INFLUENCE OF DUAL TOP-DRESS NITROGEN APPLICATIONS ON WINTER WHEAT (TRITICUM AESTIVUM L.) GRAIN YIELD

By

JONATHAN TYLER CARPENTER

Bachelor of Science in Plant and Soil Science

Oklahoma State University

Stillwater, OK

2019

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2021

INFLUENCE OF DUAL TOP-DRESS NITROGEN

APPLICATIONS ON WINTER WHEAT (TRITICUM

AESTIVUM L.) GRAIN YIELD

Thesis Approved:

Dr. William Raun

Thesis Adviser

Dr. Brian Arnall

Dr. Sergio Abit

Name: JONATHAN TYLER CARPENTER

Date of Degree: MAY, 2021

Title of Study: INFLUENCE OF DUAL TOP-DRESS NITROGEN APPLICATIONS ON WINTER WHEAT (TRITICUM AESTIVUM L.) GRAIN YIELD

Major Field: PLANT AND SOIL SCIENCES

ABSTRACT

Winter wheat (*Triticum aestivum*) is commonly grown throughout Oklahoma and is notably the state's top cash crop. Nitrogen (N) is one of the most heavily applied nutrients in wheat by producers across the state as it is often the most deficient macronutrient. Nitrogen use efficiency (NUE) has recently been documented at 35% in cereal crop production worldwide (Omara et al., 2019). At such a low value, research must continue to explore management options to improve NUE. One way to do so is to optimize the timing of N, in order to provide the plant with the nutrients they need at the most critical growth stage. The objectives of this study were to evaluate two timings of top-dress N at different rates on winter wheat grain yield, grain N, and NUE. Nitrogen was applied in early spring before and after visible response with single and split N applications. Nitrogen rates varied from 0 kg ha^{-1} to 101 kg ha^{-1}. Urea Ammonium Nitrate (UAN) and Urea were the two sources of N used in this study. Data was collected during the 2019 and 2020 growing seasons at Hennessey and Lahoma, OK. Split N applications commonly resulted in significantly higher grain yields when a higher rate was applied at the earlier application. This was also true for grain N results. Differences among NUE were not significant, however. It was seen that the application methods with a higher N rate early tended to have a higher grain yield and NDVI value. When N was applied later in the season, this generally resulted in higher grain N.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

Oklahoma is known for its extensive winter wheat (*Triticum aestivum L.*) production. Thus, winter wheat is regarded as one of the top cash crops grown within the state. Over 1.9 million Mg of wheat were produced within the state in 2018 attributing to nearly $360 million in state revenue (Marshall, 2018). Production has been noted to increase as revenues generated increased to $473 million in 2019 with 1.7 million hectares planted. (USDA, 2020). In 2020 the estimated average yield across the state was listed at 2.69 Mg ha^{-1} .

Producers commonly apply nitrogen (N) in winter wheat production as it is generally the most limiting nutrient. Overtime, research has evaluated numerous factors that come into play when determining the optimum N rate for winter wheat grain production. Such factors include N fertilizer application rate, timing, method, and placement. It is generally noted that split N applications often result in higher grain yield and nitrogen use efficiency (NUE) (Efretuei et al, 2016). World NUE of cereal crop production was found to be 33% in 1999 (Raun and Johnson, 1999)). Since then, small improvements have been made with a current global NUE estimate of between 35% and 40% efficiency has been noted within the United States alone (Omara et al., 2019). At this low percentage, research must continue to evaluate N management practices in cereal grain production.

One of the common methods utilized to increase NUE and improve grain yields is to apply N at critical growth stages that will further optimize response when plant N demand is greatest. Considering the relatively low grain price of wheat, producers may wait to apply N later in the growing season depending on the likelihood of N response to save on cost. Therefore, evaluating later season N applications is needed to provide Oklahoma farmers with more concrete recommendations. Through the years, the use of N rich strips accompanied with GreenSeeker™ sensors have been used to help producers with in-season N application rates. The Oklahoma State University winter wheat algorithms for these sensors are shown to be most accurate when 80 to 115 growing degree days (GDD >0) have been accumulated (Figuerido et al., 2020). This metric is based on N rate studies that were generally planted in October and then fertilized early to mid-March. This work aims to show the impact of late season full and split application N rates on winter wheat NDVI, grain N content, and grain yield.

Objective

The objective of this study was to evaluate the impact of the timing rate and source of top-dress applied N on winter wheat in-season NDVI, grain yield, grain N concentration and NUE.

CHAPTER II

REVIEW OF LITERATURE

Nitrogen Timings

The timing of N applications in winter wheat has been a well-researched topic overtime. Zebarth and Sheard (1992) stressed the importance of N fertilizer application timing for optimum yield and grain grain N to be achieved. Current common N application practices are to apply both pre-plant and in-season applications of N fertilizers. However, late season N applications could be more beneficial for grain yield and protein achieved based on previous study findings. Protein in winter wheat was noted to increase by applying N in the spring compared to the fall (Brown and Petrie, 2006). This study evaluated yield and protein in irrigated winter wheat influenced by N rate and timing. Protein content is crucial when looking at irrigated wheat considering premium losses that occur when low protein content is present. Work by Woolfolk et al., 2002 also evaluated late-season N applications in winter wheat to determine the effect on grain protein. Their study evaluated five foliar N rates ranging from 0 to 45 kg N ha^{-1} with pre and post-flowing timings. The authors did not find any consistent benefit for grain and straw yield nor straw N content with these applications. However, foliar applications of N consistently increased grain N content by 2.4 to 2.7 g kg^{-1} compared to the check. Other research has noted split applications to (fall and spring applied) to slightly decrease grain yield (Woodward and Bly, 2008). However, foliar split applications in this experiment increased grain protein by 0.8%,with late season foliar applications further increasing protein by 1.6%.

Nitrogen Rate

In addition to the timing of N applications, applying the optimum rate is just as important to further optimize grain yield. Gandorfer and Rajsic, 2008 conducted an experiment to evaluate the economic optimum N rate using rates ranging from 40 to 200 kg N ha^{-1}. The yield for this study ranged from 4.61 to 8.50 Mg ha^{-1}. This study found that the optimum N rate varied by year and variety, with the optimum rate ranging from 100 to 168 kg N ha^{-1} (Zhen-Ling et al, 2006). The optimum N rate needed for a cropping season can also be influenced by the residual soil N levels. Over eight sites, the highest N rate varied from 0 to 189 kg N ha^{-1} and the yield yield ranged from what to what?   A study conducted at Lativa University looked at the impact of varying N rate, varieties and years effects on final grain yield. This study showed that year and cultivar play a crucial role at determining the optimum N rate. The study attributed 34% of the variability in optimum N rates to cultivar, 33% to year and 13% to the interaction of the two variables. Nitrogen rates of 60, 90, 120, and 150 kg ha^{-1} were used with and where a peak was seen at 90 kg N ha^{-1} (Linina and Ruza, 2018). A study conducted in Colorado by Halvorson et al., 2004 looked at N rate effect on grain N across nine locations. This study included N rates of 0, 28, 56, 84, and 112 kg ha^{-1}. The amount of N recovered in grain ranged from 23 to 130 kg N ha^{-1}. Since the check treatment recovered 23 kg N ha^{-1}, it was apparent that residual soil N levels were present. Of all the years and N rates, the highest amount of grain N achieved was observed using a rate of 84 kg N ha^{-1}.

Nitrogen Placement

A study conducted by Rao and Dao (1996) examined the effects of N placement on N distribution within the plant and final grain yield. Placement methods used were broadcast, band below the seed, and band between rows in both conventional till and no-till systems. All plots outside of the check received 60 kg N ha^{-1}. The study concluded there were increased grain yields in the below seed and between row treatments in no-till only. However, placement does not always play a factor in the overall efficiency of N fertilizer applications. Mahler et al, 1994 evaluated two N sources at single and split applications both above and below the soil surface. The author's concluded that the timing of applications was more critical than the source used or placement in obtaining higher NUE and grain yield. A study in southern Alberta was also conducted to evaluate the effects of fertilizer source, timing and placement (Middleton et al, 2004). This study was conducted for two years at three locations. The results showed that there was no difference in final grain yield between placement with the seed, between rows, and top-dress applications. Considering these studies, it is evident that placement methods of N may not always have a large impact on overall yield results.

Application of Sensor Based Technology

Sensor based in-season fertilizer applications have become more common in the recent years with the development of yield prediction algorithms. A study conducted by Li et al., (2009) compared the efficiency rate of using sensor-based N recommendations compared to farmer practice and recommendations solely based off soil sample test results. In this experiment, both the sensor based and soil sample based recommendations used a fifth of the N of the traditional farmer's practice. However, recorded yields across the three methods were not significantly different, the sensor-based and soil test-based methods greatly improved NUE compared to the farmer's practice. The authors conducted similar work the following year to evaluate the use of GreenSeeker™ to collect NDVI and evaluate the use of NDVI to predict plant biomass and N uptake (Li et al, 2010). The study was conducted using 13 field experiments and 69 farmer fields. The study concluded that NDVI readings obtained from the GreenSeeker™ sensor could predict wet biomass up to 3736 kg ha^{-1}. If the amount of biomass present was too great, then a ratio vegetation index should be used. Additionally, a study in Egypt used both a chlorophyll meter and NDVI to validate their ability to predict yield in-season at Feekes 6 (Ali et al, 2020). Their study used varying N rates to evaluate their efficiencies. The chlorophyll meter was able to explain 53% variation in final grain yield, whereas NDVI was able to explain 60%. Lei et al., 2012 conducted a study evaluating the feasibility of using NDVI data at a variety of growth stages and N rates in order to predict final grain yield. The study found that at early grain fill, their model was highly correlated to final grain yield. It also showed an even higher significance when readings were obtained during later grain fill periods. It was noted that NDVI values increased across higher N rates and also as the season progressed.

CHAPTER III

MATERIALS AND METHODS

Trial Establishment

To accomplish the objective of this study, trials were established at Hennessey and Lahoma, OK during the 2018-19 and 2019-20 growing seasons. A randomized complete block design with 3 replications and 13 treatments was used. The main factors of this experiment include two different timings of N application those being early season top-dress and late-season top dress (Table 1). Five total rates of N were evaluated with rates of 0, 32, 67, 84, and 101 kg N ha^{-1}. These total N rates were evaluated as both single applications and different combinations of split application rates as outlined in Table 1. Early top-dress was applied in the spring prior to visible N response. Late top-dress was applied after visible N response. The UAN (28-0-0) applications were applied using streamer nozzles on an ATV. Urea was applied by hand in measured quantities. Seeding rate was 78 kg seed ha^{-1} on 19 cm row spacing and seeded with a Great Plains no-till drill. Wheat varieties used in this experiment include Bentley and Double Stop during 2019 and 2020 harvest seasons, respectively. Double Stop was planted in the 2020 harvest season to lessen weed pressure. Dates of all field activities are included in Table 2

Prior to planting, soil samples were collected for analysis by replication at a depth of 0-15 cm. Approximately 18 cores were pulled from each replication and combined to obtain one composite sample. Samples were oven dried for 12 hours at 105℃ and rolled to pass through a 1 mm screen sieve. Samples were then analyzed for soil test NO_3-N, NH_4-N, P, and K as well as pH using standard procedures (Table 3). Analysis results are noted in Table 2. Soil type at Hennessey and Lahoma was noted to be Bethany silt loam (fine, mixed, superactive, thermic Pachic Paleustoll) and Grant silt loam (fine-silty, mixed, superactive, thermic, Udic Argiustoll), respectively (USDA, 2021)

Data Collection

Data collected in this experiment includes, normalized difference vegetative index (NDVI) readings, grain N content, estimated N use efficiency (NUE), and grain yield. Optical NDVI sensor readings were collected every two weeks near Feekes 3, 4, 5, and 7 (Large, 1945) growth stages or approximately 64 to 118 growing degree days above 0 (GDD >0). Readings were collected using the Trimble GreenSeeker™ model 505 sensor. Normalized difference vegetative index is calculated as

$$NDVI= [(NIR\text{-}Red) / (NIR + Red)].$$

The wavelengths for NIR and Red light bands are 780 nm and 671 nm, respectively (Mullen et al., 2003). This index is commonly used as an indicator of plant health and measurement of biomass production. Raun et al., 2001 also noted NDVI readings can be used to estimate yield in-season to better obtain mid-season N fertilizer rates.

Grain yield was collected at harvest using a Kincaid 8XP plot combine. Grain samples and weights were collected for each plot during harvest using a Harvest Master and analyzed for grain N content. Samples were oven dried at 105℃ for 24 hours. A milling grinder was used to grind samples and then samples were further refined through a rolling process to achieve appropriate particle fineness. Grain N content was determined using a Leco CN 828 instrument in which 150 mg of grain was combusted at 950°C. Using grain N content, nitrogen use efficiency (NUE) was also determined and was calculated as

$$\text{NUE (\%)} = \frac{\text{Grain N \%* Grain Yield (kg ha}^{-1}\text{) - Grain N \% *Grain Yield (kg ha}^{-1}\text{)}}{\text{N Applied (kg N ha}^{-1}\text{)}}$$

Statistical analysis was performed using SAS 9.4 software. A generalized linear model was used to analyze the main effects of N timing, rate, and source on the dependent variables NDVI, grain N content, grain yield, and NUE. Single-degree-of-freedom contrasts were conducted to determine specific treatment differences.

Climate data was collected from the Mesonet past data. The temporal and rainfall data was plotted in a bar graph to evaluate climates effect on NDVI, grain N, grain yield and NUE.

CHAPTER IV

RESULTS AND DISCUSSION

Hennessey 2018-19

Pre-plant soil samples showed that the pH across reps ranged from 5.51 to 5.67 (Table 3). Nitrate N ranged from 1.5 to 2 mg kg^{-1}. Ammonium N ranged from 17 to 17.5 mg kg^{-1}. Phosphorus ranged from 71 to 82 mg kg^{-1}. Potassium ranged from 376 to 403 mg kg^{-1}. Rainfall was higher than average in October and May (Figure 1). November through April were all below average rainfall. Ambient temperature was above average in April and June. Ambient temperature was below average in all other months.

Limited differences were noted across treatments at this location. Sensor readings were higher at the high N rates. Differences in NDVI readings collected were not evident until 80 GDD (Table 4). Beginning at 80 GDDs, split applications totaling 67 and 101 kg total N ha^{-1} resulted in significantly greater NDVI values compared to applying those rates once, later in the season(treatments 3,4 vs. 6,8) (α=0.05). When comparing the timing of those total N rates, applying N earlier in the season improved NDVI readings compared to later season applications (treatments 3,4 vs. 12, 13) (α=0.05). Timing treatments (7 vs. 10 and 8 v.11) showed no significance at any GDD for NDVI. Later in season NDVI readings were correlated with grain yield (Figure 2).

Grain yields at this location ranged from 1.57 to 3.4 Mg ha^{-1}. Bentley produced 3.4 Mg ha^{-1} in the variety trial conducted by Oklahoma State University Small Grains (OSU). The highest grain yield was observed in treatment 11 containing a 67-34 split application. Split applications that had a higher N rate early in the season tended to result in greater yields. Significant differences were noted when comparing single and split applications, late and early application dates, and some timing treatments (2 vs 5 and 4 vs 13). Applying all N once, early in the top-dress season significantly improved grain yield compared to applying the total rate later in the season 2.93 Mg ha^{-1} to 2.43 $Mgha^{-1}$, respectively.

N content of wheat grain at this location ranged from 1.68% to 1.90%. Similarly, grain N for Bentley was stated at 2.13% by Oklahoma State University Small Grains (OSU). Treatment 11 using the 67-34 split application resulted in the highest grain N. Late application dates resulted in a significantly high grain N compared to early applications. This trend carried throughout the other timing treatments. Single vs split and urea vs UAN showed no significant differences in grain N.

NUE ranged from 22% to 44%. It was also noted that NUE significantly improved when split applications were used compared to single applications. Treatments 2 and 5 also showed a significant difference on NUE in that applying 34 kg N ha^{-1} earlier improved grain yield compared to applying the same rate after visual response. Urea vs UAN and other timing treatments were not significantly different.

Hennessey 2019-20

Pre-plant soil samples showed that the pH across reps ranged from 5.61 to 5.74 (Table 3). Nitrate N ranged from 9 to 15 mg kg^{-1}. Ammonium N ranged from 17.5 to 20.5 mg kg^{-1}. Phosphorus ranged from 115 to 136 mg kg^{-1}. Potassium ranged from 506 to 567 mg kg^{-1}. Rainfall was higher than average in January, March, and November (Figure 3). All other months were all below average rainfall. Ambient temperature was above average in January, February, March, June, and December. Ambient temperature was below average in all other months.

Few treatments showed a significant difference at this location. Sensor readings only differed slightly among N Rates. There were no significant differences seen in NDVI readings until 85 GDD (Table 5). At 85 GDDs, late applications of 67 and 101 kg N ha^{-1} showed a slightly higher NDVI value than split applications of 34-34 and 34-67 (3,4 vs 6,8) (α=0.05). Treatments with later applied N rates tended to show a slightly higher NDVI value. Source and timing treatments showed no significant difference at any GDD. Early sensor NDVI readings were not correlated with grain yield (Figure 4).

Grain yield at this location ranged from 2.82 to 5.95 Mg ha^{-1}. Double Stop showed to have similar yields in variety trial (OSU). Double Stop produced 3.3 Mg ha^{-1} in the variety trial conducted by Oklahoma State University Small Grains. The highest grain yield was observed in treatment 9 containing 34-67 split application. Applications with a higher N application early tended to have a higher grain yield. Significant differences were noted when comparing N source where urea resulted in a higher grain yield (8 vs 9). Single and split, early and late, and timing treatments illustrated limited differences.

N content of wheat grain for this location ranged from 1.64% to 2.25%. Similarly,grain N for Double Stop was stated at 2.24% by Oklahoma State University Small Grains (OSU). Treatment 9 using urea resulted in the highest grain N. Urea 34-67 split significantly improved grain N over UAN 34-67 split. Grain N tended to be higher when N was applied at later dates. There were no significant differences observed in single and split, early and late, and timing treatments.

NUE for this location ranged from 42% to 88%. Treatment 9 using urea resulted in the highest NUE. Applying urea as 34-67 split application resulted in a significantly higher NUE than when applying UAN as 34-67 split. There were no trends in NUE with application timing and rates. There were no significant differences observed in single and split, early and late, and timing treatments.

Lahoma 2018-19

Pre-plant soil samples were not evaluated at this location. Rainfall was higher than average in October and May (Figure 5). November through April were all below average rainfall. Ambient temperature was above average in April. Ambient temperature was below average in all other months.

A limited number of significant differences across treatment were noted at this location. Sensor readings were higher with higher N rates applied. Differences in NDVI readings where not seen until 97 GDD (Table 6). Beginning at 97 GDD early applied treatments showed a significantly higher NDVI value compared to applying later in season (3,4 vs 12,13) (α=0.05). At 104 and 118 GDD, early applied treatments showed a significantly higher NDVI value compared to applying later (3,4 vs 12,13) (α = 0.01). At 104 and 118 GDD early application had a significantly higher NDVI value then later applied (3 vs 12) (α=0.05). There were no significant differences in NDVI with single and spilt applications, urea and UAN, and timing treatments. Later in season NDVI was correlated with grain yield (Figure 6).

Grain yield at this location ranged from 1.14 to 2.06 Mg ha^{-1}. Bentley produced 3.4 Mg ha^{-1} in the variety trial conducted by Oklahoma State University Small Grains (OSU). The highest grain yield was observed in treatment 13 containing 101 kg N ha^{-1} applied early. Treatments with higher N applications early tended to produce higher grain yield. Significant differences were observed when comparing single and split, early and late, and some timing applications. Applying a split application resulted in a significantly higher grain yield than a single application. Early applications resulted in a significantly higher grain yield compared to later applications.

N content of wheat grain for this location ranged from 1.14% to 2.06%. Similarly,grain N for Bentley was stated at 2.13% by Oklahoma State University Small Grains (OSU). Treatment 13 (101 kg N ha^{-1} applied early) resulted in the highest grain N. Early applications resulted in a significantly higher grain N when compared to late applications (3,4 vs 12,13). Treatment 13 early–applied, 101 kg N ha-1 produced significantly more grain N than the same rate applied later in season. Treatment 11, the 67-34 split was significantly higher than treatment 8, 34-67 split. Single vs split and urea vs UAN had no significant differences.

NUE for this location ranged from 7% to 35%. Treatment 5, applying 34 kg N ha^{-1} resulted in the highest NUE. There were no trends in NUE across application timing and rates. Single vs split, urea vs UAN and timing treatments showed no significant differences.

Lahoma 2019-20

Pre-plant soil samples showed that the pH across reps ranged from 5.85 to 6.20 (Table 3). Nitrate N ranged from 7 to 8.5 mg kg^{-1}. Ammonium N ranged from 16 to 21 mg kg^{-1}. Phosphorus ranged from 8 to 10 mg kg^{-1}. Potassium ranged from 198 to 238 mg kg^{-1}. Rainfall was higher than average in December and January (Figure 7). All other months were all below average rainfall. Ambient temperature was above average in January, February, March, and December. Ambient temperature was below average in all other months.

A limited number of significant differences were noted across treatments at this location. Highest NDVI readings were recorded when applied in a 34-50 split application (Table 7). There were no significant differences in NDVI values. Also, NDVI was not correlated with grain yield (Figure 8).

Grain yield at this location ranged from 1.65 to 4.37 Mg ha^{-1}. Double Stop produced 3.3 Mg ha^{-1} in the variety trial conducted by Oklahoma State University Small Grains (OSU). The highest grain yield observed was treatment 4 with a single late application of 101 kg N ha^{-1}. It was noted that treatments with a split N application tended to produce higher grain yield. Significant differences were observed when comparing single and split, early and late, and some timing treatments. Split applications had higher grain yields than single applications. Furthermore, late applications resulted in higher grain yields compared to early applications.

N concentration in wheat grain for this location ranged from 1.92% to 2.43%. Similarly, grain N for Double Stop was stated at 2.24% by Oklahoma State University Small Grains (OSU). Treatment 9, the 34-67 urea split application resulted in the highest grain N. Applications later in season produced significantly more grain N (3,4 vs 12,13). Treatment 4, applying 101 kg N ha^{-1} later in season resulted in a significant improvement of grain N when compared to the early application in treatment 13. Single vs split, urea vs UAN and other timing applications did not result in a significant difference.

NUE for this location ranged from 39% to 70%. Treatment 4 a single late application of 101 kg N ha^{-1} resulted in the highest NUE1. Treatments with later N applications tended to have a higher NUE. A single application of 101 kg N ha-1 later in season resulted in a significantly higher NUE when the same rate was applied early. Single vs split, urea vs UAN, and all other timing treatments did not result in a significant difference.

Discussion

Sensor NDVI values went up with higher N rates. Significant differences did not appear at most sites until later in the season. Treatments with early applications tended to have significantly higher NDVI values. This result is likely due to the late application being applied only after a visual difference has occurred. The timing of sensor reading after late applications were limited not allowing to fully show the recovery after application. There were no readings taken further than a week after application due to hollow stem being reached. Later applied N alone is harder to recover in vegetative growth than N applied earlier in-season.

Grain yield was limited in the 2018-19 growing season from a shortage of rainfall at both locations from dormancy up to jointing. The environment for 2019-20 growing season allowed for much higher grain yield. Grain yield depended highly upon N rate and application timing. The trend of N applied early both alone or in split applications had did impact grain yield. A study conducted by Weisz et al. (2001) showed similar results in that split applications increased final grain yield and tiller counts. The difference in grain yield and tiller counts was dependent upon freeze timing. This solidified these results. Three out of the four locations had the highest grain yield when N was applied early or in a split application. These locations had warm temperatures and a lack of rainfall after application likely leading to volatization. The forth location received rainfall within two days of the late application. This allowed for better incorporation of the late applications.

N concentration in wheat grain was highly dependent upon application rate and timing. There were no trends observed when compared to weather data. When N was applied at higher rates grain N tended to go up. Split applications also tended to help raise grain N. Early applications usually had a lower grain N concentration with the exception of one site. This trend was also seen in a study conducted by Bly and Woodward, 2003 where they found a 70% increase in grain protein with a late N application due to the availability when the shift to reproduction occurs. It is advantageous to apply N later in season when a protein premium is available.

Estimated NUE varied by location. NUE was higher in site years with higher rainfall from January thru March. The results were inconsistent across sites and years. Some locations showed that a split application resulted in the highest NUE. Other location's results showed that N applied early in season gave the highest NUE. While another location showed that late applications resulted in the highest NUE. Nitrogen application timings at late tillering has also been found to improve grain yield and NUE (Efretuei et al, 2016). More years are needed to determine the best strategy for maximizing NUE.

CHAPTER V

CONCLUSION

The biomass produced from early applications of N was greater than that produced by a delayed application. This trend was only seen in years with greater rainfall (2018-2019). Similar findings were noted in grain yield where applying greater rates of N early on significantly improved grain yield compared to delayed only applications. However, split applications showed consistent benefits when a higher N rate was used for the first application compared to applying the full rate at once. Furthermore, there was not a consistent difference between the N source (UAN vs. Urea). Grain N did increase with higher N rates and was most influenced by the timing of application out of the dependent variables evaluated. Results from this study indicate the benefit of late season split N applications to improve grain protein, however, yield benefits are largely more variable. Nonetheless, split applications of N containing a higher N rate at the initial application offer producers a method to boost grain yield and protein content. Further research is needed in order to better predict optimal timing and rates.

REFERENCES

Ali, A.M., Ibrahum, S.M., Bijay-Singh. (2020). Wheat Grain Yield and Nitrogen Uptake Prediction Using atLeaf and GreenSeeker Portable Optical Sensors at Jointing Growth Stage. Information Processing in Agriculture, Vol. 7, Issue 3, 375-383.

Bly, A.G., Woodward, H.J., Foliar Nitrogen Application Timing Influence of Grain Yield and Protein Concentration of Hard Red Winter and Spring Wheat. Agronomy Journal, Vol. 95, Issue 2, 335-338.

Brown, B.D., S. Petrie (2006) Irrigated hard winter wheat response to fall, spring, and late season applied nitrogen. Field Crops Research Vol.1, Issues 2-3, 260-268. https://doi.org/10.1016/j.fcr.2005.07.011

Efretuei, A., Gooding, M., White, E., Spink, J., Hackett, R. (2016). Effect of Nitrogen Fertilizer Application Timing on Nitrogen Use Efficiency and Grain Yield of Winter Wheat in Ireland. Irish Journal of Agricultural and Food Research, Vol. 55, No. 5, 63-73.

Figueiredo, B., J. Dhillon, E. Eickhoff, E. Nambi, and W. Raun. (2020). Value of composite Normalized Difference Vegetative Index and growing degree days data in Oklahoma, 1999 to 2018. *Agrosystems, Geosciences & Environment*, *3*(1), e20013.

Gandorfer, Markus & Rajsic, Predrag, 2008. "Modeling Economic Optimum Nitrogen Rates for Winter Wheat When Inputs Affect Yield and Output-Price," Agricultural Economics Review, Greek Association of Agricultural Economists, vol. 9(2).

Halvorson, A.D., Neilsen, D.C., Reule, C.A. (2004). Nitrogen Fertilization and Rotation Effects on No-Till Dryland Wheat Production. Agronomy Journal, Vol. 96, Issue 4, 1196-1201.

Large, E.C. (1945). Growth Stages in Cerals Illustration of the Feekes Scale. Plant Pathology, Vol. 3, Issue 4, 128-129.

Lei, W., YouLu, B., YanLi, L., He, W., LiPing, Y. (2012). NDVI Analysis and Yield Estimation in Winter Wheat Based on GreenSeeker. Acta Agronomica Sinica, Vol. 38, No. 4, 747-753.

Li, F., Miao, Y., Zhang, F., Cui, Z., Li, R., Chen, X., Zhang, H., Schroder, J., Raun, W.R., Jia, L. (2009). In-Season Optical Sensing Improves Nitrogen-Use Efficiency for Winter Wheat. Soil Science Society of America Journal, Vol. 73, Issue 5, 1566.

Li, F., Zhang, H., Jia, L., Bareth, G., Miao, Y., Chen, X. (2010). Estimating Winter Wheat Biomass and Nitrogen Status Using Active Crop Sensor. Intelligent Automation and Soft Computing, Vol. 16, Issue 6, 1221-1230.

Linina, A. Ruza, A. The Influence of Cultivar, Weather Conditions and Nitrogen Fertilizer on Winter Wheat Grain Yield (2018). Agronomy research, Vol. 16, No. 1,147-156.

Mahler, R.L., Koehler, F.E., Lutcher, L.K. (1994). Nitrogen Source, Timing of Application, and Placement: Effects on Winter Wheat Production. Agronomy Journal, Vol. 86, Num. 4, 637-642.

Middleton, A.B., Bremer, E., McKenzie, R.H.(2004). Winter Wheat Response to Nitrogen Fertilizer Form and Placement in Southern Alberta. Canadian Journal of Soil Science, Vol. 84, No. 1.

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

Oklahoma State University. Central Region Summary. Avaliable at: http://wheat.okstate.edu/variety-testing/summary-of-all-regions/Central.pdf/

Omara, P., L. Aula, F. Oyebiyi, and W. R. Raun. (2019). World cereal nitrogen use efficiency trends: Review and current knowledge. *Agrosystems, Geosciences & Environment*, *2*(1), 1-8.

Rao, S.C., Dao, T.H. (1996). Nitrogen Placement and Tillage Effects on Dry Matter and Nitrogen Accumulation and Redistribution in Winter Wheat. Agronomy Journal, 88(3):365-371

Raun, W. R., and G.V. Johnson. (1999). Improving nitrogen use efficiency for cereal production. *Agronomy Journal*, *91*(3), 357-363.

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

USDA, 2020. 2020 State Agriculture Overview of Oklahoma. Accessed March 8, 2021. https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=OKLAHOMA

USDA., Web Soil Survey. 2021. Available at: https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx (Accessed: February 25, 2021)

Weisz, R., Crozier, C.R., Heiniger, R.W., Optimizing Nitrogen Application Timing in No-Till Soft Red Winter Wheat. Agronomy Journal, Vol. 93, Issue 2, 435-442.

Woolfolk, C. W., W.R. Raun, G.V. Johnson, W.E. Thomason, R. W. Mullen, K. J. Wynn, and K. W. Freeman. (2002). Influence of late-season foliar nitrogen applications on yield and grain nitrogen in winter wheat. *Agronomy Journal*, *94*(3), 429-434.

Zebrath, B.J., and R.W. Sheard. (1992) Influence of rate and timing of nitrogen fertilization on yield and quality of hard red winter wheat in Ontario. Canadian Journal of Plant Science. https://doi.org/10.4141/cjps92-002

Zhen-Ling CUI, Xin-Ping CHEN, Jun-Liang LI, Jiu-Fei XU, Li-Wei SHI, Fu-Suo ZHANG, Effect of N Fertilization on Grain Yield of Winter Wheat and Apparent N Losses1 1Project supported by the National Natural Science Foundation of China (Nos. 30390084 and 30270772) and the Natural Science Foundation of Beijing (No. 6010001).,Pedosphere,Volume 16, Issue 6,2006,Pages 806-812,ISSN 1002-0160,https://doi.org/10.1016/S1002-0160(06)60117-3.

APPENDICES

Table 1.Treatment Structure for Hennessey and Lahoma, OK (2018 and 2020).

Treatment	Early Topdress (kg N ha^{-1})	Late Topdress (kg N ha^{-1})	Total N (kg N ha^{-1})	N Source
1	0	0	0	UAN
2	0	34	34	UAN
3	0	67	67	UAN
4	0	101	101	UAN
5	34	0	34	UAN
6	34	34	67	UAN
7	34	50	84	UAN
8	34	67	101	UAN
9	34	67	101	Urea
10	50	34	84	UAN
11	67	34	101	UAN
12	67	0	67	UAN
13	101	0	101	UAN

UAN – urea ammonium nitrate, 28-0-0

Table 2. Planting, fertilizer application, and harvest dates

Year	Location	Sowing Date	Early N Application	Late N Application	Harvest Date
2018-19	Hennessey	10/9/2018	2/21/2019	4/5/2019	6/21/2019
2019-20	Hennessey	10/18/2019	2/7/2020	3/6/2020	6/12/2020
2018-19	Lahoma	10/18/2018	2/21/2019	4/5/2019	6/22/2019
2019-20	Lahoma	10/8/2019	2/7/2020	3/6/2020	6/11/2020

Table 3. Soil pH, nitrate-N, ammonium-N, potassium, and phosphorus levels prior to planting for each site year.

Year	Location	Rep	pH	NO_3-N mg kg^{-1}	NH_4-N mg kg^{-1}	K mg kg^{-1}	P mg kg^{-1}
2018-19	Henn	1	5.51	2	17	387	82
2018-19	Henn	2	5.62	1.5	17.5	376	71
2018-19	Henn	3	5.67	2	17.5	403	79
2019-20	Henn	1	5.68	15	20.5	536	136
2019-20	Henn	2	5.74	10.5	17.5	567	129
2019-20	Henn	3	5.61	9	19	506	115
2019-20	Lahoma	1	6.2	8.5	21	238	8
2019-20	Lahoma	2	5.85	8.5	16	223	10
2019-20	Lahoma	3	6.05	7	17	198	9

Table 4.Treatment structure, treatment means, and single-degree-of-freedom contrasts for NDVI, wheat grain yield, and NUE Hennessey, OK, 2018-2019											
Treatment	Early Topdress (kg N ha^{-1})	Late Topdress (kg N ha^{-1})	N Source	NDVI, GDD>0					Grain Yield (Mg ha^{-1})	Grain N %	NUE %
				51	55	61	80	101			
1	0	0	UAN	0.20	0.23	0.24	0.29	0.34	1.57	1.76	0
2	0	34	UAN	0.19	0.23	0.23	0.29	0.38	2.09	1.77	27
3	0	67	UAN	0.20	0.24	0.24	0.31	0.40	2.78	1.81	33
4	0	101	UAN	0.20	0.24	0.23	0.29	0.41	2.77	1.81	22
5	34	0	UAN	0.19	0.23	0.22	0.35	0.44	2.53	1.68	44
6	34	34	UAN	0.19	0.24	0.23	0.37	0.47	3.05	1.77	39
7	34	50	UAN	0.20	0.24	0.23	0.39	0.49	2.87	1.85	30
8	34	67	UAN	0.20	0.24	0.24	0.40	0.49	3.12	1.87	30
9	34	67	Urea	0.20	0.24	0.24	0.37	0.48	3.27	1.86	33
10	50	34	UAN	0.19	0.23	0.23	0.36	0.48	3.22	1.77	34
11	67	34	UAN	0.20	0.24	0.23	0.39	0.52	3.40	1.90	36
12	67	0	UAN	0.19	0.24	0.23	0.39	0.48	2.91	1.68	31
13	101	0	UAN	0.19	0.24	0.24	0.41	0.49	3.33	1.73	30
SED				0.01	0.01	0.01	0.03	0.02	0.19	0.04	4
CV,%				5.76	3.91	6.25	11.09	6.51	8.16	2.59	16.79
Contrast											
Single v. Split (3,4 v. 6,8)				ns	ns	ns	**	**	*	ns	*
UAN v. Urea (8 v. 9)				ns	ns	ns	ns	ns	ns	ns	ns
Late v. Early (3,4 v. 12,13)				ns	ns	ns	**	**	*	**	ns
Timing Treatments (2v5)(3v12)(4v13)				ns,ns,ns	ns,ns,ns	ns,ns,ns	ns,*,**	*,**,**	*,ns,**	*,**,*	**,ns,ns
Timing Treatments (7v10)(8v11)				ns,ns	ns,ns	ns,ns	ns,ns	ns,ns	ns,ns	*,ns	ns,ns
UAN- urea ammonium nitrate, 28-0-0, NDVI- normalized difference vegetative index, GDD>0 – growing degree days > 0 SED - standard Error of Difference, CV - coefficient of variation), ns - no significants, * - significant at α = 0.05, ** - significant at α = 0.01											

Table 5.Treatment structure, treatment means, and single-degree-of-freedom contrasts for NDVI, wheat grain yield, and NUE Hennessey, OK, 2019-2020

Treatment	Early Topdress (kg N ha^{-1})	Late Topdress (kg N ha^{-1})	N Source	NDVI, GDD>0			Grain Yield (Mg ha^{-1})	Grain N %	NUE %
				64	67	85			
1	0	0	UAN	0.26	0.30	0.47	2.82	1.64	0
2	0	34	UAN	0.27	0.31	0.49	3.81	1.75	63
3	0	67	UAN	0.28	0.31	0.48	4.15	1.80	43
4	0	101	UAN	0.27	0.31	0.51	5.32	1.95	57
5	34	0	UAN	0.28	0.30	0.45	3.62	1.68	42
6	34	34	UAN	0.25	0.28	0.39	4.59	1.75	51
7	34	50	UAN	0.26	0.32	0.50	4.83	1.85	51
8	34	67	UAN	0.27	0.31	0.46	4.51	1.78	34
9	34	67	Urea	0.26	0.29	0.44	5.95	2.25	88
10	50	34	UAN	0.28	0.32	0.43	5.07	1.89	58
11	67	34	UAN	0.28	0.31	0.48	5.21	1.89	52
12	67	0	UAN	0.27	0.31	0.44	4.45	1.89	57
13	101	0	UAN	0.26	0.29	0.47	5.15	1.86	49
SED				0.02	0.02	0.04	0.31	0.09	15
CV,%				8.85	6.95	11.83	8.29	5.97	36.13
Contrast									
Single v. Split (3,4 v. 6,8)				ns	ns	*	ns	ns	ns
UAN v. Urea (8 v. 9)				ns	ns	ns	**	**	**
Late v. Early (3,4 v. 12,13)				ns	ns	ns	ns	ns	ns
Timing Treatments (2v5)(3v12)(4v13)				ns,ns,ns	ns,ns,ns	ns,ns,ns	ns,ns,ns	ns,ns,ns	ns,ns,ns
Timing Treatments (7v10)(8v11)				ns,ns	ns,ns	ns,ns	ns,ns	ns,ns	ns,ns

UAN- urea ammonium nitrate, 28-0-0, NDVI- normalized difference vegetative index, GDD>0 – growing degree days > 0 SED - standard Error of Difference, CV - coefficient of variation), ns - no significants, * - significant at α = 0.05, ** - significant at α = 0.01

Table 6.Treatment structure, treatment means, and single-degree-of-freedom contrasts for NDVI, wheat grain yield, and NUE Lahoma, OK, 2018-2019

Treatment	Early Topdress (kg N ha^{-1})	Late Topdress (kg N ha^{-1})	N Source	NDVI, GDD>0						Grain Yield (Mg ha^{-1})	Grain N %	NUE %
				71	78	85	97	104	118			
1	0	0	UAN	0.31	0.28	0.29	0.29	0.26	0.33	1.14	1.81	0
2	0	34	UAN	0.32	0.30	0.30	0.30	0.27	0.37	1.49	2.09	32
3	0	67	UAN	0.29	0.25	0.26	0.26	0.25	0.34	1.24	2.32	13
4	0	101	UAN	0.29	0.26	0.27	0.27	0.25	0.35	1.29	2.46	11
5	34	0	UAN	0.32	0.30	0.31	0.34	0.31	0.41	1.74	1.85	35
6	34	34	UAN	0.31	0.29	0.30	0.34	0.32	0.43	1.79	2.19	28
7	34	50	UAN	0.31	0.29	0.30	0.33	0.31	0.42	1.76	2.23	22
8	34	67	UAN	0.28	0.26	0.27	0.30	0.28	0.38	1.66	2.41	20
9	34	67	Urea	0.30	0.28	0.29	0.31	0.29	0.40	1.71	2.40	20
10	50	34	UAN	0.30	0.28	0.29	0.34	0.32	0.43	1.81	2.16	23
11	67	34	UAN	0.29	0.27	0.29	0.33	0.33	0.44	1.77	2.31	20
12	67	0	UAN	0.31	0.29	0.31	0.36	0.34	0.44	1.88	1.94	24
13	101	0	UAN	0.30	0.28	0.29	0.34	0.33	0.43	2.06	2.03	21
SED				0.03	0.04	0.04	0.04	0.04	0.04	0.31	0.10	8
CV,%				12.49	16.45	16.42	17.11	16.42	13.69	8.29	24.04	46.18
Contrast												
Single v. Split (3,4 v. 6,8)				ns	ns	ns	ns	ns	ns	*	ns	ns
UAN v. Urea (8 v. 9)				ns	ns	ns	ns	ns	ns	ns	ns	ns
Late v. Early (3,4 v. 12,13)				ns	ns	ns	*	**	**	*	**	ns
Timing Treatments (2v5)(3v12)(4v13)				ns,ns,ns	ns,ns,ns	ns,ns,ns	ns,ns,ns	ns,*,ns	ns,*,ns	*,ns,**	*,**,**	ns,ns,ns
Timing Treatments (7v10)(8v11)				ns,ns	ns,ns	ns,ns	ns,ns	ns,ns	ns,ns	ns,ns	ns,ns	ns,ns

UAN- urea ammonium nitrate, 28-0-0, NDVI- normalized difference vegetative index, GDD>0 – growing degree days > 0 SED - standard Error of Difference, CV - coefficient of variation), ns - no significants, * - significant at α = 0.05, ** - significant at α = 0.01

Table 7. Treatment structure, treatment means, and single-degree-of-freedom contrasts for NDVI, wheat grain yield, and NUE Lahoma, OK, 2019-2020

Treatment	Early Topdress (kg N ha^{-1})	Late Topdress (kg N ha^{-1})	N Source	NDVI, GDD>0			Grain Yield (Mg ha^{-1})	Grain N %	NUE %
				72	75	92			
1	0	0	UAN	0.37	0.36	0.42	1.65	2.01	0
2	0	34	UAN	0.35	0.34	0.43	2.93	1.92	67
3	0	67	UAN	0.37	0.37	0.40	3.02	2.08	44
4	0	101	UAN	0.38	0.37	0.43	4.37	2.37	70
5	34	0	UAN	0.37	0.37	0.40	2.76	2.03	68
6	34	34	UAN	0.35	0.35	0.42	3.41	2.01	53
7	34	50	UAN	0.37	0.36	0.46	3.90	2.23	64
8	34	67	UAN	0.37	0.37	0.43	3.92	2.24	54
9	34	67	Urea	0.36	0.35	0.42	3.63	2.43	54
10	50	34	UAN	0.36	0.35	0.44	3.58	2.10	50
11	67	34	UAN	0.36	0.36	0.39	3.84	2.22	52
12	67	0	UAN	0.36	0.35	0.40	3.42	2.00	53
13	101	0	UAN	0.36	0.35	0.42	3.52	2.08	39
SED				0.01	0.02	0.04	0.26	0.10	9
CV,%				5.01	5.41	12.51	9.27	5.51	21.93
Contrast									
Single v. Split (3,4 v. 6,8)				ns	ns	ns	*	ns	ns
UAN v. Urea (8 v. 9)				ns	ns	ns	ns	ns	ns
Late v. Early (3,4 v. 12,13)				ns	ns	ns	*	**	ns
Timing Treatments (2v5)(3v12)(4v13)				ns,ns,ns	ns,ns,ns	ns,ns,ns	*,ns,**	ns,ns,**	ns,ns,*
Timing Treatments (7v10)(8v11)				ns,ns	ns,ns	ns,ns	ns,ns	ns,ns	ns,ns

UAN- urea ammonium nitrate, 28-0-0, NDVI- normalized difference vegetative index, GDD>0 – growing degree days > 0, SED - standard Error of Difference, CV - coefficient of variation), ns - no significants, * - significant at α = 0.05, ** - significant at α = 0.01

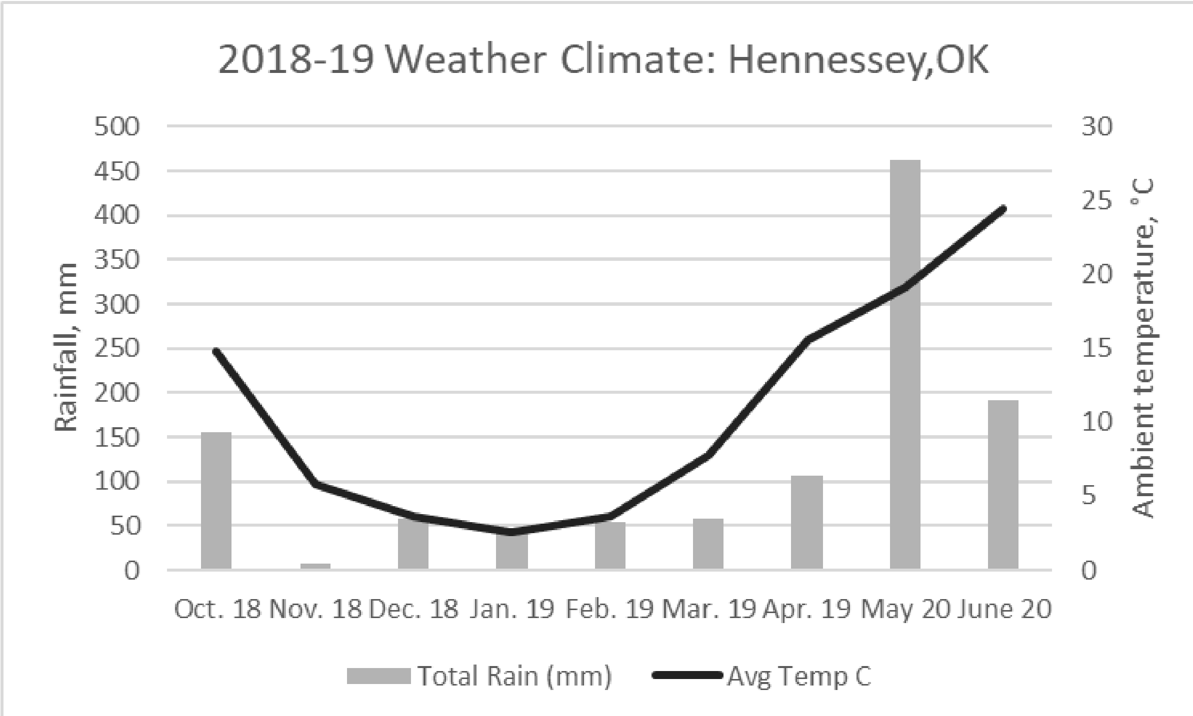

Figure 1. Average rainfall and air temperature by month during the growing season, Hennessey, OK 2018-19.

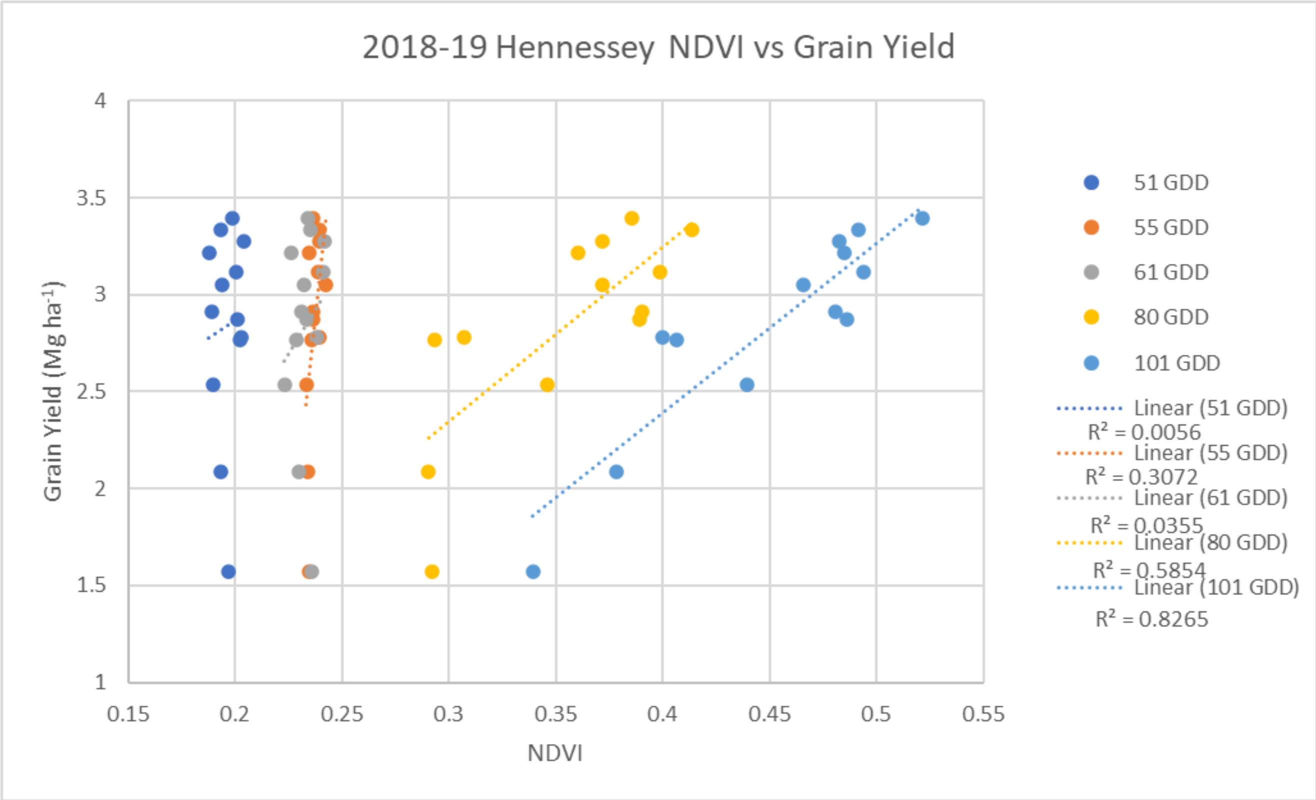

Figure 2. Relationship between wheat grain yield and NDVI with advancing growth stage or growing degree days (GDD), Hennessey, OK 2018-19.

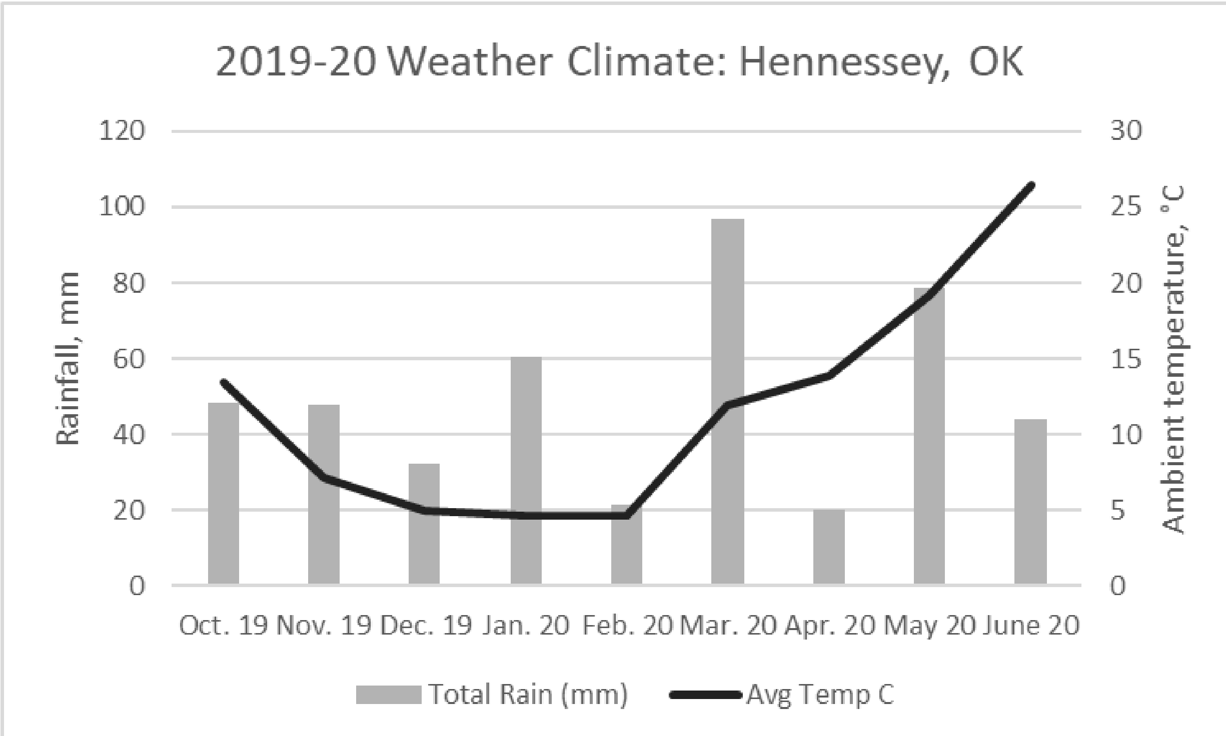

Figure 3. Average rainfall and air temperature by month during the growing season, Hennessey, OK 2019-20.

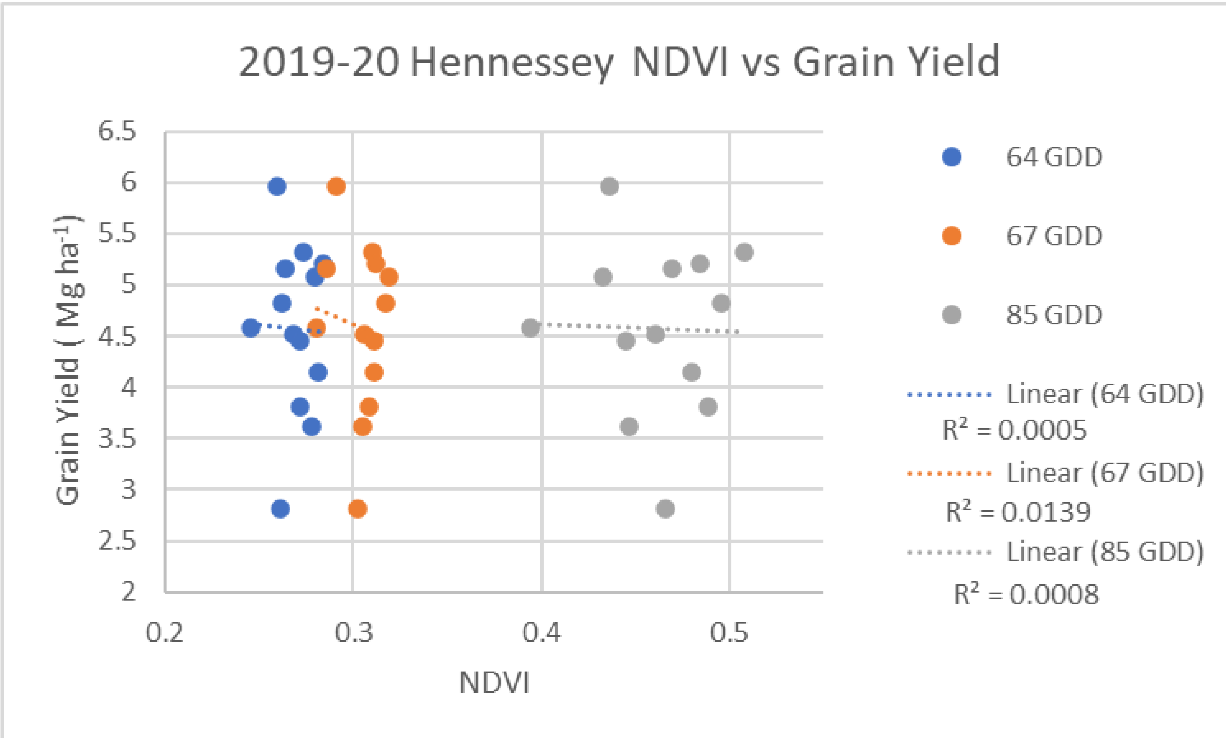

Figure 4. Relationship between wheat grain yield and NDVI with advancing growth stage or growing degree days (GDD), Hennessey, OK 2019-20.

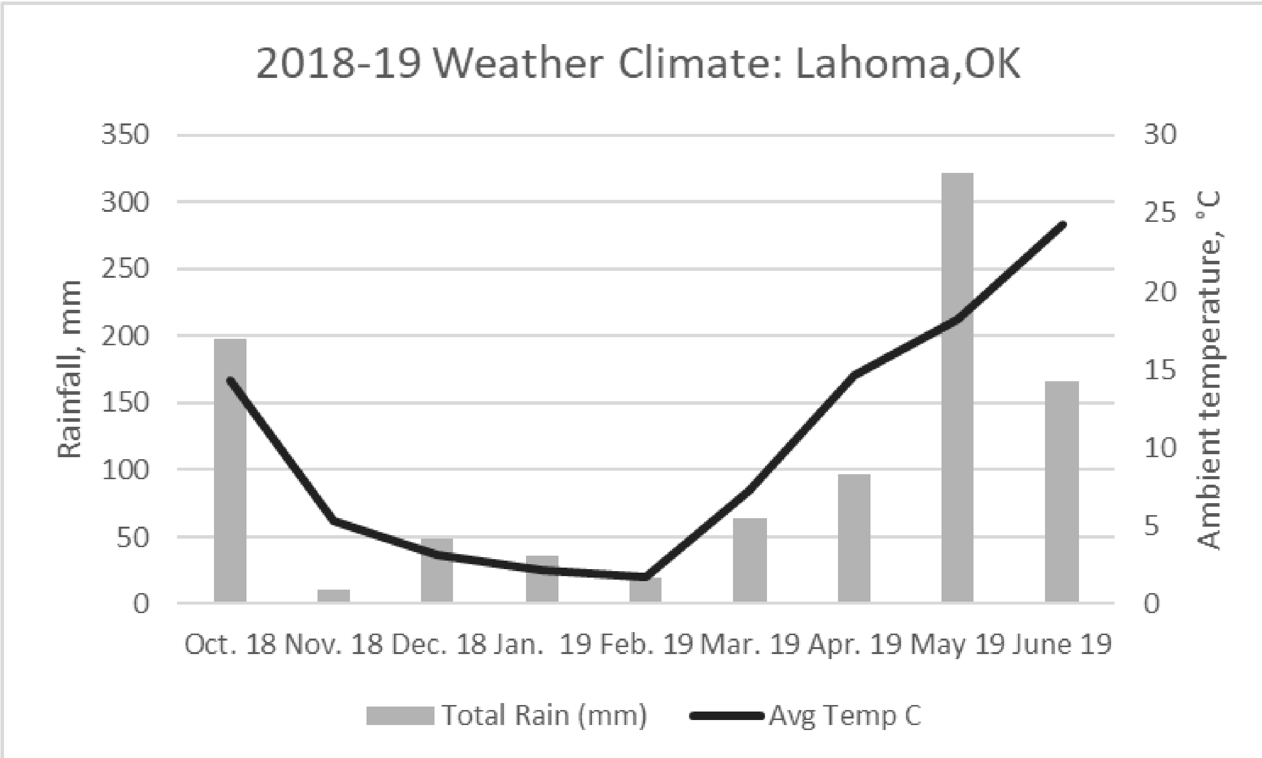

Figure 5. Average rainfall and air temperature by month during the growing season, Lahoma, OK 2018-19.

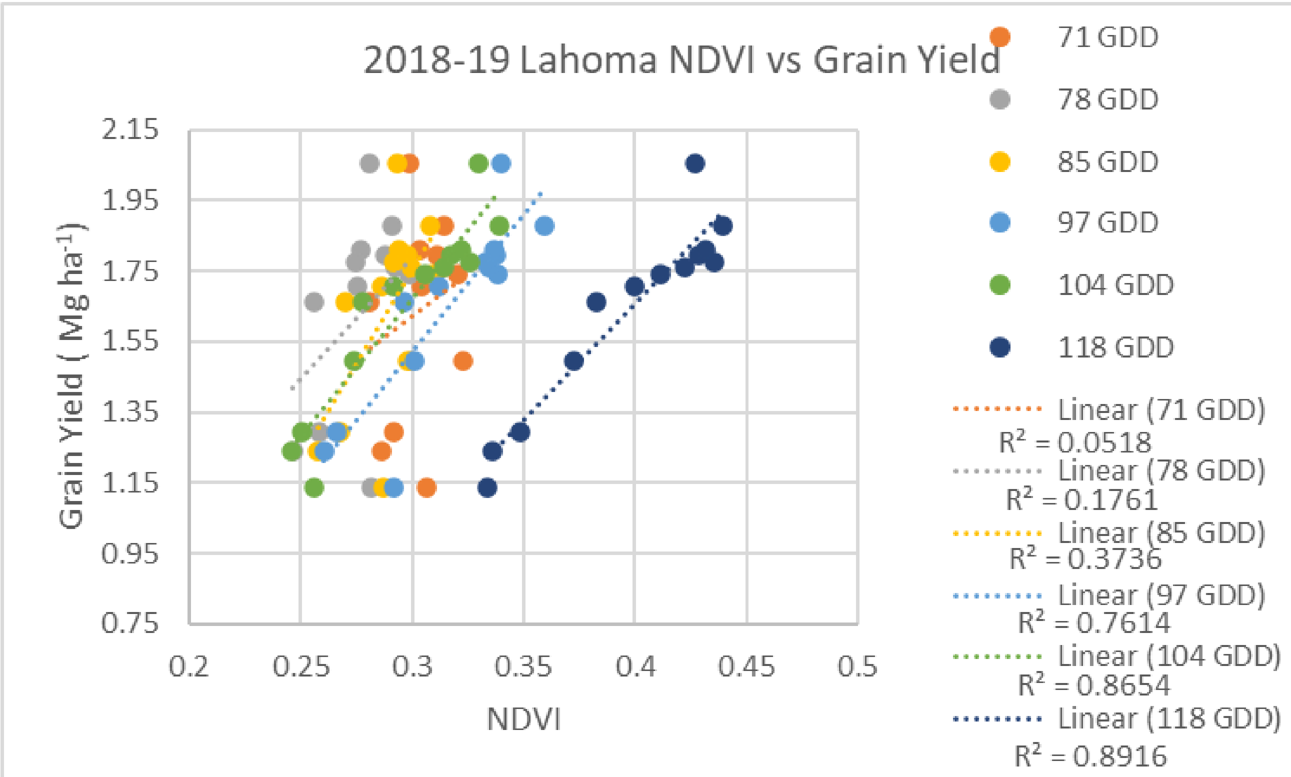

Figure 6. Relationship between wheat grain yield and NDVI with advancing growth stage or growing degree days (GDD), Lahoma, OK 2018-19.

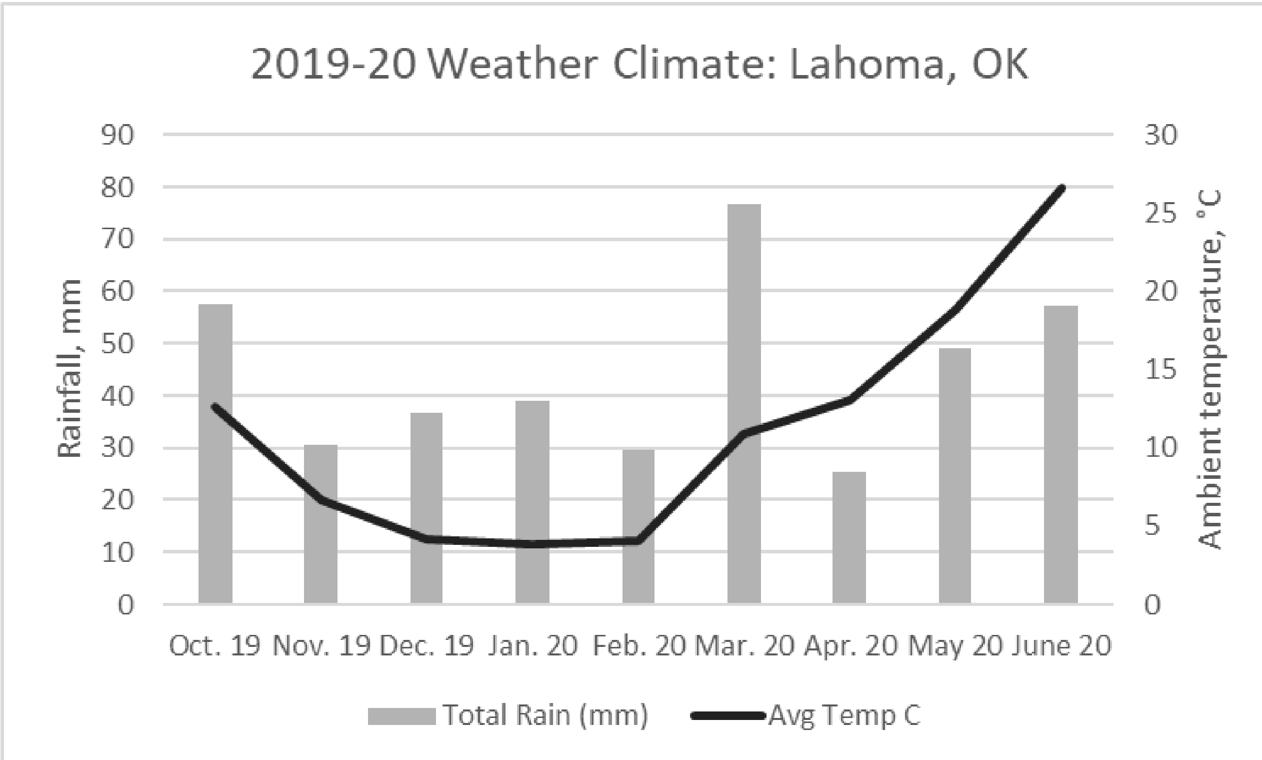

Figure 7. Average rainfall and air temperature by month during the growing season, Lahoma, OK 2019-20.

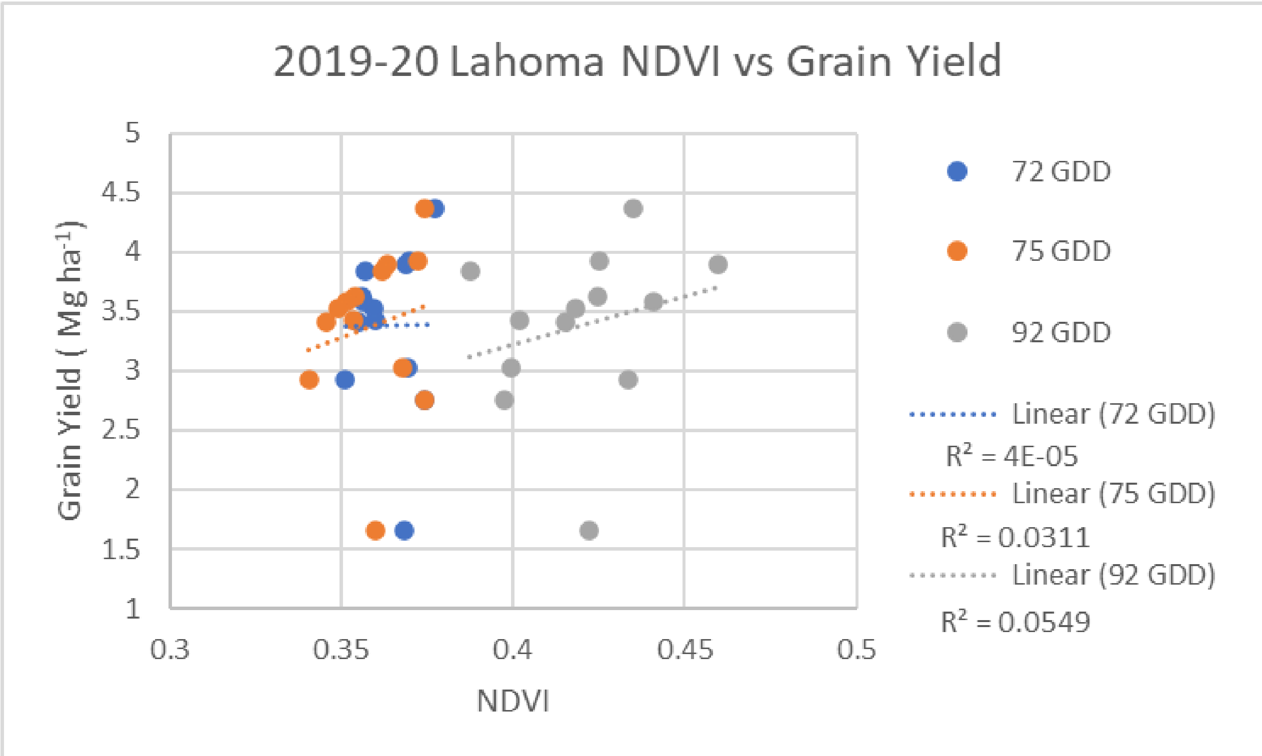

Figure 8. Relationship between wheat grain yield and NDVI with advancing growth stage or growing degree days (GDD), Lahoma, OK 2019-20.

Image 1. Lahoma March 2019

Image 2. Lahoma April 2019

Image 3. Lahoma May 2019

Image 4. Harvesting wheat 2020

VITA

Jonathan Tyler Carpenter

Candidate for the Degree of

Master of Science

Thesis: INFLUENCE OF DUAL TOP-DRESS NITROGEN APPLICATIONS ON WINTER WHEAT (TRITICUM AESTIVUM L.) GRAIN YIELD

Major Field: Plant and Soil Science

Biographical:

Education:

Completed the requirements for the Master of Science in Plant and Soil Sciences at Oklahoma State University, Stillwater, Oklahoma in May, 2021

Completed the requirements for the Bachelor of Science in Plant and Soil Sciences at Oklahoma State University, Stillwater, Oklahoma in May, 2019.

Experience:

Graduate Research Assistant (2019-present).

Professional Memberships:

American Society of Agronomy