OPTIMUM PREPLANT NITROGEN RATES IN WINTER WHEAT (TRITICUM aestivum L.) AND MAIZE (ZEA mays L.)

By

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MAIZE (ZEA mays L.)

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Title of Study: OPTIMUM PREPLANT NITROGEN RATES IN WINTER WHEAT (TRITICUM aestivum L.) AND MAIZE (ZEA mays L.)

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Abstract (winter wheat): The optimum amount of preplant nitrogen (N) for winter wheat changes from year to year and depends greatly on the production environment in which it is grown. Optimizing mid-season N rates is possible using normalized difference vegetation index (NDVI) sensor based methods. The objective of this experiment was to determine the minimum amount of preplant N in wheat accompanied by N applied mid-season for maximum yields and increased nitrogen use efficiency (NUE). Four field experiments were conducted where N as urea ammonium nitrate (UAN, 28-0-0, N-P-K) was applied preplant at rates of 0, 17, 34, 51, 67, and 101 kg N ha^{-1}. Preplant fertilizer was applied on October 6 for the Perkins and Hennessey locations, and October 8 and 9 for Lahoma and Lake Carl Blackwell, respectively. Normalized difference vegetative index data was was collected from the Feekes 3 growth stage and continued to the Feekes 7 growth (Large, 1954). At Feekes 5 growth stage, topdress N was applied at rates of 34 kg N ha^{-1} and 67 kg N ha^{-1}. . The optimum preplant N rate for these studies was 67 kg N ha^{-1} (Tables 7, 8, 9, 10). In order to maximize yields, at least 34 kg N ha^{-1} applied topdress was needed.

Abstract (maize): Overuse of nitrogen (N) fertilizer for maize production is prevalent. Optimizing mid-season N rates are possible using normalized difference vegetation index (NDVI) sensor based methods. The objective of this experiment was to determine the minimum amount of preplant N in maize accompanied by N applied mid-season for maximum yields and increased nitrogen use efficiency (NUE). Two maize trials were conducted where N as urea ammonium nitrate (UAN, 28-0-0, N-P-K) was applied preplant at rates 0, 17, 34, 67, 101, 134, and 168 kg N ha^{-1}. Preplant fertilizer was applied within four days prior to planting at both locations. Normalized vegetative index data was collected at the V5, V6 and V9 growth stages.. Mid-season sidedress fertilizer N application was applied at the V-6 growth stage at a rate of 168 kg N ha^{-1}. . This research should assist in recognizing the growth stage when maize plants will visibly show a deficiency. Due to environmental anomalies encountered, this maize N study will be conducted in the 2016 growing season. This work should determine the minimum preplant N rate needed combined with sidedress N for maximum yields in maize.

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CHAPTER I

Review of Literature

Introduction

Cereal grains, especially wheat (Triticum aestivum L), maize (Zea mays L.), and rice (Oryza sativa L.) are crucial in feeding our growing world population. In 2014, there were 1,021,616,583 metric tons of maize, 715,909,258 tons of wheat, and 728,966,757 tons of rice produced in the world (FAO, 2015). With a current world population of 7.3 billion people (FAO, 2015) and 9.7 billion projected for 2050, production of cereal grains will be vital to feed the world (United Nations, 2015). At current growth levels, we will likely be unable to feed this population. It is crucial to think of the world population when addressing maize, wheat and rice production due to the large dependence on these crops in many diets.

The use of inorganic nitrogen (N) fertilizers in agriculture has been in effect since first introduced in the 1940's. Nitrogen is well documented as a limiting nutrient in crop production and is considered one of the best producer inputs to increase profitability under an appropriate management system (Teal et al., 2006). Many wheat, maize, and rice cropping systems, depend on the use of nitrogen fertilizers in order to produce at a high level. Nitrogen is vital to maintain current production practices. Mohammed et al. (2011) stated it is one of the most limiting plant nutrients globally since it exists in the atmosphere in a form that cannot be used by plants. Thus, industrialized nitrogen fertilizer, became a major factor in agriculture. With the implementation of N fertilizers, producers can see an increase in yield and in protein content if nitrogen is applied later in the growing season. With regard to wheat, Wuest and Cassman (1992) noted that N should be supplied late in the season to improve N uptake during grain fill. When N is applied late, it can be utilized to increase protein content, which can allow producers to receive a premium price for their grain. Wheat grain N and wheat grain yields increased when preplant and sidedress N were applied (Boman et al., 1995). Both increased protein and yield lead to an increase in profit for the grower. Mohammed et al. (2011) showed that increased rates of N fertilizer delivered increased grain yield, protein content, and grain N uptake. As a result of the incentives for higher yield and grain protein, N fertilizer is typically applied in large quantities, to ensure that yield potential is not limited due to the lack of available N. Without tools to address spatially variable crop N need, farmers tend to apply enough N, at uniform rates, to meet crop needs in the more N-demanding areas of the field, resulting in greater risk of N loss from field areas needing less N (Hong et al., 2007). This method ensures nitrogen will be supplied, and can be a major reason why N loss occurs.

The importance of N fertilization for wheat, maize, and rice is not debated. Because the economic optimum nitrogen rate (EONR) is spatially variable and difficult to predict at the field or subfield scale, producers will often add more N than required for optimum maize production as a form of insurance to maximize yield everywhere in a field (Dellinger et al., 2008). However, in many cases, over application takes place and results in a smaller bottom line for the producer. As was found by Mullock et al. (2009), when preplant N rates exceeded the optimum needed for maximum grain yields, no benefits of by-plant N fertilization were observed.

Current Management Strategies

A common producer practice for N fertilization is to apply the full amount of fertilizer for the growing season as a pre-plant application for both winter wheat and maize. This ensures the crop will have access to N in the beginning of its life cycle, and it costs the producer less in fuel, due to only applying once as opposed to multiple trips across the field. Producers use this method of management, because it is cost effective and limits crop deficiency symptoms. This method is convenient for producers, because it limits the amount of time spent applying fertilizer to each field. Many wheat producers in the eastern Great Plains prefer to preplant apply both fertilizer N (all or a portion of the total N requirement) and fertilizer P together in one field operation to facilitate more rapid and timely planting (Kelley and Sweeney, 2007). It also avoids yield losses because of early season N deficiency. A management strategy to reduce N loss would be to apply enough fertilizer N in the fall to establish the crop and apply the remaining N requirement in the late winter or early spring before rapid growth occurs (Boman et al., 1995). Nitrogen deficiency at early growth stages can result in stunted seedling growth negatively affecting tiller formation, eventually resulting in a grain yield reduction (Mohammed et al., 2011). The benefits of N, along with the negatives associated with not applying, encourage over application of N fertilizers.

When N is applied in excess, it allows for losses to take place that not only affect the producer, but also the environment. According to Raun and Johnson (1999), these losses are a result of gaseous plant emission, soil denitrification, surface runoff, volatilization, and leaching and lead to diminished nitrogen use efficiency (NUE), estimated at 33% for cereal production in the world. Many soil N losses occur when N fertilizer is applied preplant, due to the amount of time between application and plant use, and therefore will affect NUE. Studies have found that pre-plant N fertilizer application can lead to losses or immobilization before plant uptake, thus greatly reducing NUE (Welch et al., 1966; Olson and Swallow, 1984; Lutcher and Mahler, 1988; Fowler and Brydon, 1989; Wuest and Cassman, 1992). In order to avoid negative environmental effects, split timing application has been an alternative method to applying all N preplant. Some N can be applied preplant, but at lower rates, with the remainder applied midseason as a topdress application. Top-dress application of N at higher rates improved grain N uptake thus reducing the risk of N losses. This indirectly minimizes environmental contamination from residual

N in the soil (Mohammed et al., 2011). In order to reduce environmental risk, NUE has been a focus of a number of studies. Moreover, the observed high grain N uptake when N is applied topdress can reduce vertical and/or horizontal movement of excess N, which will minimize environmental concerns and increase NUE (Mohammed et al., 2011). Improving NUE is crucial for farming in the future with the increase in nitrogen fertilizer prices, and environmental risk.

Nitrogen use efficiency is a focal point in moving forward in agriculture because of the many benefits that can be brought about from proper implementation. As discussed by Mohammed et al. (2011), improved N fertilizer management is a primary research focus to improve NUE. This will in turn increase production, minimize N losses, lower input costs and optimize resources (Mohammed et al., 2011). There is opportunity for improvement when it comes to NUE. As noted earlier, Raun and Johnson (1999) addressed the issue of NUE reporting that, worldwide, NUE for cereal production is approximately 33%. Similarly, Olson and Swallow (1984) reported that only 27 to 33% of fertilizer N had been recovered in the grain. In turn, this means that 67% of the N fertilizer is lost (leaching, runoff, denitrification, volatilization) or unaccounted for. High N uptake in the grain is desirable to increase crop grain quality and to minimize residual soil N after harvest that can move vertically and/or horizontally polluting the environment and water bodies (Mohammed et al. 2011). In order to improve NUE, better management of N fertilizer needs to be implemented as well as other technologies.

Current management strategies aim to simplify N application, via taking place only once, before planting. In general, one of the most common methods of determining preplant fertilizer N rates has been the use of yield goals whereby farmers average by-field yield levels over the last 5 years and then add 30% to establish the goal (Raun et al., 2004). This in general results in a fixed rate for the entire field. Current N recommendations for maize are usually determined on a field or farm scale and only consider the average EONR for a field. The economic optimum nitrogen rate concept is challenging since organic

N sources are present that provide variability in mineralizable N (Dellinger et al., 2008). Furthermore, Shanahan et al. (2007) suggested that many current fertilizer N recommendation procedures are "yield-based", meaning a yield goal is set before the crop is planted and multiplied by a constant factor to estimate N fertilizer requirement. However, inflated yield goals may also suggest that producers do not use actual whole-field averages, but rather rely on yield expectations from the highest producing areas of a field (Shanahan et al., 2007). Furthermore, Teal et al. (2006) reported that setting unrealistic yield goals and not accounting for yield variation between fields and within a field, can lead to consistent, excessive N application. For better management practices of N fertilizer, management must be conducted with respect to spatial variability. Current methods of applying nitrogen (N) fertilizer do not treat small scale variability that is known to exist (Mullock et al., 2009). By acknowledging variability, NUE is more likely to improve.

Variability can exist in a field through space, time, by plant, and temporally. Current N management decisions also overlook year-to-year weather variation and sometimes fail to account for soil N mineralized in warm, wet years, ignoring indigenous N supply (Shanahan et al., 2007). Therefore, in addition to nutrient management practices, environmental factors can significantly affect the efficiency of applied fertilizers (Walsh et al., 2012). It has been shown that crop response to N varies significantly from year to year, and that the magnitude of response is difficult to predict from one year to the next (Walsh et al., 2012). Since N response varies by year, so should the N recommendation. This emphasizes the need to make fertilizer decisions in-season (Johnson and Raun 2003). In-season management decisions will allow for N fertilizer recommendations to react to growth of the crop, and will limit N loss through leaching, runoff, and denitrification when N is applied preplant. Development of innovative strategies that improve NUE and minimize off-field losses are crucial to sustaining cereal-based farming (Shanahan et al., 2007). Improved N management is essential to maintain producer income and diminish environmental degradation (Teal et al., 2006). Better management practices will be beneficial to the producer and the environment especially if combined with the precision agriculture technologies that are available.

Benefits of Sensor Based Technologies

Precision agriculture technologies can be beneficial when implemented into a management strategy. Precision agriculture techniques such as remote sensing for variable-rate fertilizer application and site-specific nutrient management help to maximize crop yield and improve grain quality while minimizing the negative impact of agricultural practices on the environment (Walsh et al., 2012). Walsh et al. (2012) further showed the advantages of precision agriculture tools such as remote sensing to evaluate crop vigor, biomass production, canopy greenness and overall plant health. The sensor based nitrogen rate calculator (SBNRC) developed at Oklahoma State University can be used to reduce preplant N applied and embraces mid-season top-dress N application. Knowledge of crop nutrient status and yield potential determined from mid-season sensor readings allow producers to adjust top-dress N rates accordingly (Walsh et al., 2012). While top-dress application is not a common practice, studies show it to be beneficial.

The use of top-dress application and employing sensor technologies can improve the accuracy of N fertilizer applied. Mascagni and Sabbe (1991) and Boman et al. (1995) established that split applications of N fertilizer are extremely important to maximize crop utilization of applied fertilizer N and improve harvest quality. In addition to the accuracy of N application rate, improvements in grain quality have been recorded as well. At higher N application rates, top-dressing N fertilizer significantly increased grain yield, improved grain protein content, and grain N uptake (Mohammed et al., 2011). Sensor based technologies have been implemented to better predict yield, thus allowing for more precise N top-dress application. Earlier work by Lukina et al. (2001) showed that early-season NDVI alone was a good predictor of final winter wheat grain yield over several locations and years. If the upper boundary for achievable yield potential changes by year, and the demand for fertilizer N changes by year, the obvious solution for improving fertilizer N rate recommendations is to be able to predict yield potential (Raun et al., 2001; Raun et al., 2002; Raun et al., 2005). Because yield level is a major concern, it is critical for identifying optimum N rates.

Improving NUE in cereal crops is a challenging task that encompasses the ability to accurately estimate a crops need for N and developing nutrient management practices that would provide the best return from fertilizer application (Walsh et al., 2012). However, optical sensors that collect NDVI data to refine N rates have been proven to increase NUE by 15% (Raun et al., 2002). Although, studies show that increased NUE can lead to an improved return when techniques are properly incorporated, producer resistance persists. As explained by Shanahan et al. (2007), while research is rich with results supporting the point that NUE is improved by synchronizing applications with crop N use, adoption by farmers, with this as an incentive, has been minor. In large part this can be attributed to significant startup costs, however many sensor based technologies have been made affordable and convenient for their users. The adoption of precision agriculture technologies possesses a great benefit when addressing NUE. A 1% increase in the efficiency of N use for cereal production worldwide would lead to a $234,658,462 savings in N fertilizer costs (Raun and Johnson, 1999). Furthermore, Gupta and Khosla (2012) state, an increase of NUE in production of three major cereal crops—wheat, maize and rice—by just 10 % would result in savings of about US $5 billion per year and substantial improvement in environmental quality. The potential for large scale improvements for both producers and the environment are vast.

The discussion of NUE in cereal crops cannot end with large revenue; it must also encompass the need to produce these crops for a growing population. Raun and Johnson (1999) discussed the importance of improved yield in cereal crops stating, increased cereal NUE must accompany increased yields needed to feed a growing world population that has yet to benefit from the promise of N2–fixing cereal crops. It is crucial that efforts continue to recognize the necessity of high yields, while still achieving enhanced NUE and addressing environmental concerns.

Importance of Optimum N Rate

Nitrogen fertilizer applications vary from year to year as well as site to site. Bundy and Andrasky (1995) found N fertilizer needs for maize vary between fields, and Malzer et al. (1996) reported variations within fields. Fiez et al. (1995) suggested that different N response between and within fields was due to both spatial and temporal variations in crop demand. The optimum N fertilizer rate changes dramatically from one maize field to the next as it is affected by the complex interactions of spring precipitation, temperature patterns, soil organic matter and crop development (Scharf et al., 2005; Scharf, 2001).

Mohammed et al. (2011) further noted that the complexity of the N cycle, spatial variability in soils, and the continued release of improved varieties with higher N demands, need to be considered. However, the need for more precise N fertilizer recommendations and better NUE remain. If the demand for N is a function of the yield level to be achieved, accurate fertilizer recommendations will need to be year specific, even at the same site (Mohammed et al., 2011). Nitrogen use efficiency is better achieved when preplant N is applied at a lower rate and mid-season top-dress or side-dress N is applied.

The optimum N rate may not be constant from one year to the next, and may vary site to site as well. It makes intuitive sense that the real benefits of by-plant N fertilization will not be realized unless evaluated at or near the optimum N rate for maximum yield (Mullock et al., 2009). With split applications of N fertilizer, sidedress N almost always increased yields (Mullock et al., 2009). Moreover, N applications increased yields when the preplant N rate was optimized (Mullock et al., 2009). Moving forward in cereal production, optimization of N fertilizer will be essential when addressing all of the concerns associated with N application.

Shanahan et al. (2007) noted that the key to optimizing the tradeoff between yield, profit and environmental protection for future N management practices is to achieve better synchrony between applied fertilizer N and crop N demand (Shanahan et al., 2007). This would result in less dependence on large pre-plant applications of uniformly applied N and greater reliance on a "reactive approach" that involves in-season estimates of crop N needs (Shanahan et al., 2007). The use of the reaction base technique correlates well with technologies that can be delivered in real time. Shanahan et al. (2007) further noted the importance of on-the-go sensors, explaining they can deliver spatially variable N applications based on crop N need. With the use of split N application, and sensor technology, optimum N rates can be achieved, and aid in improving NUE, increasing producer profits, and limiting negative environmental effects.

Objective

The objective of this field research project is to determine the optimum amount of preplant N in wheat and maize, and ensuing topdress N to maintain yield and improve nitrogen use efficiency (NUE).

CHAPTER II

Optimum Preplant N Rate in Winter Wheat

Materials and Methods

In order to evaluate the effect of mid-season N application in winter wheat the experiment took place at four different locations over the 2015-2016 growing season. These locations included Perkins, Lake Carl Blackwell, Hennessey, and Lahoma, OK.

A randomized complete block design with 12 treatments and three replications was used in all wheat trials. Treatment structure included a 0-N check that did not receive N preplant or additional N mid-season (Treatment 1). Treatments 2 through 6 received 17, 34, 51, 67, and 101 kg ha^{-1} preplant N respectively and no top-dress N. Treatments 7, 8, 9, and 11 received 0, 34, 67, and 101 kg N ha^{-1} with an additional 34 kg N ha^{-1} applied mid-season. Treatments 10 and 12 received 0 and 67 kg N/ ha pre-plant, respectively and 67 kg N ha^{-1} applied mid-season (Table 1). Urea ammonia nitrate (UAN, 28-0-0) fertilizer was the fertilizer N source for all applications. Use of UAN as a spring topdress material is common (Boman et al., 1995). Field trials had plot sizes 3 m wide by 6 m long with 3 m alleys between each of the replications. All trials were planted with Oklahoma Foundation Seed, 'Iba' variety. At all sites Proc GLM (SAS Institute, Cary, NC, USA) was used to partition treatment effects. Specifically, non-orthogonal contrasts were used to decipher the presence and/or absence of a linear N response for preplant and topdress N.

Field Methodology

For all trials, commercial pesticides were used as necessary to lessen the populations of weeds and insects. All trials received pesticide application prior to planting, and midseason applications were conducted at the Feekes 2 and 5 growth stages (Large, 1954). A GreenSeeker® sensor was used to collect NDVI data throughout the growing season. For all locations reported in the work, collection of NDVI sensor data began at Feekes growth stage 3 and continued weekly through growth stage 7 (Large, 1954). Warm soil temperatures past Feekes 7 growth stage lead to rapid wheat growth and thus increased nutrient demand (Boman et al., 1995). Field activities are reported in Table 2. In the conventional tillage trials, a chisel was used as the primary preplant tillage and a field cultivator for secondary tillage and seedbed preparation. A modified 'Tye' drill was used to plant wheat. For the no-till sites, wheat was planted using a Great Plains no-till drill with compression-coulter openers. The seeding rates were 82 kg ha^{-1} for the Lahoma site, 84 kg ha^{-1} for the Lake Carl Blackwell and Perkins locations, and 101 kg ha^{-1} at the Hennessey site. A Kincaid, 8XP self-propelled combine was used to harvest wheat. Grain yields were collected at harvest, subsampled, dried for 24 hours, ground and analyzed for total N content.

Results (Overall N Response)

At all four sites, a significant linear trend was observed for N rate on winter wheat grain yield (Tables 3-6). This comes from the non-orthogonal "Pre-N rate linear" contrast reported first in each table and that included treatments 1 through 6. Similarly, a response to "Topdress N linear", treatments 5, 9, 10, was observed at 3 of the 4 sites. The latter contrast evaluating topdress N response only included treatments where 67 kg N ha^{-1} had been applied preplant (0, 34, and 67 kg N ha^{-1} topdress). These trends were also noted for the Feekes 7 growth stage NDVI readings (Tables 7-10). It was interesting to find that the 34-0 versus 0-34 rate comparison (Treatment 3 versus 7) showed no significant difference at 3 of the 4 sites. This suggests that early season N stress did not affect wheat grain yield. This was also the case observed when comparing the higher rate (67-0 versus 0-67, 3 of 4 locations, Tables 3-6). This was confirmed when evaluating final grain yield, excluding the Perkins site where an increase of 0.61 Mg ha^{-1} was found as a result of applying N later in the season (Table 7).

Perkins (2015-2016)

Yield data was collected at harvest and ranged from 3.14 to 6.23 Mg ha^{-1} with an average of 4.87 Mg ha^{-1} (Table 7). Treatment 11 (101 preplant + 34 topdress, Table 7) had numerically higher yields when compared to all other treatments. However, no significant difference was seen between this treatment and treatments 8, 10, and 12 for yield data. Treatments 10 and 11 had 34 kg N ha^{-1} preplant and treatment 12 received 67 kg N ha^{-1}. Normalized difference vegetative index readings at the Feekes 7 growth stage showed highly significant treatment differences. Higher NDVI values were found for all treatments when compared to the check (Table 7) at all growth stages. However, only when NDVI data was collected at the Feekes 7 growth stage, were all treatments (treatments $2^{-1}2$, Table 7) significantly different than the check plot. At both the low and high N rates, topdress N applied (34 and 67 kg N ha^{-1}) with 0 N preplant did result in higher yields (treatment 3 versus 7) at this site.

Lake Carl Blackwell (2015-2016)

Yield data was collected at harvest and ranged from 2.86 to 4.54 Mg ha^{-1} with an average of 3.91 Mg ha^{-1} (Table 6). In general, limited differences in either yield and/or NDVI were recorded at this site. Differences due to treatment were difficult to detect as plot to plot variability was present coming from heavy weed pressure of Italian ryegrass (*Lolium multiflorum L.*). Numerically higher yields were recorded for treatment 8 (34 kg N ha^{-1} preplant + 34 kg N ha^{-1} topdress). However, this was only significantly different from treatments 1 and 2 (no topdress N, and less than 17 kg N ha^{-1} preplant). Normalized difference vegetative index readings at the Feekes 7 growth stage were shown to be influenced by treatment. Mean separation found higher NDVI values in treatments 11, 10, 7, 6, 9, and 4 when compared to the check (Table 8). All other treatments had lower NDVI readings versus the check. The difficulty in recognizing treatment differences at this location was further reflected in the standard error of the difference between two equally replicated means (SED) that was quite high (0.69). At the low N rate, topdress N applied with 0 N preplant did result in higher yields (treatment 3 versus 7).

Hennessey (2015-2016)

Yield data was collected at harvest and ranged from 2.59 to 5.80 Mg ha^{-1} with an average of 4.16 Mg ha^{-1} (Table 9). Treatment 10 had numerically higher yields when compared to all other treatments, but not significantly different from treatments 9, 11, and 12. Normalized difference vegetative index readings at the Feekes 7 growth stage showed highly significant treatment differences. Mean separation showed higher NDVI values in all treatments at Feekes 7 compared to the check, with the exception of treatment 2 (Table 9). When NDVI was collected (Table 2), treatments 2 and 7 had lower values compared to the check. Field observations later in the season at this site noted that treatment 7 had an increase in NDVI and was higher than that of the check. This was not recorded at all sites. The NDVI for treatment 2 remained less than the check due to not receiving topdress N, and that was expected (Table 1). No differences were found when comparing preplant N versus topdress N methods of application at the same total N rate (34-0 vs 0-34 and 67-0 vs 0-67).

Lahoma (2015-2016)

Because yield levels were low at this location (all less than 2.37 Mg ha^{-1}), detecting treatment differences is more difficult. This was further evidenced where limited differences were found in the contrasts performed (Table 6). Yield data was collected at harvest and ranged from 1.16 to 2.37 Mg ha^{-1} with an average of 1.97 Mg ha^{-1} (Table 10). Treatment 10 (Table 10) had numerically higher yields compared to all other treatments, but was only different from treatments 2 and 1. The main effect of treatment was highly significant for NDVI readings collected at the Feekes 7 growth stage. Mean separation showed higher NDVI values in all treatments compared to the check (Table 10) at all growth stages. However, only when NDVI data was collected at the Feekes 7 growth stage, were all treatments, with the exception of treatment 2 significantly different than the check plot (Table 10). When comparing the preplant N versus topdress N methods of application at the same total N rate (34-0 vs 0-34 and 67-0 vs 0-67), no discernable differences were recorded.

Discussion

Perkins and Hennessey were under no-tillage practices while Lahoma and Lake Carl Blackwell were conventionally tilled. Differences between the two practices were thus expected. Treatment 10 (67 pre + 67 topdress) was observed as the highest yielding treatment at Hennessey and Lahoma, and this was the highest total N rate evaluated. This preplant and topdress combination also had high yields at Perkins (no-tillage), and Lake Carl Blackwell (conventional tillage). Furthermore, treatments 8 (34 pre + 34 topdress), 11 (101 pre + 34 topdress), and 12 (0 pre + 67 topdress) were the highest yielding at three of four locations. All had at least 34 kg N ha^{-1} applied topdress. Additionally, treatment 9 (67 pre + 34 topdress) had high yields at two of the four locations. The Lake Carl Blackwell location had a high population of Italian ryegrass, which could have led to skewed NDVI readings and yield levels. Furthermore, the Lahoma trial had a poor plant stand due to the sloping terrain and resultant erosion. We were unable to replant this trial due to lack of available space and excess precipitation limited reentry to this site.

Treatments 8, 9, 10, 11, and 12 were consistently the highest yielding treatments (all had at least 34 kg N ha^{-1} topdress). Although treatment 12 did not receive any preplant N (Table 1), yield levels remained high when compared to those having both pre and topdress N (three of four sites). It should be noted that treatment 8 and treatment 12 received a total of 68 and 67 kg N ha^{-1}, respectively, and treatment 12 had a numerically higher yield at all locations except Lake Carl Blackwell (Tables 7, 8, 9, 10). In a previous study, Morris et al. (2006) found that even with early

N stress, topdress N rates did produce yields equivalent to those where preplant N was applied. Furthermore, they found that maximum yields were achievable when no preplant N was applied and a topdress rate of 45 kg $ha^{-1}$was included (Morris et al., 2006). Their work supports findings that winter wheat can produce competitive yields with limited preplant N followed by topdress N applied in the spring. Spring N applications have been shown to be effective for increasing grain yields in winter wheat production and can reduce potential for N loss (Boman et al., 1995). Nitrogen management is an important aspect of production, and with elevated environmental concerns, plus costs to producers, it is imperative to use best management practices.

An added observation from this study was that grain yield levels were higher at Perkins and Hennessey where no-till management was employed. A tendency to buffer against moisture/heat stress existed at these sites but that could not be substantiated. Optimum preplant N rates for winter wheat change from year to year, site to site, and depend greatly on the production environment (Raun et al., 2011). As stated by Boman et al. (1995) nitrogen fertilizer management is important in winter wheat production since excess fertilization can cause an accumulation of residual soil nitrate-N and contribute to possible environment degradation. Due to the importance of N management, studies such as this must continue due to the changing environmental impacts encountered from one season to the next. The optimum preplant N rate for these studies was 67 kg N ha^{-1} (Tables 7, 8, 9, 10). This must be understood in the context that at least 34 kg N ha^{-1} applied topdress was needed. A final observation was that topdress N applied where no preplant N was included, resulted in increased yields in 2 of 4 sites. This was consistent with earlier work by Morris et al. (2006).

CHAPTER III

Optimum N Rate in Maize

Materials and Methods

In order to evaluate the effects of mid-season N application in maize, two trials were conducted at one location over the 2015 growing season. Trials were located at the Lake Carl Blackwell experiment station, one conventional tillage site and the other under no-tillage.

A randomized complete block design with 14 treatments was used. The treatment structure included each of the following preplant applications: 0, 17, 34, 67, 101, 135 and 168 kg N ha^{-1}. Treatments 1 through 7 received 0 kg N ha^{-1} mid-season N, and treatments 8 through 14 received 168 kg N ha^{-1} (Table 11). Sidedress N was applied at the V6 growth stage on June 10th, 2015. The fertilizer applied was UAN (28-0-0) for both preplant and top-dress. The trial consisted of 3 replications with plot sizes of 3 x 6 m with 3 m alleys between each replication. All maize was planted with Pioneer Hybrid P0636AM. Analysis of yield and NDVI data was conducted utilizing SAS 9.4 and that employed the general linear model (GLM) procedure, single-degree-of-freedom-contrasts, and Dunnett's test (alpha = 0.01, 0.05, and 0.10).

Field Methodology

Commercial pesticides were used as necessary to lessen the populations of weeds and insects throughout the growing season. An Oklahoma State University developed GreenSeeker sensor was used to collect NDVI data throughout the growing season. Normalized difference vegetative index data collection took place at the V5, V6, and V9 growth stages (Iowa State University, 2009). Teal et al (2006) explain that predicting the yield potential at V8 is highly desirable for maximum effectiveness of sidedress N application. Field activities are reported in Table 12. In the conventional tillage trials, a chisel was used as the primary preplant tillage and a field cultivator was used for secondary tillage and seedbed preparation. A John Deere four row MaxEmerge planter was used to plant maize at 64,220 seeds ha^{-1}. A Massey Ferguson, 8XP self-propelled combine was used to harvest maize. Maize grain was collected at harvest, subsampled, dried for 24 hours, ground and analyzed for total N content.

Results

Lake Carl Blackwell (2015)

Sensor NDVI data was collected at the V5 and V6 growth stages. Yield data was collected at harvest and ranged from 2.22 to 5.00 Mg ha^{-1} with an average of 3.27 Mg ha^{-1} (Table 14). Using the GLM model (3 reps, 14 treatments), differences due to treatment could be detected. However, by implementing mean separation in the analysis, treatment 11 (Table 14) was observed having higher yields than all other treatments. Orthogonal single-degree-of-freedom-contrasts showed that yields were significantly better when sidedress N was applied versus when no side-dress was applied (No side-dress vs side-dress, Table 13). Normalized difference vegetative index readings at the V6 growth stage showed highly significant treatment difference. Single degree of freedom contrast showed higher NDVI values in all treatments compared to the check (check vs all, Table 13). However, no significant difference was detected with or without side-dress on NDVI values with single degree of freedom contrasts.

Discussion

Inconsistency of results for 2015 required that four additional locations be evaluated in 2016. These will be harvested in August, 2016. Extensive heat resulted in significant crop stress during pollination and grain fill in the 2015 study. Furthermore, post-maturity disease incidence (Fusarium diploidia), dramatically lowered grain yields and adversely influenced treatment response. This environment was characterized by receiving 53 cm of rainfall throughout the growing season, 31 cm of which came in the two weeks following planting (Figure 5). This characterized the stressed growth encountered and led to the loss of the no-till site. This amount of rainfall, would have met the needs for the crop if it had been received in parsed amounts and throughout the entire season. As stated by Teal et al. (2006), the environment is not controlled by a single factor but rather compounded effects of soil fertility, climate, and inputs. Nonetheless, environmental differences cannot be ignored and are an integral part of both treatment response and final interpretation. The other problem in this experiment was being unable to irrigate when the maize needed water, resulting in water stress and water being the limiting resource instead of N. The lack of a response to fertilizer N was due to the severe stress encountered. Also, the lack of irrigation throughout the growing season significantly impacted maize grain yields. Measures have been taken to ensure adequate supply of moisture during the growing season for 2016.

No significant grain yield differences were observed between preplant N treatments (Table 14). The lack of a response and significant stress required further evaluation over the 2016 growing season, and that included 4 additional sites. With the corrections made to our irrigation system, we hope to ensure results that will allow the determination of optimum preplant N rates for maize.

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List of Tables

Table 1. Treatment Structure, Wheat

Treatment	Preplant N (kg N/ ha)	Sidedress N (kg N/ ha)	Total N (kg N/ ha)
1	0	0	0
2	17	0	17
3	34	0	34
4	51	0	51
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 2. Summary of Location, Soil Type, Tillage Method, Preplant N Date, Planting Date, and Seeding Density to evaluate optimum N rate in winter wheat, 2015-2016, OK.

Location	Soil Type	Tillage Method	Preplant N Date	Planting Date	Top Dress N Date	Seeding Density (kg/ ha)	Harvest Date
Lake Carl Blackwell	Port-Oscar Complex	Conventional	9-Oct-15	19-Oct-15	25-Feb-16	84	13-Jun-16
Lahoma	Grant Silt Loam	Conventional	8-Oct-15	9-Oct-15	28-Feb-16	82	11-Jun-16
Hennessey	Bethany Silt Loam	No-till	6-Oct-15	28-Oct-15	26-Feb-16	101	7-Jun-16
Perkins	Konawa and Teller Fine Silty Loam	No-till	6-Oct-15	13-Oct-15	25-Feb-16	84	8-Jun-16

Table 3. Treatment differences from non-orthogonal contrasts, winter wheat N study under no-tillage, Perkins, OK 2015-2016.

Non-orthoganal contrast	Grain Yield	Grain N Content	Feekes 3	Feekes 5	Feekes 6	Feekes 7
Pre-N rate linear (1-6)	**	NS	**	**	**	**
Topdress N linear (5, 9, 10)	@	*	**	**	**	**
67-0 vs 0-67	*	**	*	*	**	NS
67-0 vs 67-67	**	**	NS	NS	NS	**
67-67 vs 0-67	NS	NS	**	**	**	**
2-6 vs $7^{-1}1$ (top N vs pre N)	**	**	NS	NS	NS	**
67-67 vs 101-34	NS	NS	NS	NS	NS	NS
101-0 vs 67-34	NS	NS	*	*	*	NS
34-0 vs 0-34	NS	NS	*	@	*	NS
67-0 vs 34-34	@	NS	NS	NS	NS	NS
0-34 vs 34-34	NS	NS	*	*	*	*

NS, not significant

@, *, **, significant at the 0.10, 0.05 and 0.01 probability levels, respectively

Table 4. Treatment differences from non-orthogonal contrasts, winter wheat N study under conventional tillage, Lake Carl Blackwell, OK 2015-2016.

Non-orthoganal contrast	**Grain Yield**	**Grain N Content**	**Feekes 3**	**Feekes 5**	**Feekes 6**	**Feekes 7**
Pre-N rate linear (1-6)	*	NS	NS	NS	NS	NS
Topdress N linear (5, 9, 10)	NS	NS	NS	NS	NS	NS
67-0 vs 0-67	NS	NS	NS	NS	NS	NS
67-0 vs 67-67	NS	**	NS	NS	NS	@
67-67 vs 0-67	NS	**	*	*	*	*
2-6 vs 7^{-1}1 (top N vs pre N)	*	**	NS	NS	@	*
67-67 vs 101-34	NS	NS	NS	NS	NS	NS
101-0 vs 67-34	NS	NS	NS	NS	NS	NS
34-0 vs 0-34	@	NS	NS	NS	NS	NS
67-0 vs 34-34	NS	NS	NS	NS	NS	NS
0-34 vs 34-34	NS	NS	NS	NS	NS	NS

NS, not significant

@, *, **, significant at the 0.10, 0.05 and 0.01 probability levels, respectively

Table 5. Treatment differences from non-orthogonal contrasts, winter wheat N study under no-tillage, Hennessey, OK 2015-2016.

Non-orthoganal contrast	Grain Yield	Grain N Content	Feekes 3	Feekes 5	Feekes 6	Feekes 7
Pre-N rate linear (1-6)	**	@	@	**	**	**
Topdress N linear (5, 9, 10)	@	NS	NS	NS	@	@
67-0 vs 0-67	NS	**	NS	NS	NS	@
67-0 vs 67-67	**	**	NS	NS	**	**
67-67 vs 0-67	@	@	*	*	**	*
2-6 vs 7-11 (top N vs pre N)	**	**	NS	NS	**	**
67-67 vs 101-34	NS	@	NS	NS	NS	NS
101-0 vs 67-34	@	NS	NS	NS	@	NS
34-0 vs 0-34	NS	*	*	**	NS	NS
67-0 vs 34-34	NS	NS	NS	NS	NS	NS
0-34 vs 34-34	*	*	**	**	**	*

NS, not significant

@, *, **, significant at the 0.10, 0.05 and 0.01 probability levels, respectively

Table 6. Treatment differences from non-orthogonal contrasts, winter wheat N study under conventional tillage, Lahoma, OK 2015-2016.

Non-orthogonal contrast	**Grain Yield**	**Grain N Content**	**Feekes 3**	**Feekes 5**	**Feekes 6**	**Feekes 7**
Pre-N rate linear (1-6)	*	*	NS	@	*	**
Topdress N linear (5, 9, 10)	*	NS	NS	NS	@	*
67-0 vs 0-67	NS	**	NS	@	NS	NS
67-0 vs 67-67	NS	**	NS	NS	NS	@
67-67 vs 0-67	NS	*	NS	NS	NS	@
2-6 vs 7-11 (top N vs pre N)	*	**	NS	NS	@	**
67-67 vs 101-34	NS	**	*	@	*	*
101-0 vs 67-34	NS	NS	NS	NS	NS	NS
34-0 vs 0-34	NS	@	NS	NS	NS	NS
67-0 vs 34-34	NS	*	NS	@	NS	NS
0-34 vs 34-34	NS	NS	NS	NS	NS	NS

NS, not significant

@, *, **, significant at the 0.10, 0.05 and 0.01 probability levels, respectively

Table 7. Effect of preplant and topdress N on wheat grain yield, grain N content, and NDVI (Feekes 7), under no-tillage, Perkins, OK 2015-2016.

				Grain Yield, Mg ha^{-1}		Grain N Content (g/kg)		NDVI (FK 7)		Weather	
Trt	Preplant N (kg N ha^{-1})	Topdress N (kg N ha^{-1})	Total N (kg N ha^{-1})	Mean	STD	Mean	STD	Mean	STD	GDD* (Temp ≥ 4.4˚C)	Precipitation** (cm)
1	0	0	0	3.14	0.34	15.61	0.48	0.36	0.01	200	64.72
2	17	0	17	3.79	1.08	14.82	0.67	0.45	0.06		
3	34	0	34	4.00	0.11	14.26	1.13	0.50	0.06		
4	51	0	51	4.84	0.28	13.92	1.17	0.53	0.04		
5	67	0	67	4.70	0.25	14.49	0.65	0.50	0.02		
6	101	0	101	4.76	-	15.77	1.37	0.60	0.09		
7	0	34	34	4.61	0.70	14.95	0.40	0.47	0.05		
8	34	34	68	5.47	0.54	15.20	1.11	0.55	0.01		
9	67	34	101	5.23	0.24	15.11	0.21	0.55	0.01		
10	67	67	134	6.04	0.31	16.31	1.08	0.60	0.03		
11	101	34	135	6.23	0.11	16.47	0.56	0.64	0.02		
12	0	67	67	5.66	0.46	16.30	0.50	0.50	0.04		
MSE				0.20		0.66		0.01			
SED				0.37		0.67		0.04			

Preplant N applied UAN, (28-0-0), 10/06/2015.
Planting, (10/13/2015)
Topdress N applied UAN, (28-0-0), Feekes 5, 02/25/2016.
NDVI, Normalized Difference Vegetation Index, collected on 03/21/2016, 121 GDD, Feekes 7.
Harvest, (06/08/2016)
* GDD, Cumulative Growing Degree Days (Temp ≥ 4.4˚ C), from planting to harvest
**Precipitation, Cumulative precipitation from planting to harvest
SED, standard error of the difference between two equally replicated means
STD, standard deviation

Table 8. Effect of preplant N and topdress N on wheat grain yield, grain N content, and NDVI (Feekes 7), under conventional tillage, Lake Carl Blackwell, OK 2015-2016.

				Grain Yield, Mg ha^{-1}		Grain N Content (g/kg)		NDVI (FK 7)		Weather	
Trt	Preplant N (kg N ha^{-1})	Topdress N (kg N ha^{-1})	Total N (kg N ha^{-1})	Mean	STD	Mean	STD	Mean	STD	GDD* (Temp ≥ 4.4˚C)	Precipitation** (cm)
1	0	0	0	3.07	1.34	14.67	1.10	0.57	0.09	180	54.71
2	17	0	17	2.86	0.55	12.73	1.18	0.51	0.12		
3	34	0	34	3.22	0.97	14.08	1.57	0.57	0.19		
4	51	0	51	4.04	1.14	14.63	1.53	0.60	0.17		
5	67	0	67	3.83	0.35	13.28	1.75	0.54	0.03		
6	101	0	101	4.10	0.24	15.47	1.47	0.67	0.08		
7	0	34	34	4.53	0.72	14.07	1.46	0.69	0.07		
8	34	34	68	4.54	0.63	14.03	0.94	0.56	0.13		
9	67	34	101	4.27	0.28	15.76	0.96	0.67	0.14		
10	67	67	134	4.32	0.83	17.77	2.14	0.70	0.12		
11	101	34	135	4.02	0.62	17.21	2.08	0.78	0.03		
12	0	67	67	4.15	0.62	14.63	1.27	0.50	0.11		
MSE				0.72		1.73		0.01			
SED				0.69		1.07		0.09			

Preplant N applied UAN, (28-0-0), 10/06/2015.
Planting, (10/13/2015)
Topdress N applied UAN, (28-0-0), Feekes 5, 02/25/2016.
NDVI, Normalized Difference Vegetation Index, collected on 03/21/2016, 121 GDD, Feekes 7.
Harvest, (06/08/2016)
* GDD, Cumulative Growing Degree Days (Temp ≥ 4.4˚ C), from planting to harvest
**Precipitation, Cumulative precipitation from planting to harvest
SED, standard error of the difference between two equally replicated means
STD, standard deviation

Table 9. Effect of preplant N and topdress N on wheat grain yield, grain N content, and NDVI (Feekes 7), under no-tillage, Hennessey, OK 2015-2016.

				Grain Yield, Mg ha^{-1}		Grain N Content (g/kg)		NDVI (FK 7)		Weather	
Trt	Preplant N (kg N ha^{-1})	Topdress N (kg N ha^{-1})	Total N (kg N ha^{-1})	Mean	STD	Mean	STD	Mean	STD	GDD* (Temp ≥ 4.4˚C)	Precipitation** (cm)
1	0	0	0	2.74	0.28	14.73	1.00	0.35	0.02	176	49.89
2	17	0	17	2.59	0.45	15.10	0.82	0.33	0.02		
3	34	0	34	3.67	0.28	15.16	0.97	0.43	0.02		
4	51	0	51	3.86	0.34	14.62	0.79	0.43	0.04		
5	67	0	67	4.09	0.21	14.85	2.00	0.46	0.02		
6	101	0	101	3.80	1.94	15.87	0.12	0.48	0.17		
7	0	34	34	3.63	0.62	16.26	1.14	0.42	0.05		
8	34	34	68	4.70	0.26	15.07	0.34	0.52	0.03		
9	67	34	101	4.81	0.26	15.69	1.74	0.55	0.08		
10	67	67	134	5.80	0.32	17.31	1.25	0.64	0.06		
11	101	34	135	5.44	0.30	16.43	1.17	0.66	0.05		
12	0	67	67	4.85	0.39	16.57	1.37	0.54	0.07		
MSE				0.41		0.37		0.01			
SED				0.52		0.49		0.05			

Preplant N applied UAN, (28-0-0), 10/06/2015.
Planting, (10/13/2015)
Topdress N applied UAN, (28-0-0), Feekes 5, 02/25/2016.
NDVI, Normalized Difference Vegetation Index, collected on 03/21/2016, 121 GDD, Feekes 7.
Harvest, (06/08/2016)
* GDD, Cumulative Growing Degree Days (Temp ≥ 4.4˚ C), from planting to harvest
**Precipitation, Cumulative precipitation from planting to harvest
SED, standard error of the difference between two equally replicated means
STD, standard deviation

Table 10. Effect of preplant N and topdress N on wheat grain yield, grain N content, and NDVI (Feekes 7), under conventional tillage, Lahoma, OK 2015-2016.

				Grain Yield, Mg ha^{-1}		Grain N Content (g/kg)		NDVI (FK7)		Weather	
Trt	Preplant N (kg N ha^{-1})	Topdress N (kg N ha^{-1})	Total N (kg N ha^{-1})	Mean	STD	Mean	STD	Mean	STD	GDD* (Temp ≥ 4.4˚C)	Precipitation** (cm)
1	0	0	0	1.16	0.23	17.47	0.76	0.25	0.01	197	43.92
2	17	0	17	1.39	0.12	16.71	0.49	0.29	0.02		
3	34	0	34	2.05	0.27	17.08	0.51	0.30	0.02		
4	51	0	51	2.01	0.84	17.40	2.11	0.30	0.02		
5	67	0	67	2.08	0.18	17.68	1.65	0.32	0.05		
6	101	0	101	1.76	0.46	19.02	1.96	0.33	0.04		
7	0	34	34	1.92	0.43	18.76	0.37	0.32	0.01		
8	34	34	68	2.24	0.07	19.78	1.34	0.31	0.04		
9	67	34	101	2.16	0.50	19.71	0.78	0.36	0.01		
10	67	67	134	2.37	0.19	22.78	0.37	0.35	0.01		
11	101	34	135	2.26	0.67	20.49	0.71	0.40	0.03		
12	0	67	67	2.29	0.24	21.06	0.34	0.32	0.01		
MSE				0.18		1.06		0.01			
SED				0.35		0.84		0.02			

Preplant N applied UAN, (28-0-0), 10/06/2015.
Planting, (10/13/2015)
Topdress N applied UAN, (28-0-0), Feekes 5, 02/25/2016.
NDVI, Normalized Difference Vegetation Index, collected on 03/21/2016, 121 GDD, Feekes 7.
Harvest, (06/08/2016)
* GDD, Cumulative Growing Degree Days (Temp ≥ 4.4˚ C), from planting to harvest
**Precipitation, Cumulative precipitation from planting to harvest
SED, standard error of the difference between two equally replicated means
STD, standard deviation

Table 11. Treatment Structure, Maize

Treatment	Preplant N (kg N/ ha)	Sidedress N (kg N/ ha)	Total N (kg N/ ha)
1	0	0	0
2	17	0	17
3	34	0	34
4	67	0	67
5	101	0	101
6	135	0	135
7	167	0	167
8	0	167	167
9	17	167	184
10	34	167	201
11	67	167	234
12	101	167	268
13	135	167	302
14	167	167	334

Table 12. Summary of Location, Soil Type, Tillage Method, Preplant N Date, Planting Date, Seed Density and Harvest Date to evaluate optimum N rate in corn, 2015, OK.

Location	Soil Type	Tillage Method	Preplant N Date	Planting Date	Seeding Density (Seed/ha)	Harvest Date
Lake Carl Blackwell	Port-Oscar Complex	Conventional	20-Apr^{-1}5	21-Apr^{-1}5	64,220	September 2, 2015
Lake Carl Blackwell	Port-Oscar Complex	No-till	30-Apr^{-1}5	30-Apr^{-1}5	51,870	--

Table 13. Treatment differences from orthogonal single-degree-of-freedom-contrasts, maize N study under conventional tillage, 2015.

Orthoganal Contrast	Grain Yield	NDVI
check vs all (1 vs 2-14)	NS	**
check vs sidedress (1 vs 7-14)	NS	*
check vs no side dress (1 vs 2-6)	NS	**
no side dress vs side dress (1-6 vs 7-14)	*	NS
0-0 vs 0-167	NS	NS
17-0 vs 17-167	NS	NS
34-0 vs 34-167	NS	NS
67-0 vs 67-167	@	NS
101-0 vs 101-167	NS	NS
135-0 vs 135-167	NS	NS
167-0 vs 168-167	NS	NS
167-0 vs 0-167	NS	@
0-167 vs 168-167	NS	NS

NS, not significant

@, *, **, significant at the 0.10, 0.05 and 0.01 probability levels, respectively

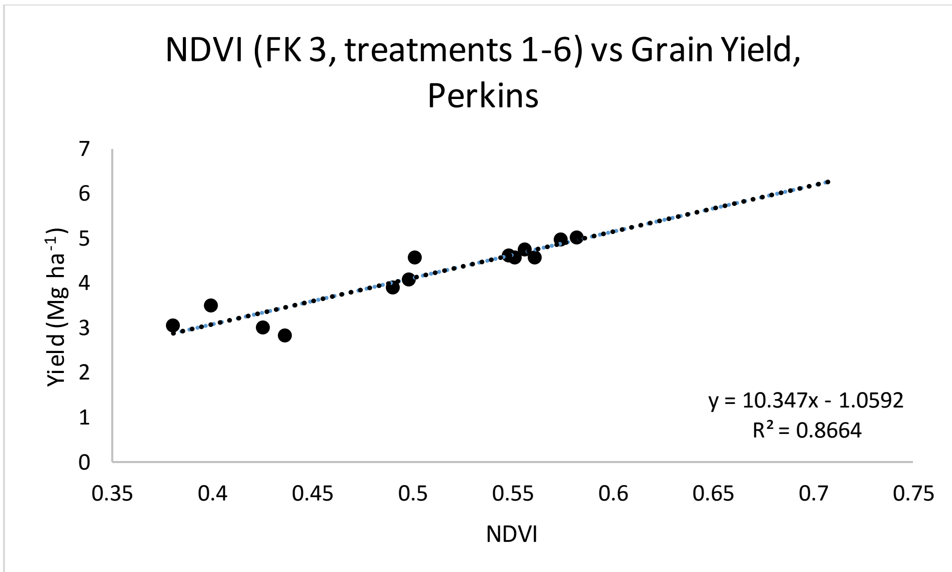
Table 14. Effect of preplant and topdress N on maize grain yield and NDVI (V6) conventional tillage, Lake Carl Blackwell, OK 2015

				Grain Yield, Mg ha^{-1}		NDVI		Weather	
Trt	Preplant N (kg N ha^{-1})	Sidedress N (kg N ha^{-1})	Total N (kg N ha^{-1})	Mean	Stddev	Mean	Stddev	Cummulative Heat Units	Precipitation (cm)
1	0	0	0	2.50	0.04	0.42	0.07	2944.5	35.23
2	17	0	17	2.25	1.50	0.46	0.13		
3	33	0	33	2.86	0.58	0.55	0.05		
4	67	0	67	2.99	0.53	0.55	0.05		
5	100	0	100	2.89	0.91	0.52	0.08		
6	133	0	133	3.95	1.14	0.56	0.08		
7	167	0	167	2.22	1.29	0.55	0.10		
8	0	167	167	4.07	0.72	0.47	0.05		
9	17	167	184	2.81	0.09	0.51	0.05		
10	33	167	200	3.26	1.16	0.48	0.19		
11	67	167	234	5.00	1.41	0.53	0.10		
12	100	167	267	3.79	1.48	0.53	0.07		
13	133	167	300	2.98	0.81	0.55	0.03		
14	167	167	334	3.98	2.50	0.53	0.11		
MSE				1.24		0.003			
SED				0.90		0.04			

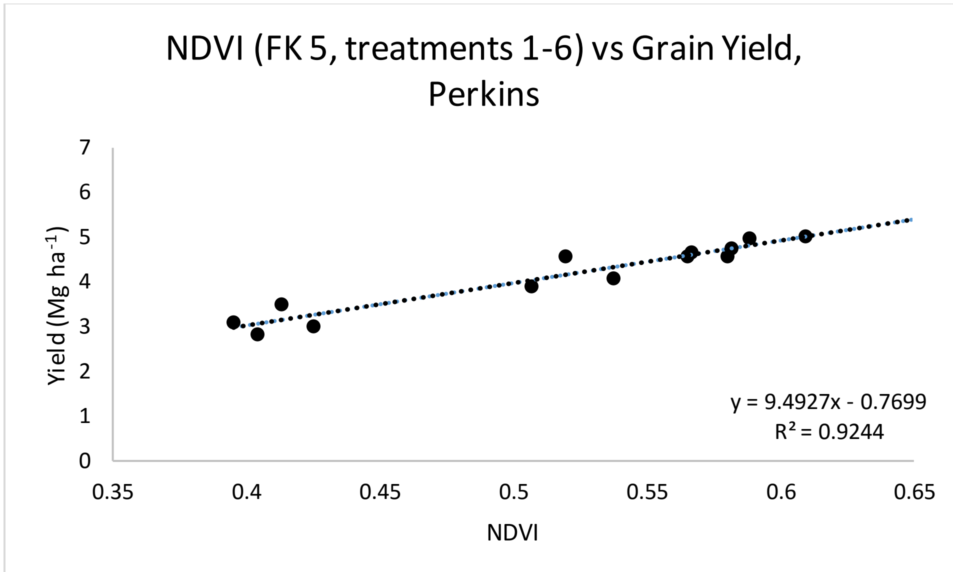
Preplant N applied using UAN, (28-0-0), 04/21/2015.
Sidedress N applied using UAN, (28-0-0), 06/10/2015, at V6.

NDVI, Normalized Difference Vegetation Index collected on 06/06/2015, at V6.
CV- coefficient of variation, %

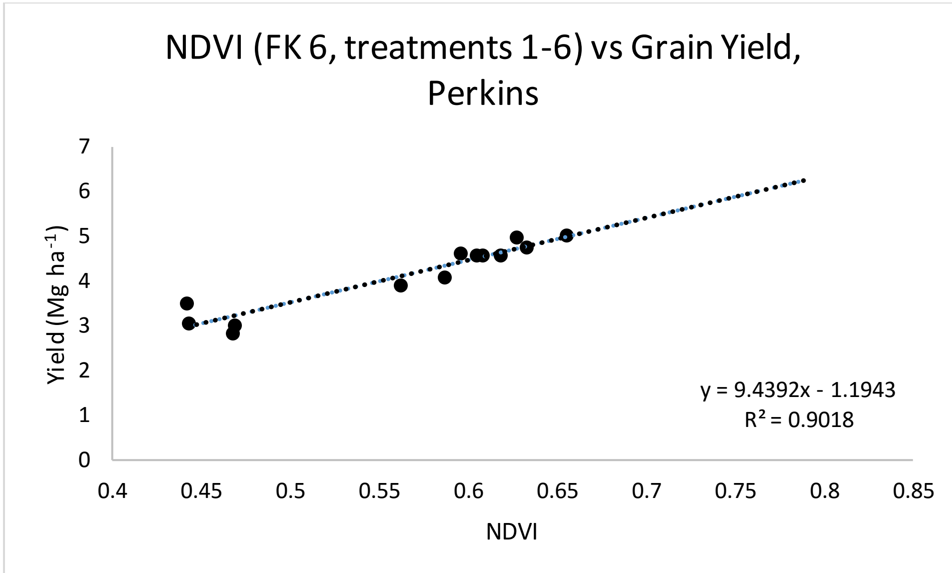
Appendices



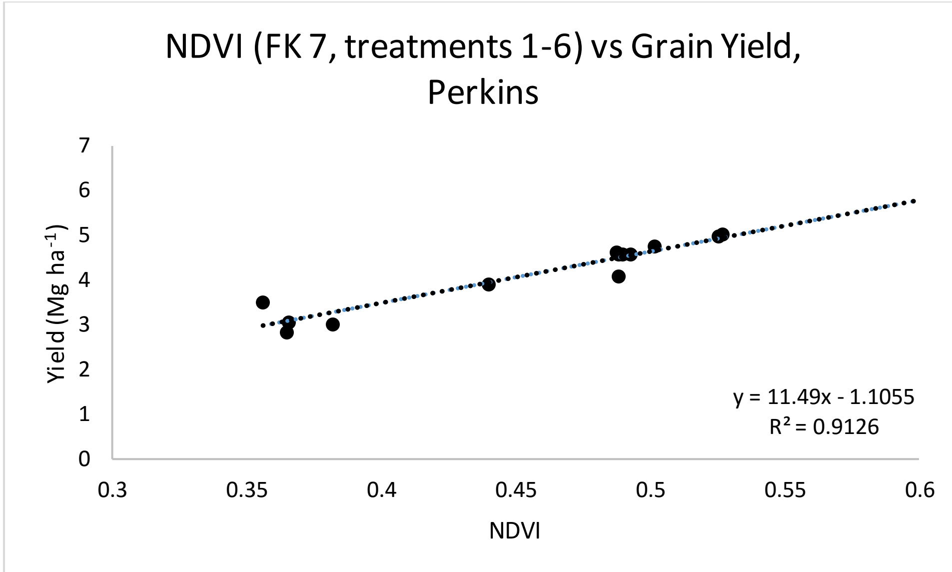
Appendix 1. NDVI (FK 3, treatments 1-6) vs Grain Yield, winter wheat, Perkins, OK, 2015-2016.



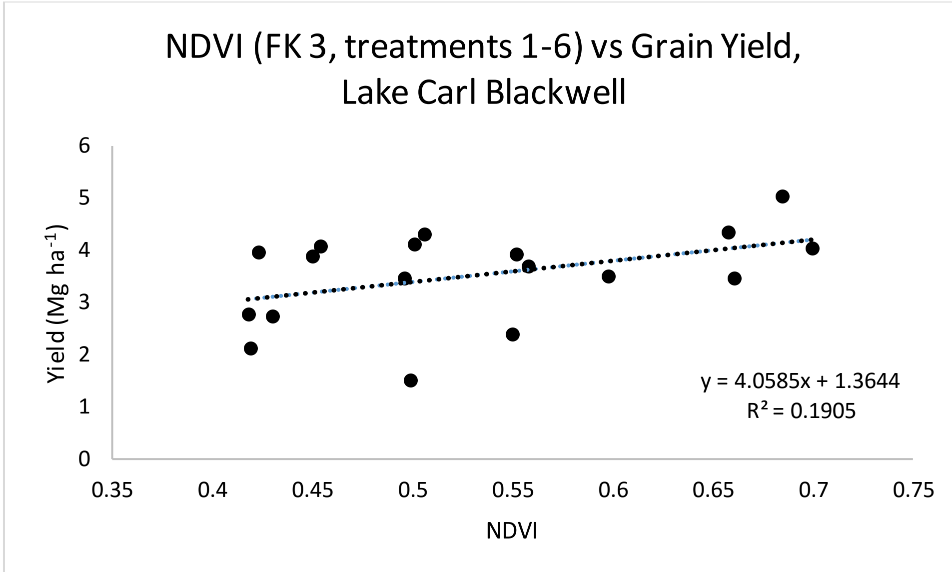
Appendix 2. NDVI (FK 5, treatments 1-6) vs Grain Yield, winter wheat, Perkins, OK, 2015-2016.



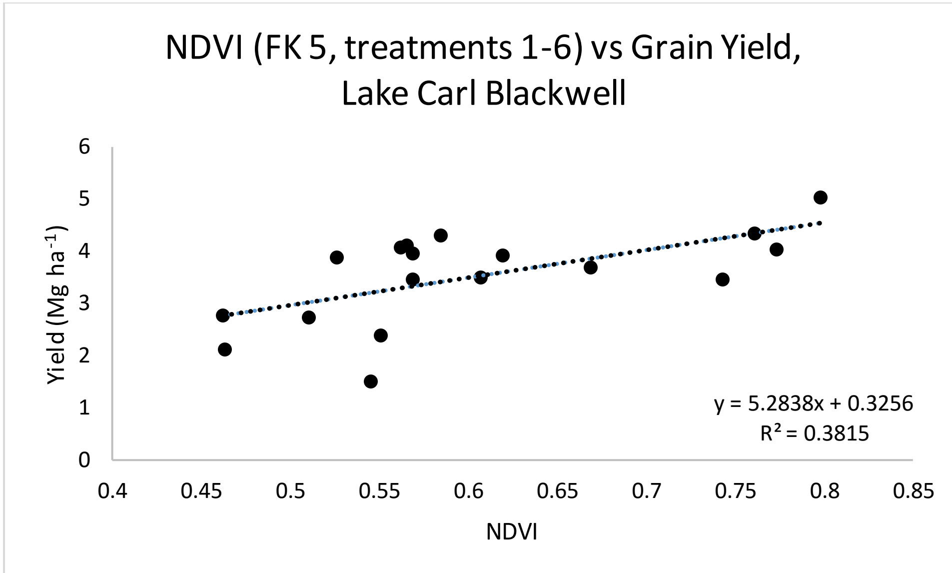
Appendix 3. NDVI (FK 6, treatments 1-6) vs Yield, winter wheat, Perkins, OK, 2015-2016.



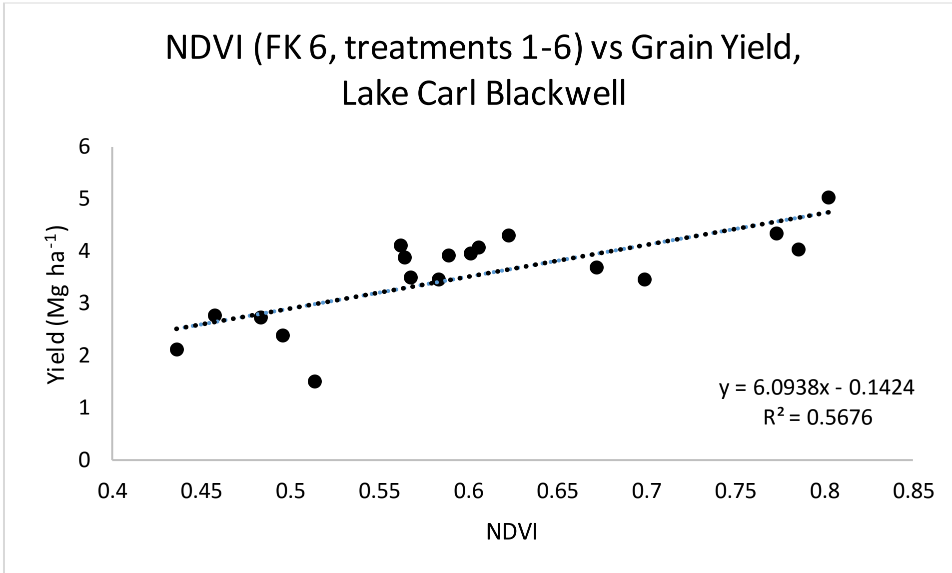
Appendix 4. NDVI (FK 7, treatments 1-6) vs Grain Yield, winter wheat, Perkins, OK, 2015-2016.



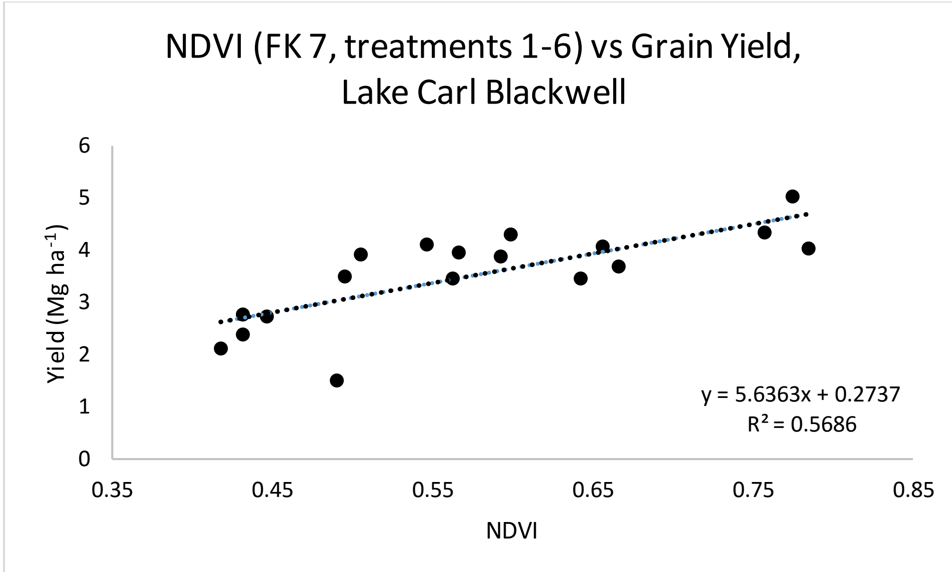
Appendix 5. NDVI (FK 3, treatments 1-6) vs Grain Yield, winter wheat, Lake Carl Blackwell, OK, 2015-2016.



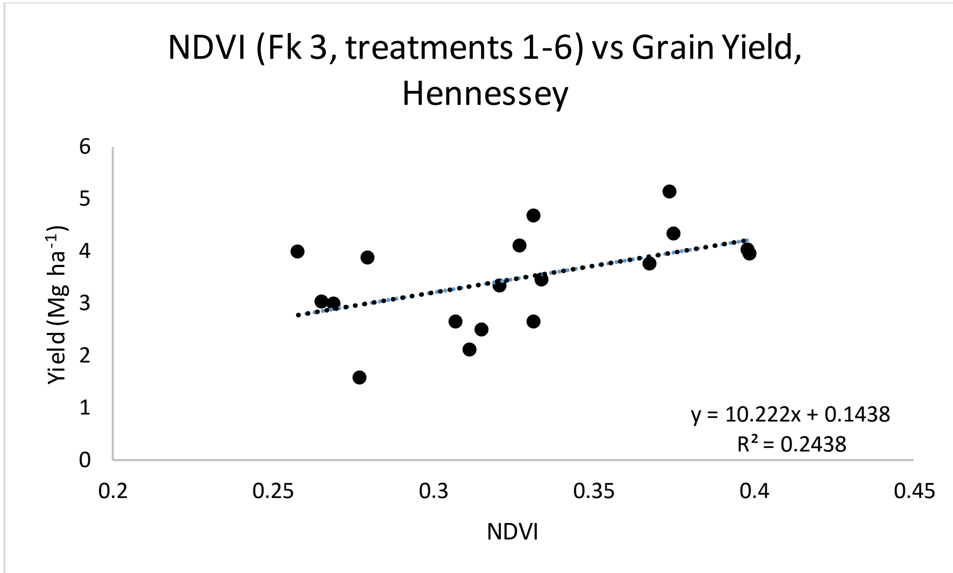
Appendix 6. NDVI (FK 5, treatments 1-6) vs Grain Yield, winter wheat, Lake Carl Blackwell, OK, 2015-2016.



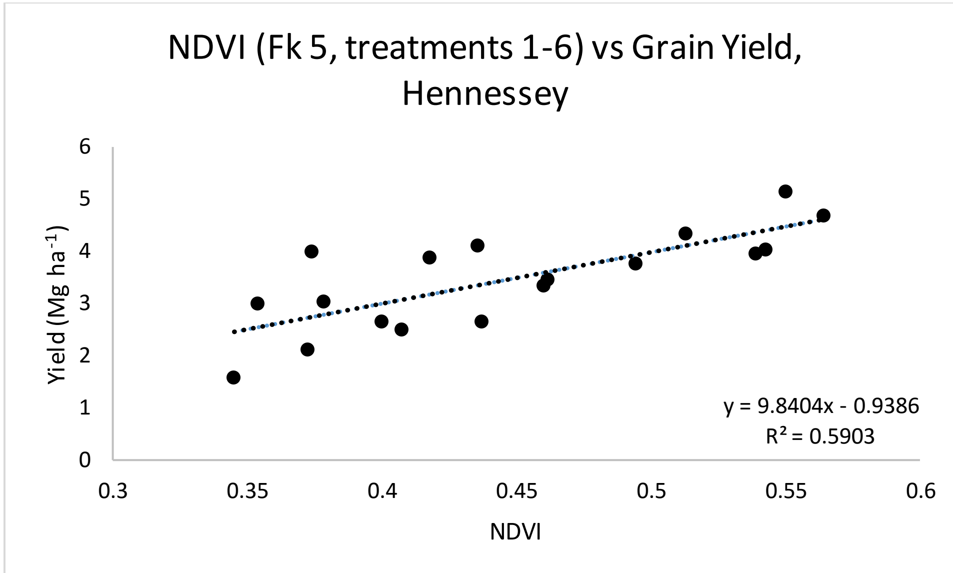
Appendix 7. NDVI (FK 6, treatments 1-6) vs Grain Yield, winter wheat, Lake Carl Blackwell, OK, 2015-2016.



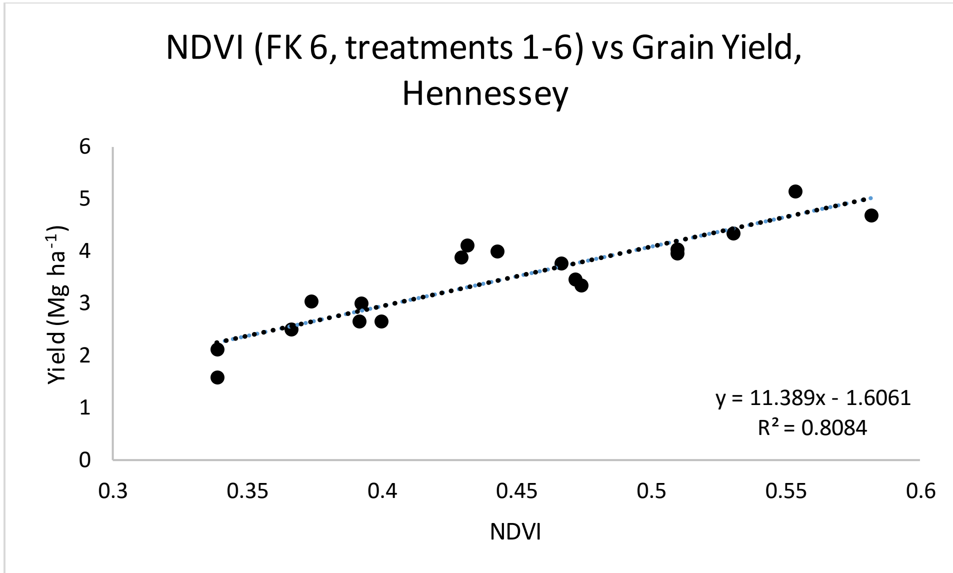
Appenix 8. NDVI (FK 7, treatments 1-6) vs Grain Yield, winter wheat, Lake Carl Blackwell, OK, 2015-2016.



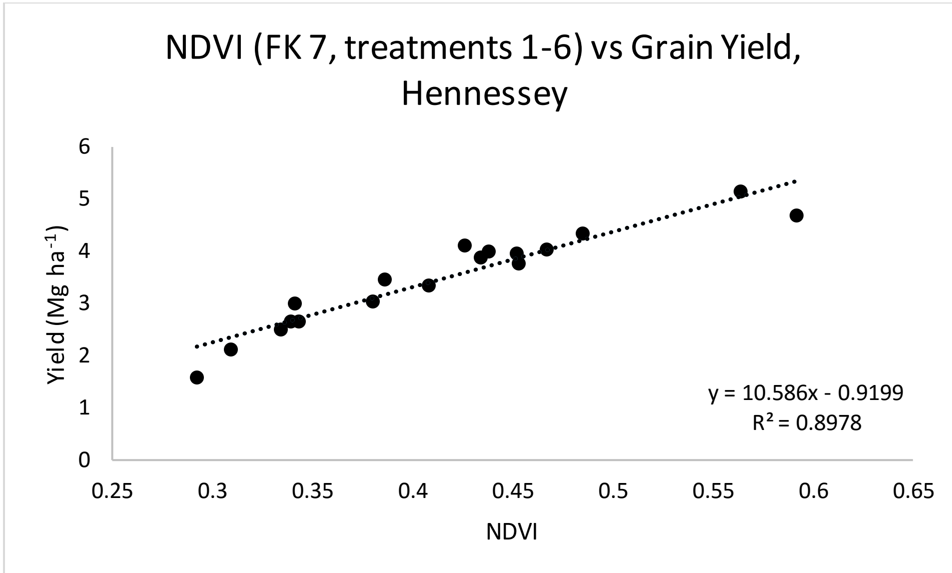
Appendix 9. NDVI (FK 3, treatments 1-6) vs Grain Yield, winter wheat, Hennessey, OK, 2015-2016.



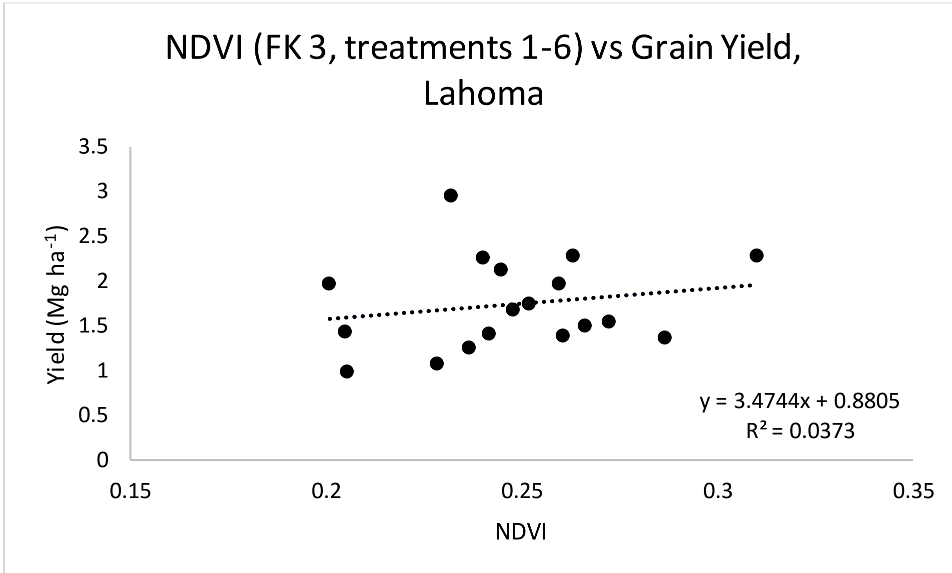
Appendix 10. NDVI (FK 5, treatments 1-6) vs Grain Yield, winter wheat, Hennessey, OK, 2015-2016.



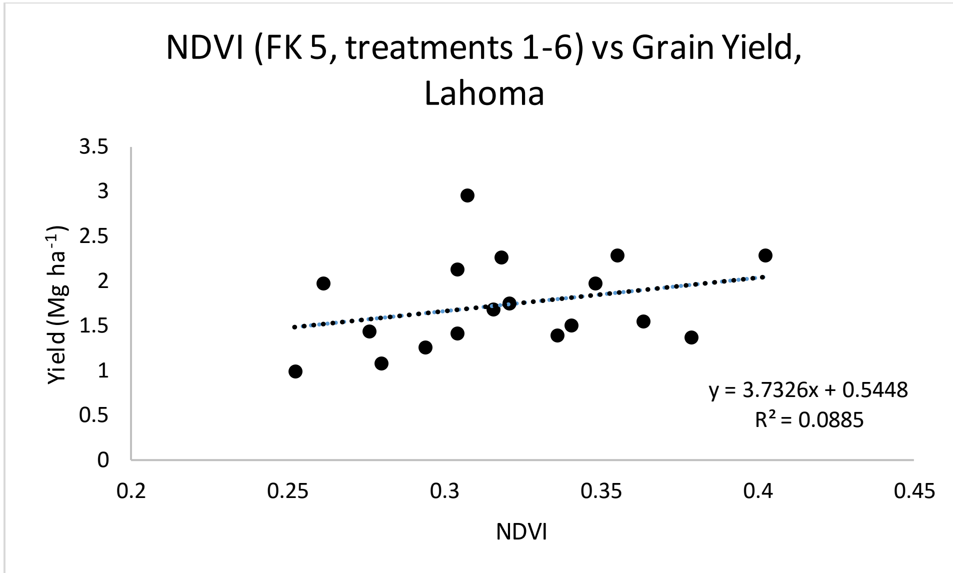
Appendix 11. NDVI (FK 6, treatments 1-6) vs Grain Yield, winter wheat, Hennessey, OK, 2015-2016.



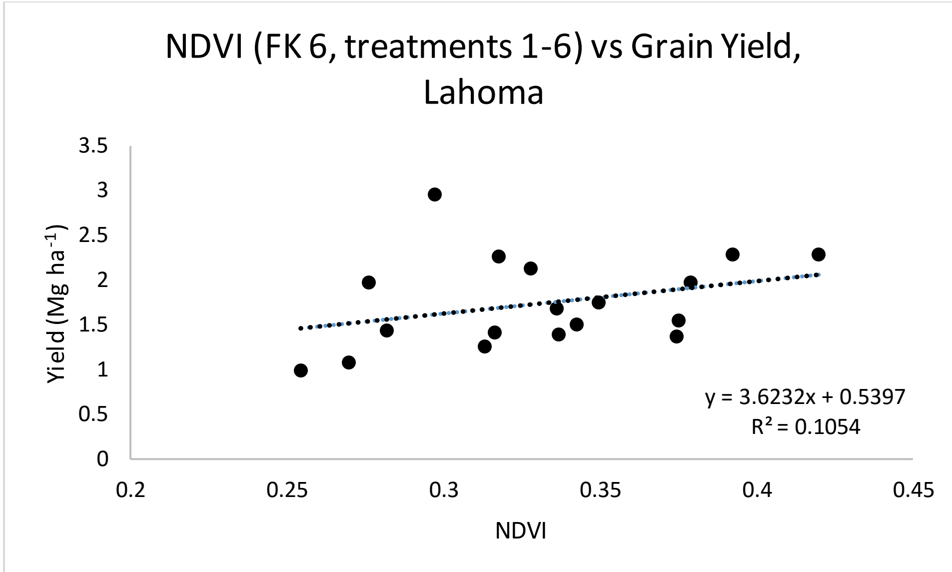
Appendix 12. NDVI (FK 7, treatments 1-6) vs Grain Yield, winter wheat, Hennessey, OK, 2015-2016.



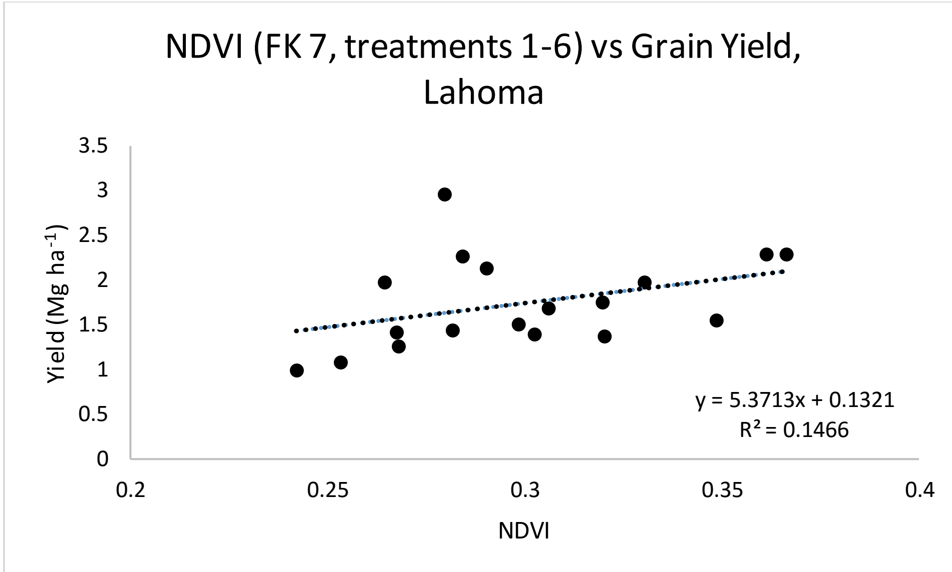
Appendix 13. NDVI (FK 3, treatments 1-6) vs Grain Yield, winter wheat, Lahoma, OK, 2015-2016.



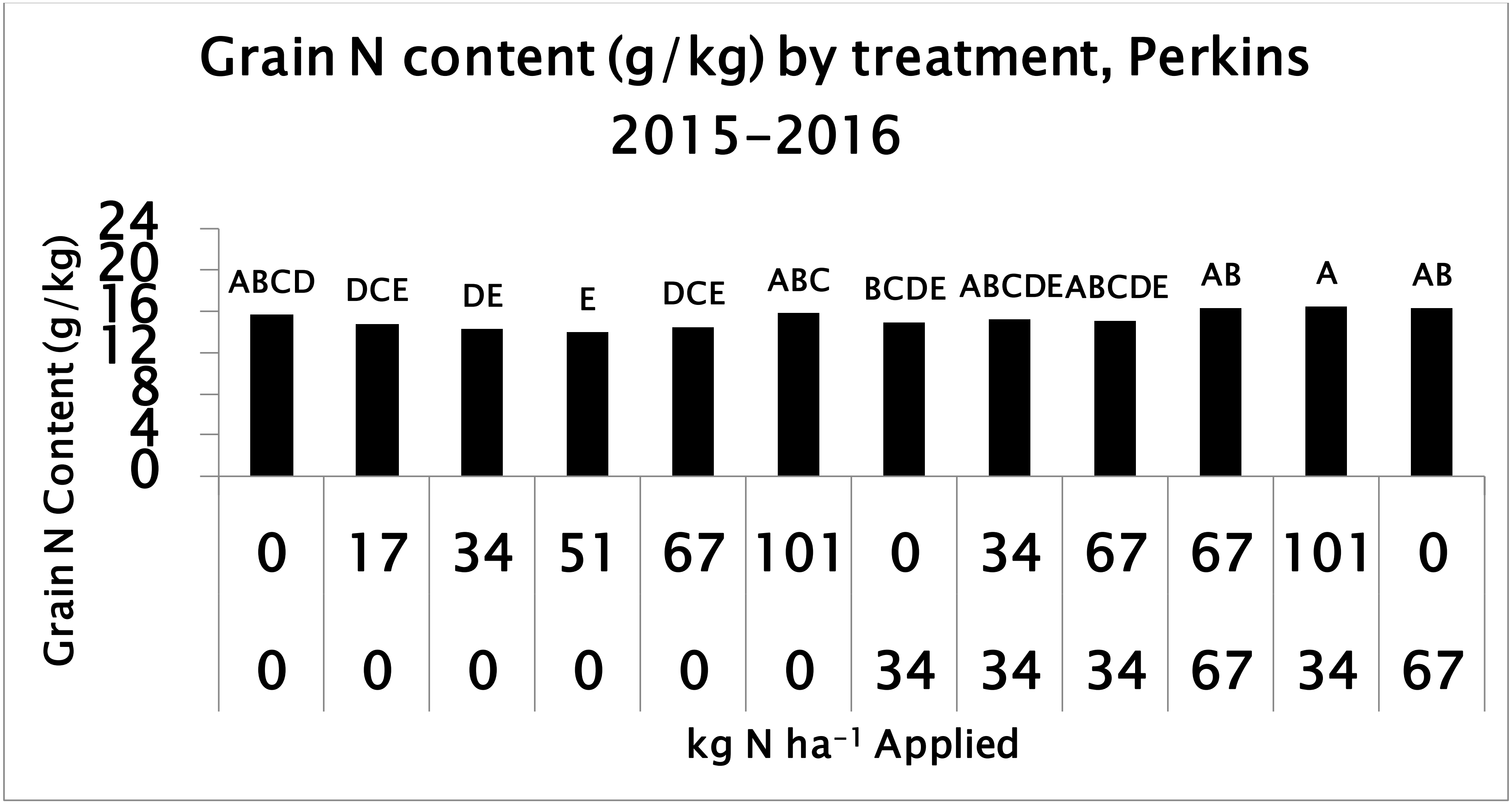
Appendix 14. NDVI (FK 5, treatments 1-6) vs Grain Yield, winter wheat, Lahoma, OK, 2015-2016.



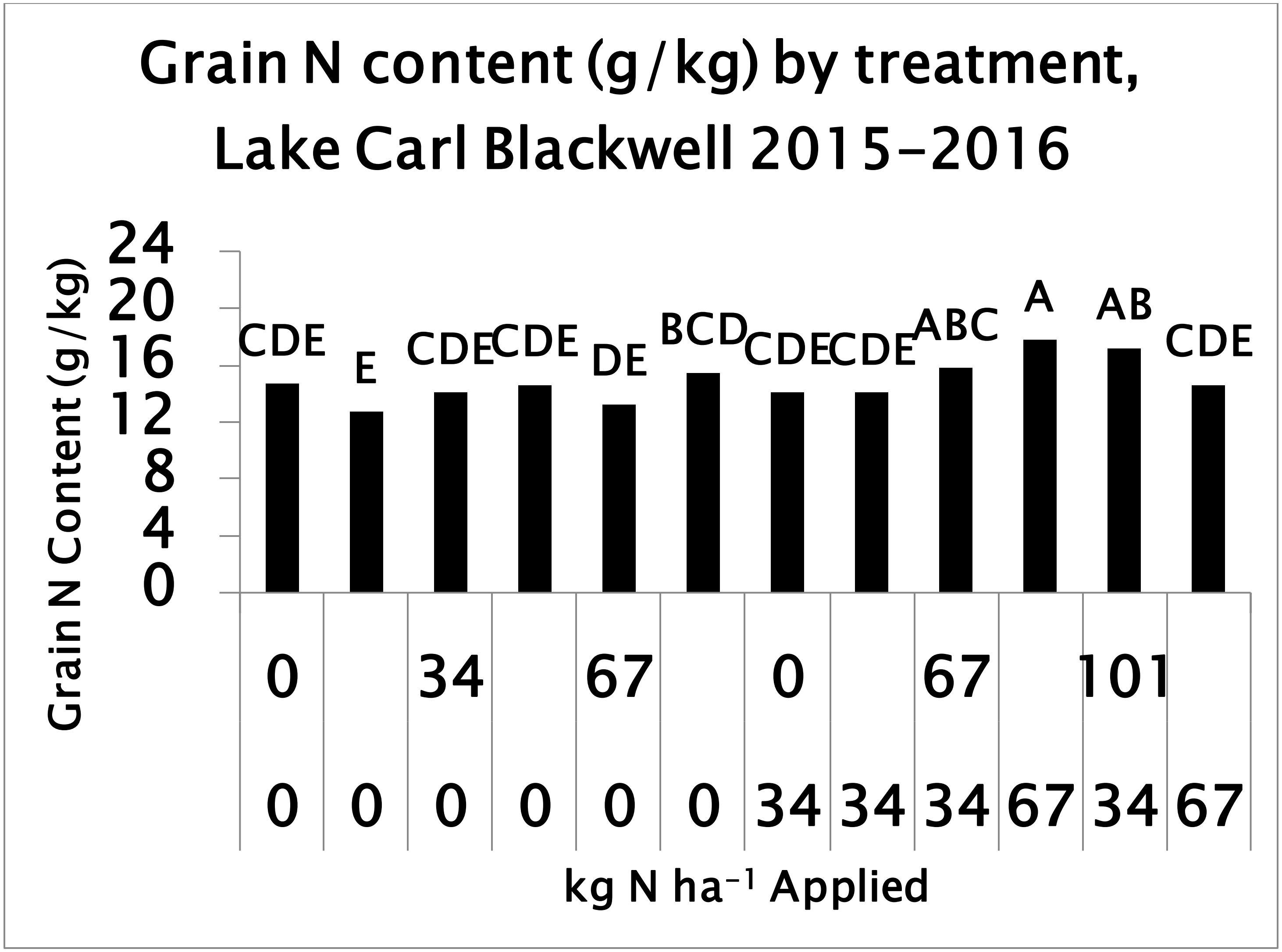
Appendix 15. NDVI (FK 6, treatments 1-6) vs Grain Yield, winter wheat, Lahoma, OK, 2015-2016.



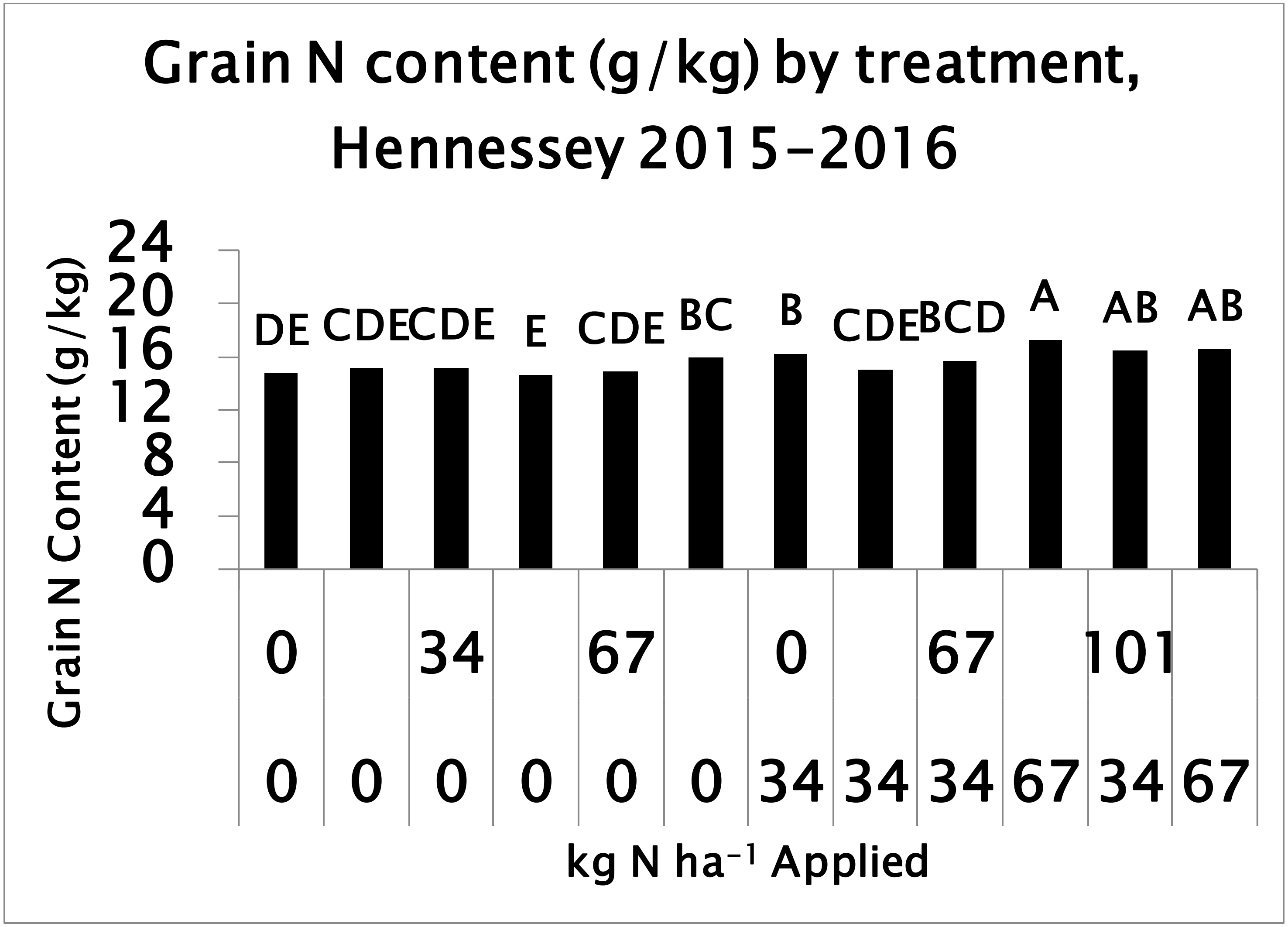
Appendix 16. NDVI (FK 7, treatments 1-6) vs Grain Yield, winter wheat, Lahoma, OK, 2015-2016.



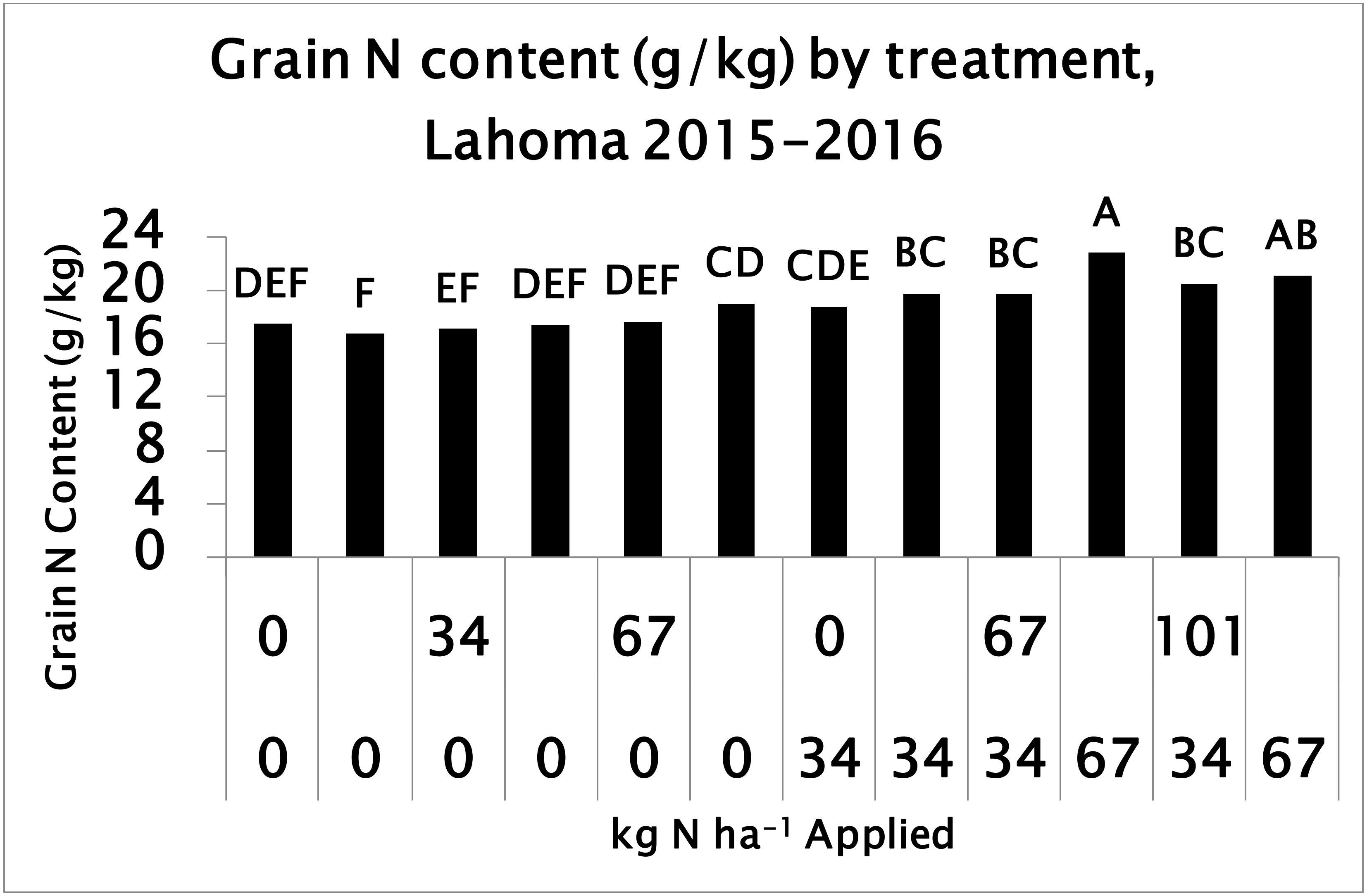
Appendix 17. Grain N content (g/kg) by treatment, winter wheat, Perkins, OK, 2015-2016.



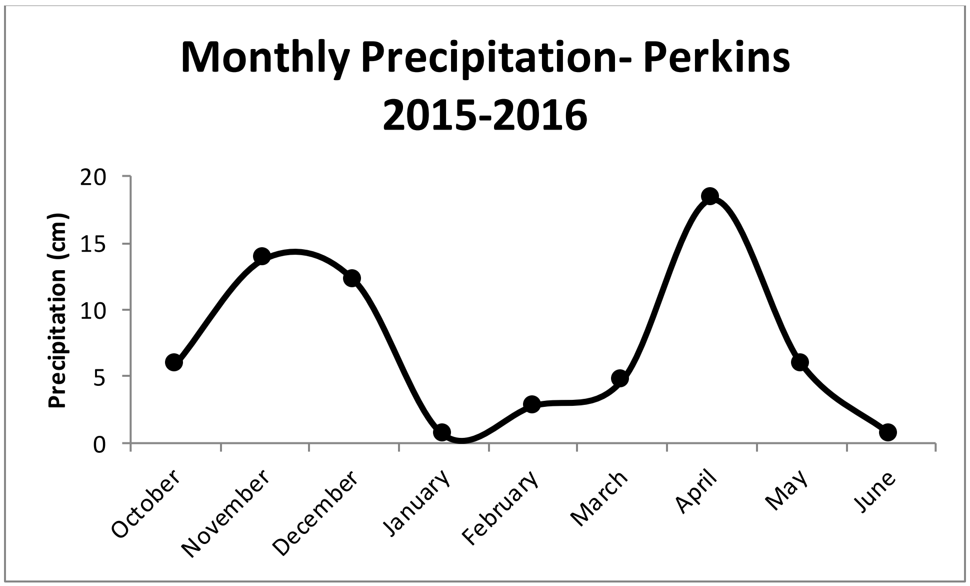
Appendix 18. Grain N content (g/kg) by treatment, winter wheat, Lake Carl Blackwell, OK, 2015-2016.



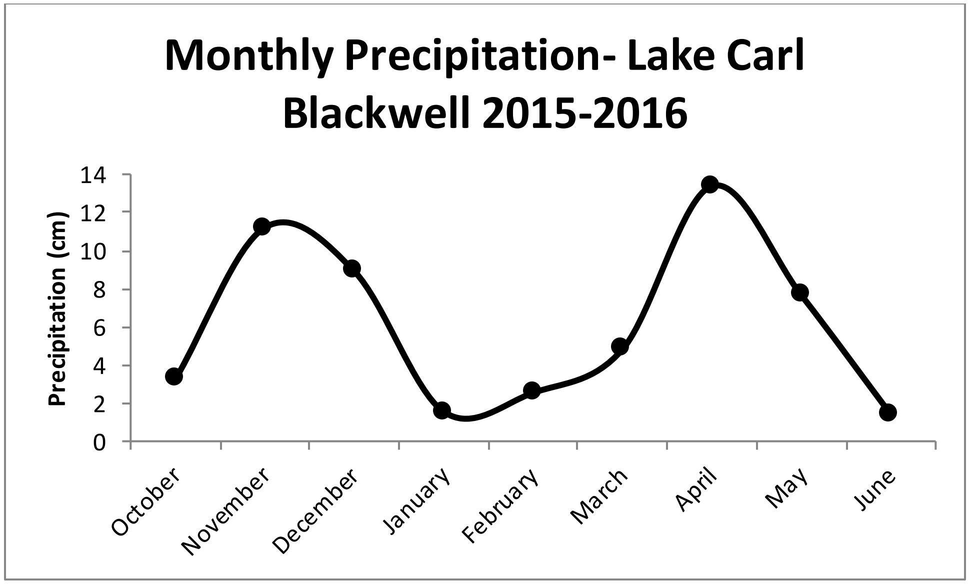
Appendix 19. Grain N content (g/kg) by treatment, winter wheat, Hennessey, OK, 2015-2016.



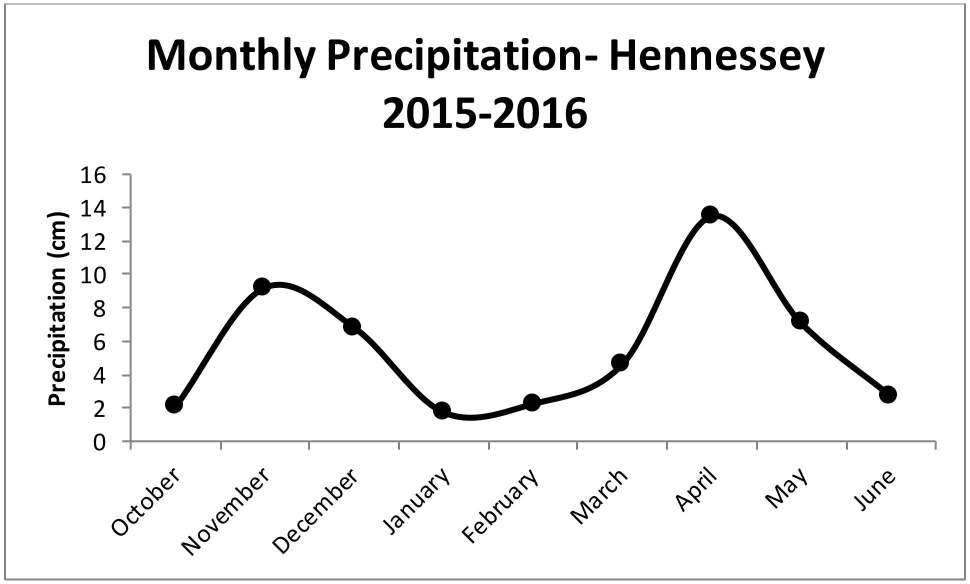
Appendix 20. Grain N content (g/kg) by treatment, winter wheat, Lahoma, OK, 2015-2016.



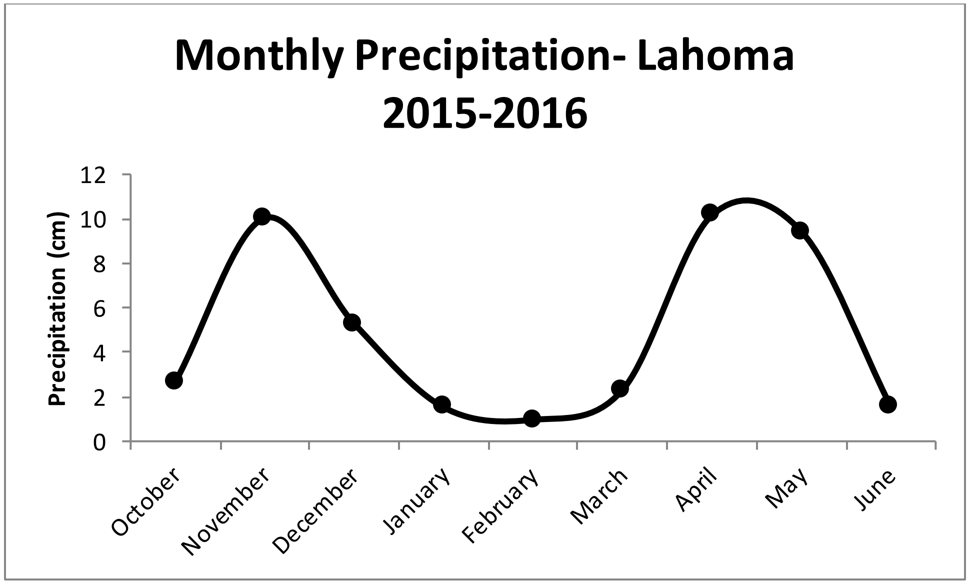
Appendix 21. Monthly precipitation, winter wheat, Perkins, OK, 2015-2016.



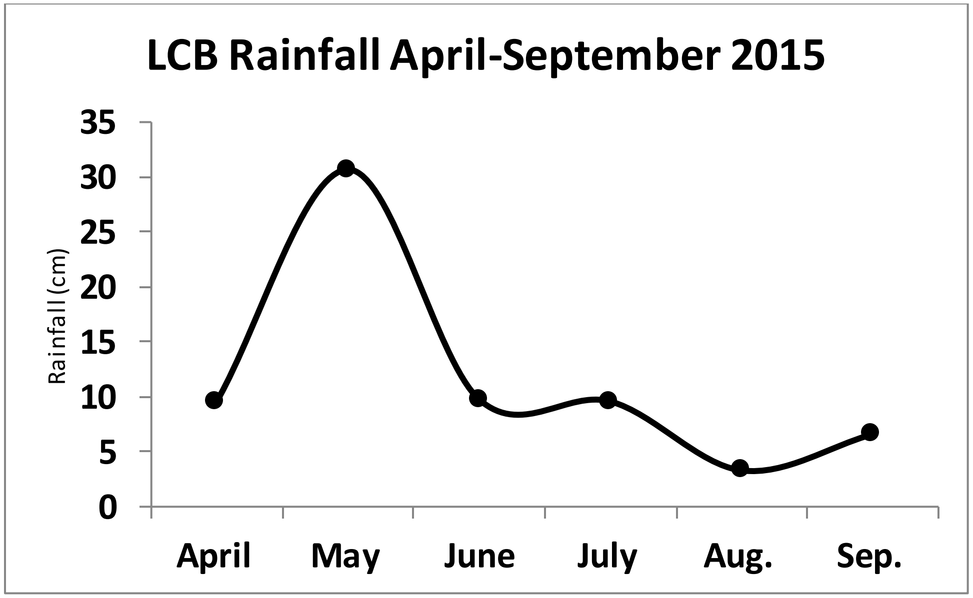
Appendix 22. Monthly precipitation, winter wheat, Lake Carl Blackwell, OK, 2015-2016.



Appendix 23. Monthly precipitation, winter wheat, Hennessey, OK, 2015-2016.



Appendix 24. Monthly precipitation, winter wheat, Lahoma, OK, 2015-2016.



Appendix 25. Monthly precipitation, maize, Lake Carl Blackwell, OK, 2015-2016.

VITA

Ethan Charles Driver

Candidate for the Degree of

Master of Science

Thesis: OPTIMUM PREPLANT NITROGEN RATES IN WINTER WHEAT (TRITICUM aestivum L.) AND MAIZE (ZEA mays L.)

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