grain yield, Lake Carl Blackwell, OK, 2017.

Treatment	Preplant N Rate (kg N ha^{-1})	Sidedress N Rate (kg N ha^{-1})	NDVI, Cumulative HU		Grain Yield (Mg ha^{-1})	(kg N ha^{-1}/ Mg ha^{-1})
			570	833		
1	0	0	0.36	0.54	0.61	0.0
2	34	0	0.44	0.63	0.73	46.6
3	67	0	0.51	0.66	1.92	34.9
4	101	0	0.48	0.73	1.57	64.3
5	134	0	0.56	0.70	2.68	50.0
6	17	17	0.42	0.54	1.21	28.1
7	34	34	0.47	0.60	1.62	42.0
8	50	50	0.57	0.71	1.59	62.9
9	67	67	0.42	0.61	2.46	54.5
10	0	34	0.34	0.53	1.51	22.5
11	0	67	0.35	0.64	1.10	60.9
12	0	101	0.34	0.52	2.50	40.4
13	0	134	0.40	0.52	3.02	44.4
SED			0.04	0.05	0.40	
CV,%			12	10	28	
Contrast						
PreplantN Rate Linear (1-5)			**	**	**	
PreplantN Rate Quadratic (1-5)			ns	ns	ns	
Sidedress N Linear (1, 10-13)			ns	ns	**	
Sidedress N Quadratic (1, 10-13)			ns	ns	ns	
Preplant + Sidedress N Linear (1,6-9)			**	*	**	
Preplant + Sidedress N Quadratic (1,6-9)			**	ns	ns	
Preplant vs Preplant + Sidedress N rates (2-5 vs 6-9)			ns	*	ns	
PreplantN vs SidedressN (2-5 vs 10-13)			**	**	ns	
Preplant + Side-dress vs Side-dress N Rates (6-9 vs 10-13)			**	*	ns	
Timing Treatments (4 vs.12) (5 vs.13) (4 vs.8)			**,**,*	**,**,ns	*, ns, ns	
Preplant, versus Preplant + Sidedress (2,3 vs 7,9)			ns	ns	*	
Preplant versus sidedress (2,3,4,5 vs 10,11,12,13)			**	**	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

Table 7. Treatment structure means, and single-degree-of-freedom contrasts for NDVI, and corn grain yield, Efaw, OK, 2018.						
Treatment	Preplant N Rate (kg N ha^{-1})	Sidedress N Rate (kg N ha^{-1})	NDVI, Cumulative HU	NUE	Grain Yield (Mg ha^{-1})	(kg N ha^{-1}/ Mg ha^{-1})
			944			
1	0	0	0.55	0.00	1.73	0.0
2	34	0	0.49	0.42	3.02	11.3
3	67	0	0.69	0.49	4.70	14.3
4	101	0	0.69	0.58	6.31	16.0
5	134	0	0.65	0.24	3.58	37.4
6	17	17	0.61	0.93	4.81	7.1
7	34	34	0.65	0.56	5.33	12.8
8	50	50	0.68	0.75	6.67	15.0
9	67	67	0.71	0.58	7.24	18.5
10	0	34	0.53	1.42	5.34	6.4
11	0	67	0.50	0.57	4.47	15.0
12	0	101	0.57	0.75	6.93	14.6
13	0	134	0.58	0.57	6.68	20.1
SED			0.03		0.70	
CV,%			6		17	
Contrast						
PreplantN Rate Linear (1-5)			**		**	
PreplantN Rate Quadratic (1-5)			ns		**	
Sidedress N Linear (1, 10-13)			ns		**	
Sidedress N Quadratic (1, 10-13)			ns		*	
Preplant + Sidedress N Linear (1,6-9)			**		**	
Preplant + Sidedress N Quadratic (1,6-9)			ns		*	
Preplant vs Preplant + Sidedress N rates (2-5 vs 6-9)			ns		**	
PreplantN vs SidedressN (2-5 vs 10-13)			**		**	
Preplant + Side-dress vs Side-dress N Rates (6-9 vs 10-13)			**		ns	
Timing Treatments (4 vs.12) (5 vs.13) (4 vs.8)			**,*,ns		ns, **, ns	
Preplant, versus Preplant + Sidedress (2,3 vs 7,9)			**		**	
Preplant versus sidedress (2,3,4,5 vs 10,11,12,13)			**		**	
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						

Table 8. Treatment structure means, and single-degree-of-freedom contrasts for NDVI, and corn grain yield, Lake Carl Blackwell, OK, 2018.							
Treatment	Preplant N Rate (kg N ha^{-1})	Sidedress N Rate (kg N ha^{-1})		NDVI, Cumulative HU		Grain Yield (Mg ha^{-1})	(kg N ha^{-1}/ Mg ha^{-1})
			716	838	1,087		
1	0	0	0.68	0.69	0.80	5.42	0.0
2	34	0	0.71	0.70	0.81	6.78	5.0
3	67	0	0.67	0.66	0.77	5.28	12.7
4	101	0	0.66	0.66	0.78	6.98	14.5
5	134	0	0.70	0.69	0.81	7.60	17.6
6	17	17	0.68	0.69	0.80	6.97	4.9
7	34	34	0.67	0.67	0.79	7.51	9.1
8	50	50	0.69	0.71	0.81	7.59	13.2
9	67	67	0.71	0.70	0.82	9.45	14.2
10	0	34	0.68	0.66	0.80	7.05	4.8
11	0	67	0.70	0.68	0.82	8.17	8.2
12	0	101	0.72	0.72	0.82	9.64	10.5
13	0	134	0.63	0.63	0.77	5.19	25.8
SED			0.03	.04	0.03	1.52	
CV,%			5	7	4	26	
Contrast							
PreplantN Rate Linear (1-5)			ns	ns	ns	ns	
PreplantN Rate Quadratic (1-5)			ns	ns	ns	ns	
Sidedress N Linear (1, 10-13)			ns	ns	ns	ns	
Sidedress N Quadratic (1, 10-13)			*	ns	ns	**	
Preplant + Sidedress N Linear (1,6-9)			ns	ns	ns	*	
Preplant + Sidedress N Quadratic (1,6-9)			ns	ns	ns	ns	
Preplant vs Preplant + Sidedress N rates (2-5 vs 6-9)			ns	ns	ns	ns	
PreplantN vs SidedressN (2-5 vs 10-13)			ns	ns	ns	ns	
Preplant + Side-dress vs Side-dress N Rates (6-9 vs 10-13)			ns	ns	ns	ns	
Timing Treatments (4 vs.12) (5 vs.13) (4 vs.8)			ns,*,ns	ns,ns,ns	ns,ns,ns	ns, ns, ns	
Preplant, versus Preplant + Sidedress (2,3 vs 7,9)			ns	ns	ns	*	
Preplant versus sidedress (2,3,4,5 vs 10,11,12,13)			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							

Table 9. Treatment structure means, and single-degree-of-freedom contrasts for NDVI, and wheat grain yield, Lahoma, OK, 2017.

Treatment	Preplant N Rate (kg N ha^{-1})	Sidedress N Rate (kg N ha^{-1})	NDVI, GDD		Grain Yield (Mg ha^{-1})	(kg N ha^{-1}/ Mg ha^{-1})
			96	99		
1	0	0	0.38	0.39	1.33	0.0
2	17	0	0.41	0.41	1.41	12.1
3	34	0	0.46	0.48	1.91	17.8
4	50	0	0.41	0.43	1.10	45.5
5	67	0	0.41	0.43	1.80	37.2
6	101	0	0.50	0.52	2.35	43.0
7	0	34	0.38	0.37	1.99	17.1
8	34	34	0.42	0.43	2.19	31.1
9	67	34	0.41	0.43	2.56	39.5
10	67	67	0.42	0.44	2.58	51.9
11	101	34	0.46	0.49	3.19	42.3
12	0	67	0.42	0.41	2.20	30.5
SED			0.04	0.03	0.34	
CV, %			10	9	20	
Contrast						
Preplant N Rate Linear (1-6)			*	**	*	
Preplant N Rate Quadratic (1-6)			ns	ns	ns	
Top dress N (7-12)			ns	ns	ns	
Preplant + Topdress 34 N (7-9,11)			*	**	ns	
Timing (10-11)			ns	ns	ns	
Preplant Linear + 34 Topdress (7,8,9,11)			*	**	**	
Preplant Quadratic + 34 Topdress (7,8,9,11)			ns	ns	ns	
Timing Treatments (5 vs 12) (6 vs 11) (8 vs 12)			ns,ns,ns	ns,ns,ns	ns,*,ns	
Timing Treatments (5 vs 8) (6 vs 9)			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

Table 10. Treatment structure means, and single-degree-of-freedom contrasts for NDVI, and wheat grain yield, Perkins, OK, 2017.

Treatment	Preplant N Rate (kg N ha^{-1})	Sidedress N Rate (kg N ha^{-1})	NDVI, GDD 125	NUE	Grain Yield (Mg ha^{-1})	(kg N ha^{-1}/ Mg ha^{-1})
1	0	0	0.23	0.00	0.50	0.0
2	17	0	0.26	0.16	0.68	25.0
3	34	0	0.27	0.09	0.69	49.3
4	50	0	0.29	0.07	0.72	69.4
5	67	0	0.32	0.09	0.88	76.1
6	101	0	0.35	0.10	1.14	88.6
7	0	34	0.24	0.25	1.03	33.0
8	34	34	0.26	0.15	1.12	60.7
9	67	34	0.32	0.14	1.22	82.8
10	67	67	0.28	0.14	1.54	87.0
11	101	34	0.34	0.12	1.50	90.0
12	0	67	0.23	0.21	1.27	52.8
SED			0.02		0.14	
CV,%			8		16	
Contrast						
Preplant N Rate Linear (1-6)			**		**	
Preplant N Rate Quadratic (1-6)			ns		ns	
Top dress N (7-12)			ns		ns	
Preplant + Topdress 34 N (7-9,11)			ns		*	
Timing (10-11)			**		ns	
Preplant Linear + 34 Topdress (7,8,9,11)			**		**	
Preplant Quadratic + 34 Topdress (7,8,9,11)			ns		ns	
Timing Treatments (5 vs 12) (6 vs 11) (8 vs 12)			**,ns,ns		**,*,ns	
Timing Treatments (5 vs 8) (6 vs 9)			**,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

Table 11. Treatment structure means, and single-degree-of-freedom contrasts for NDVI, and wheat grain yield, Efaw, OK, 2018.

Treatment	Preplant N Rate (kg N ha^{-1})	Sidedress N Rate (kg N ha^{-1})	NDVI, GDD		NUE	Grain Yield (Mg ha^{-1})	(kg N ha^{-1}/ Mg ha^{-1})
			88	102			
1	0	0	0.38	0.47	0.00	3.11	0.0
2	17	0	0.39	0.49	0.39	3.34	5.1
3	34	0	0.42	0.53	0.38	3.59	9.5
4	50	0	0.41	0.52	0.23	3.57	14.0
5	67	0	0.43	0.56	0.29	3.66	18.3
6	101	0	0.37	0.45	0.15	3.40	29.7
7	0	34	0.38	0.47	0.36	3.40	10.0
8	34	34	0.40	0.53	0.37	3.88	17.5
9	67	34	0.35	0.45	0.18	3.46	29.2
10	67	67	0.40	0.51	0.23	3.88	34.5
11	101	34	0.35	0.44	0.17	3.54	38.1
12	0	67	0.40	0.50	0.32	3.69	18.2
SED			0.04	0.05		0.23	
CV,%			12	12		8	
Contrast							
Preplant N Rate Linear (1-6)			ns	ns		ns	
Preplant N Rate Quadratic (1-6)			ns	*		ns	
Top dress N (7-12)			ns	ns		ns	
Preplant + Topdress 34 N (7-9,11)			ns	ns		ns	
Timing (10-11)			ns	ns		ns	
Preplant Linear + 34 Topdress (7,8,9,11)			ns	ns		ns	
Preplant Quadratic + 34 Topdress (7,8,9,11)			ns	ns		ns	
Timing Treatments (5 vs 12) (6 vs 11) (8 vs 12)			ns,ns,ns	ns,ns,ns		ns,ns,ns	
Timing Treatments (5 vs 8) (6 vs 9)			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

Table 12. Treatment structure means, and single-degree-of-freedom contrasts for NDVI, and wheat grain yield, Hennessey, OK, 2018.

Treatment	Preplant N Rate (kg N ha^{-1})	Sidedress N Rate (kg N ha^{-1})	NDVI, GDD				Grain Yield (Mg ha^{-1})	(kg N ha^{-1}/ Mg ha^{-1})
			67	85	97	111		
1	0	0	0.38	0.51	0.55	0.49	2.98	0.0
2	17	0	0.39	0.52	0.57	0.51	3.05	5.6
3	34	0	0.44	0.59	0.64	0.57	3.78	9.0
4	50	0	0.41	0.55	0.61	0.53	3.38	14.8
5	67	0	0.47	0.63	0.72	0.65	4.39	15.3
6	101	0	0.45	0.63	0.70	0.65	4.10	24.6
7	0	34	0.34	0.47	0.51	0.48	3.79	9.0
8	34	34	0.42	0.56	0.62	0.59	4.14	16.4
9	67	34	0.47	0.63	0.71	0.67	4.37	23.1
10	67	67	0.48	0.65	0.73	0.70	4.64	28.9
11	101	34	0.53	0.69	0.76	0.72	4.36	31.0
12	0	67	0.33	0.46	0.51	0.48	3.73	18.0
SED			0.03	0.03	0.03	0.03	0.29	
CV,%			8	6	6	6	9	
Contrast								
Preplant N Rate Linear (1-6)			**	**	**	**	**	
Preplant N Rate Quadratic (1-6)			ns	ns	ns	ns	ns	
Top dress N (7-12)			ns	ns	ns	ns	ns	
Preplant + Topdress 34 N (7-9,11)			**	**	**	**	ns	
Timing (10-11)			ns	ns	ns	ns	ns	
Preplant Linear + 34 Topdress (7,8,9,11)			**	**	**	**	*	
Preplant Quadratic + 34 Topdress (7,8,9,11)			ns	ns	ns	ns	ns	
Timing Treatments (5 vs 12) (6 vs 11) (8 vs 12)			**,*,**	**,ns,*	**,ns**	**,*,**	*,ns,ns	
Timing Treatments (5 vs 8) (6 vs 9)			ns,ns	*,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

Table 13. Treatment structure means, and single-degree-of-freedom contrasts for NDVI, and wheat grain yield, Lahoma, OK, 2018.

Treatment	Preplant N Rate (kg N ha^{-1})	Sidedress N Rate (kg N ha^{-1})	NDVI, GDD	Grain Yield (Mg ha^{-1})	(kg N ha^{-1}/ Mg ha^{-1})
			94		
1	0	0	0.35	1.60	0.0
2	17	0	0.38	1.75	9.7
3	34	0	0.36	1.54	22.1
4	50	0	0.37	1.70	29.4
5	67	0	0.39	1.77	37.9
6	101	0	0.36	1.37	73.7
7	0	34	0.33	1.45	23.4
8	34	34	0.36	1.58	43.0
9	67	34	0.39	1.78	56.7
10	67	67	0.38	1.66	80.7
11	101	34	0.38	1.87	72.2
12	0	67	0.37	1.65	40.6
SED			0.19	0.23	
CV,%			6	17	
Contrast					
Preplant N Rate Linear (1-6)			ns	ns	
Preplant N Rate Quadratic (1-6)			ns	ns	
Top dress N (7-12)			*	ns	
Preplant + Topdress 34 N (7-9,11)			ns	ns	
Timing (10-11)			ns	ns	
Preplant Linear + 34 Topdress (7,8,9,11)			**	ns	
Preplant Quadratic + 34 Topdress (7,8,9,11)			ns	ns	
Timing Treatments (5 vs 12) (6 vs 11) (8 vs 12)			ns,ns,ns	ns,*,ns	
Timing Treatments (5 vs 8) (6 vs 9)			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

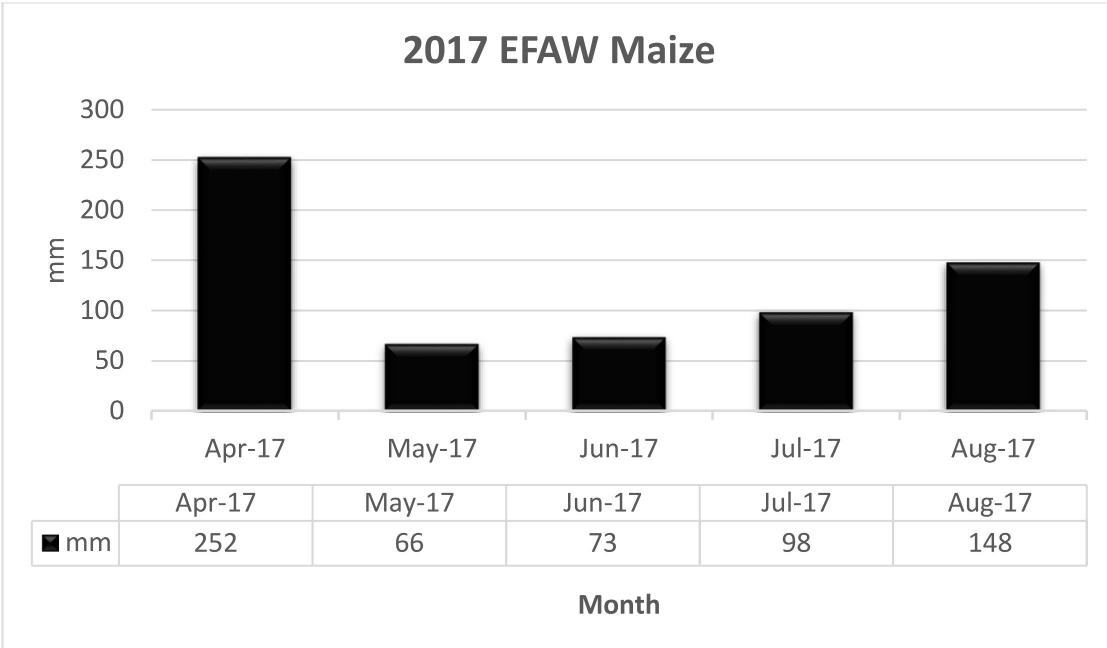


Figure 1. Average rainfall by month during the growing season, EFAW, OK 2017

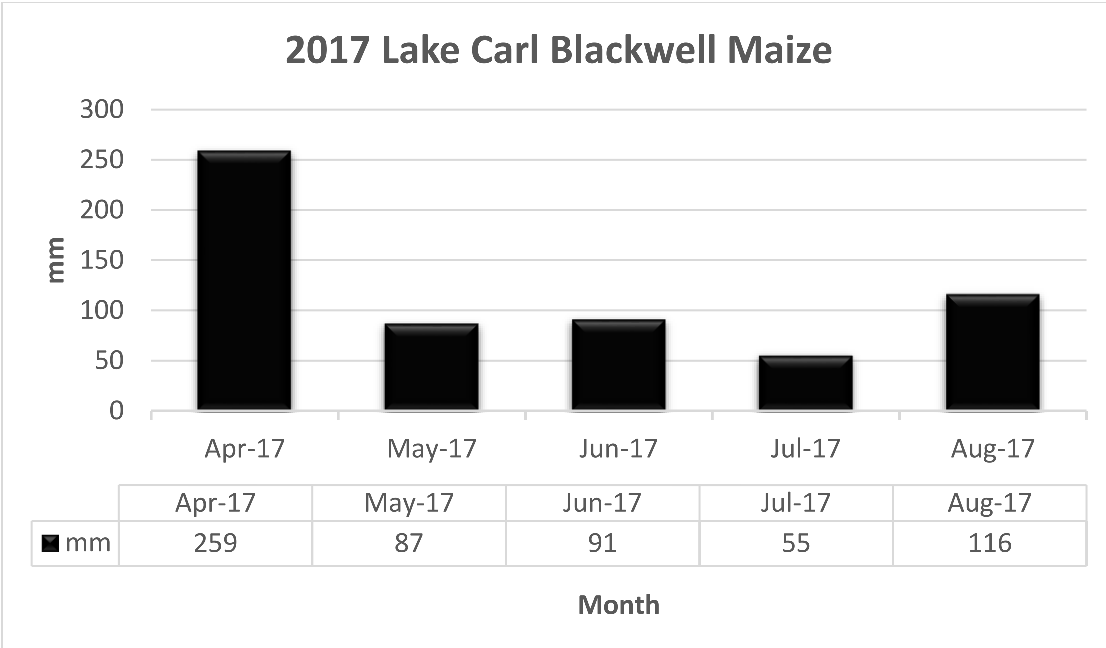
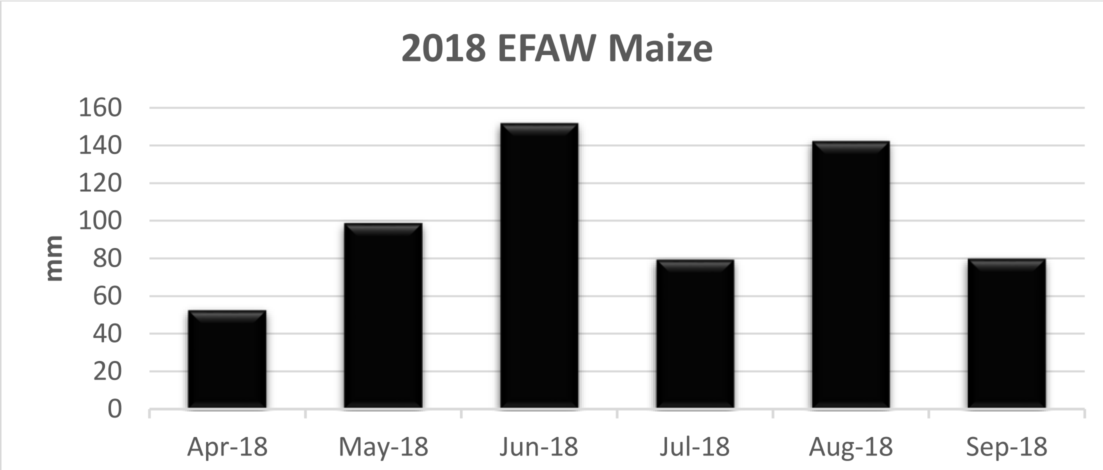
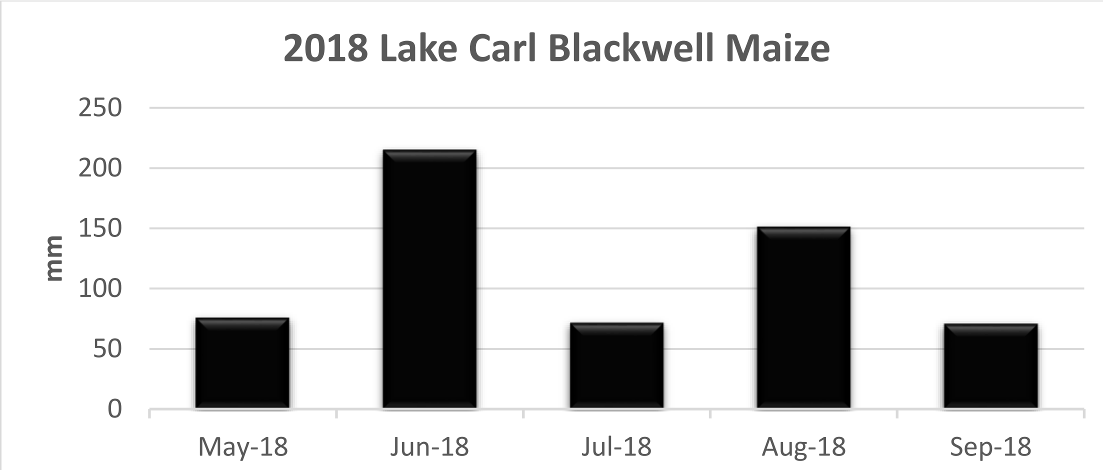


Figure 2. Average rainfall by month during the growing season, Lake Carl Blackwell, OK 2017



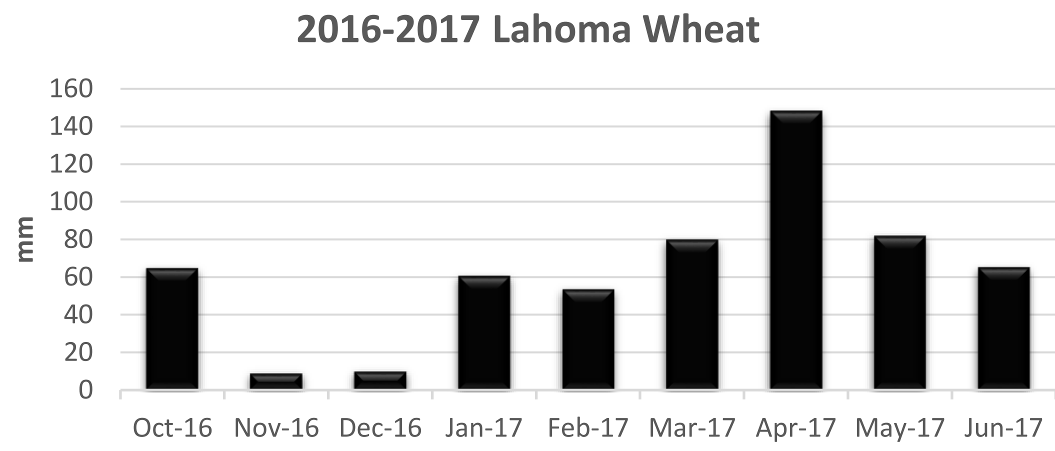
	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18
mm	52	99	152	79	142	80

Figure 3. Average rainfall by month during the growing season, EFAW, OK 2018



	May-18	Jun-18	Jul-18	Aug-18	Sep-18
mm	76	215	71	151	71

Figure 4. Average rainfall by month during the growing season, Lake Carl Blackwell, OK 2018



	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17
mm	65	9	10	60	53	80	148	82	65

Figure 5. Average rainfall by month during the growing season, Lahoma, OK 2016-2017

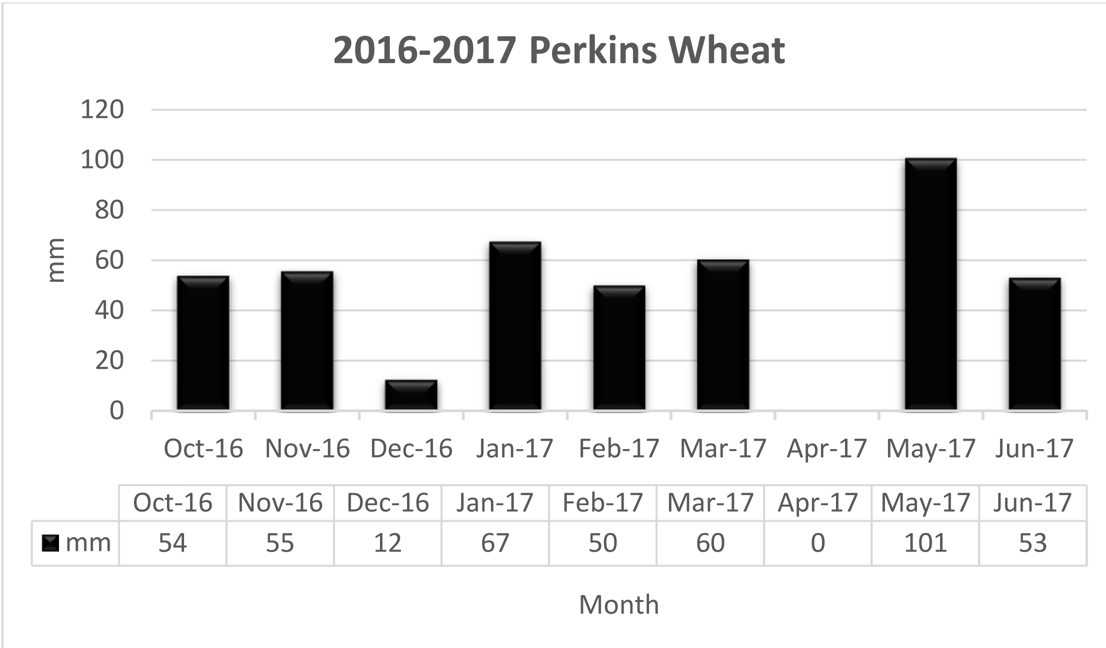
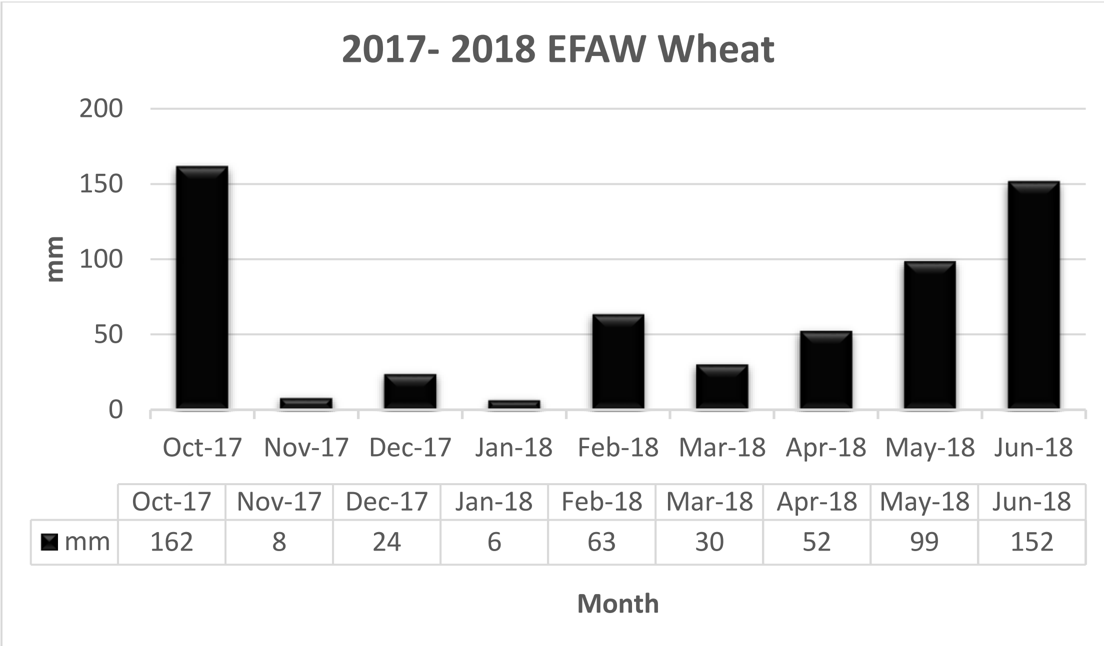


Figure 6. Average rainfall by month during the growing season, Perkins, OK 2016-2017



	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18
mm	162	8	24	6	63	30	52	99	152

Figure 7. Average rainfall by month during the growing season, EFAW, OK 2017-2018

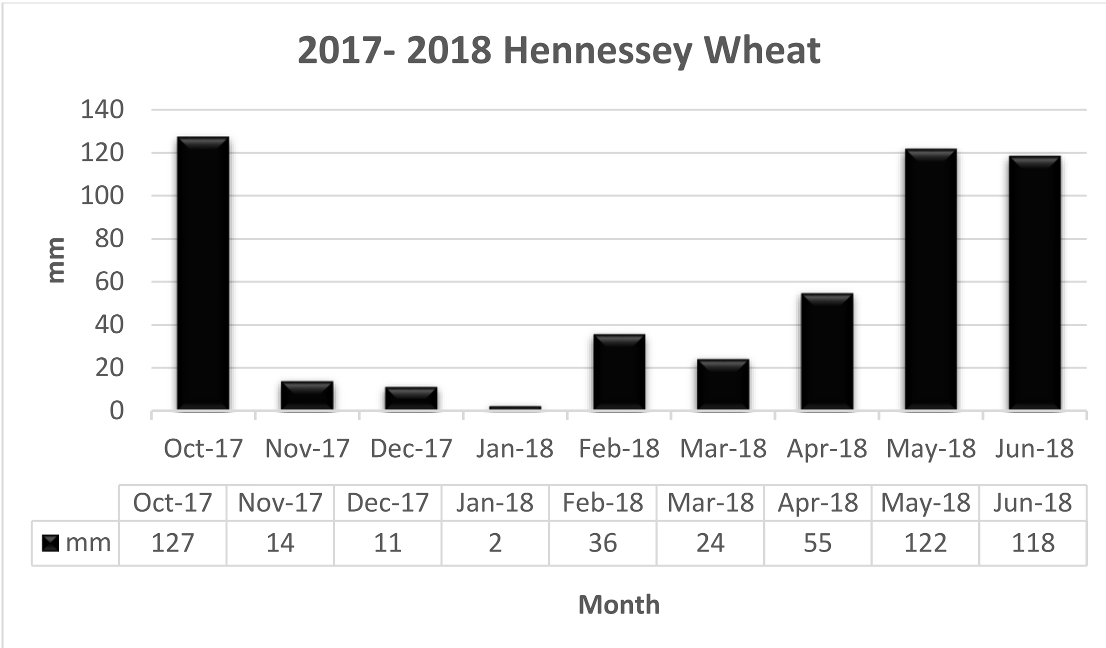


Figure 8. Average rainfall by month during the growing season, Hennessey, OK 2017-2018

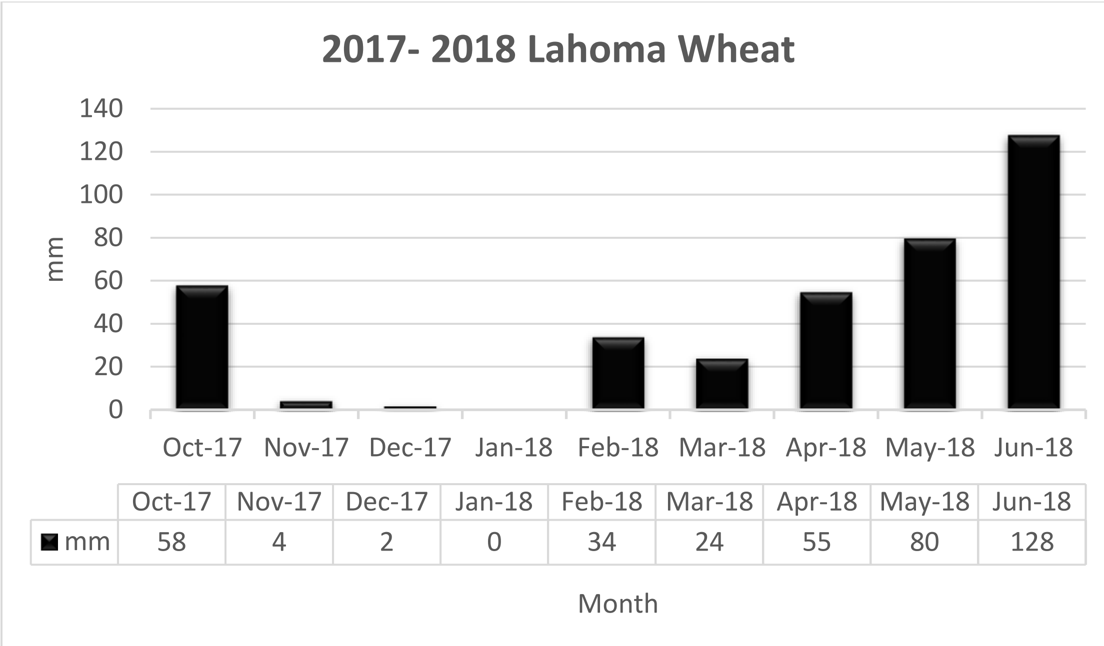


Figure 9. Average rainfall by month during the growing season, Lahoma, OK 2017-2018

Figure 10. Planting corn at Lake Carl Blackwell, OK, 2018

Figure 11. Mid-season picture of corn at Lake Carl Blackwell, OK, 2018

Figure 12. Drone footage of corn at Lake Carl Blackwell, OK, 2018

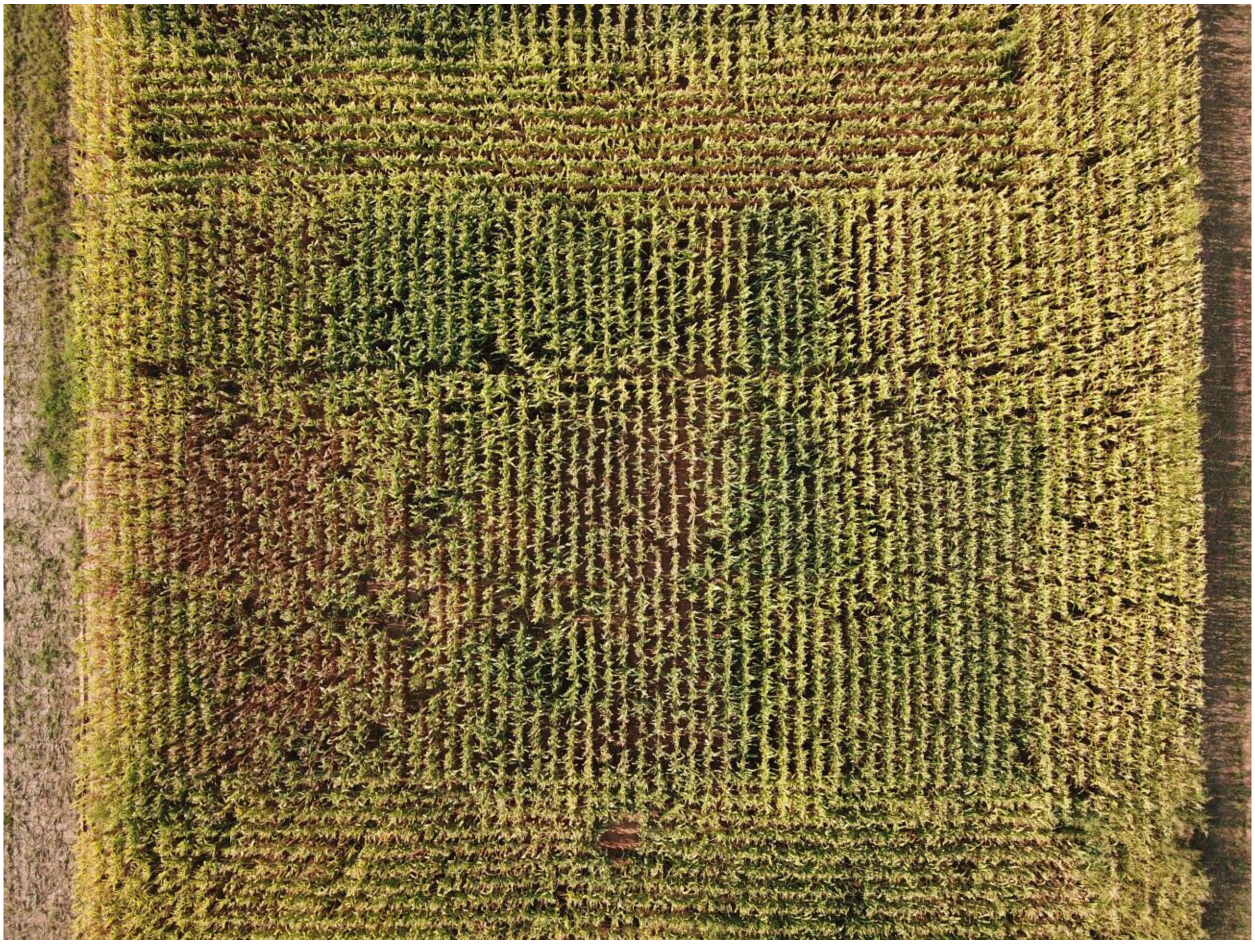


Figure 13. Drone footage of corn drying down at Lake Carl Blackwell, OK, 2018


Figure 14. Harvesting Corn at Efaw, OK, 2018

Figure 15. Wheat at Efaw, OK, 2018

Figure 16. Wheat at Hennessey, OK, 2018

VITA

Robert Benjamin Lemings

Candidate for the Degree of

Master of Science

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