EFFECTS OF PLANT POPULATION AND NITROGEN RATE ON SPECTRAL PROPERTIES AND GRAIN YIELD OF WINTER WHEAT (*TRITICUM AESTIVUM* L.)

By

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CHAPTER I

INTRODUCTION

Two of the most important and expensive operator controlled inputs in producing a winter wheat crop are nitrogen (N) fertilizer and seed wheat. As the market price for a unit of wheat increases, the cost of inputs required to produce that unit of wheat steadily rise. Therefore, it is imperative that continued advances in production methods be made that improve input efficiency and reduce input costs to keep wheat competitive with other crops competing for acreage. When input prices become too high, producers will react by using fewer inputs, less expensive resources, or switch to a different crop altogether. With much money flowing to the research of more profitable crops than wheat, like corn, soybeans, and cotton; new technology in wheat production is lagging behind. In fact, the number of acres planted to wheat in the United States has declined by nearly 30 percent since the early 1980’s (Vocke et al., 2005).

It has been estimated that world N use efficiency (NUE) is only 33% for cereal crops (Raun and Johnson, 1999). Therefore, improving NUE would be a great place to start. Raun and Johnson (1999), further explained that the poor NUE is due to a combination of factors including: plant gaseous losses, volatilization, denitrification, surface runoff, and leaching. One method to improve NUE is to split apply N rather than apply one large amount pre-plant. Split application of N is more efficient since wheat plants need very little N until they break dormancy and begin rapid growth. As little as 17 to 34 kg ha^{-1} of pre-plant N fertilizer is needed prior to dormancy to meet plant requirements (M. M. Alley, 2009; Weisz and Heiniger, 2000). If the season's quota of N is applied pre-plant then it is at the mercy of the environment and prone to losses. Alternatively, if part of the N is applied mid-season, only the first application is exposed to a full season of environmental conditions. At mid-season, producers can then evaluate weather conditions, crop health, and prices of fertilizer and grain to make more informed input decisions. Also, producers will be applying N nearer to the time of uptake, further reducing the potential for losses.

Typical central plains wheat producers apply the same amount of pre-plant and top-dress N each year regardless of environmental conditions. This is inefficient since fluctuating environmental conditions provide varying amounts of N from organic matter, rainfall, mineralization, nitrification, and other factors each year. Oklahoma State University has developed an active sensor (GreenSeeker) for recommending mid-season N rates. It has proven to increase the N use efficiency in winter wheat by 15% by predicting yield mid-season and calculating a wheat response index from the first half of the growing season (Teal, 2004). By measuring wheat characteristics such as biomass, forage N, grain N, N uptake, tiller density, grain yield, and plant reflectance through a normalized difference vegetative index (NDVI) at three seeding rates (SRs) and N rates (NRs), the sensor is able to more accurately predict plant needs mid-season and recommend more accurate top-dress NRs that lead to improved use efficiency of N fertilizer inputs.

CHAPTER II

LITERATURE REVIEW

Each variable that was collected to refine the prediction of final grain yield and mid-season vegetative relationships is outlined below along with the factors that influence them.

Tiller Density

A tiller is a growth shoot on a wheat plant with two or more unfolded leaves. Each tiller is capable of producing its own head with corresponding roots (Fowler, 2002). Therefore, increased tillering is beneficial to final grain yield. However, Rickman and Klepper (1991) found that tillers will abort if the environment will not support them. Past experiments have proven that tillering is correlated to final grain yield (Girma et al., 2006). However, only tillers with two or more leaves are counted as tillers. This is because growth shoots with less than two leaves have not yet formed their corresponding roots. Also, by the Feekes 5 (F5) growth stage, plant shoots with less than two leaves are likely to abort before harvest.

Total Grain Nitrogen

Total grain N is a measure of the amount of N that is accumulated in the grain. Grain N content is highly correlated with protein content. Higher protein levels are associated with higher quality and thus can earn a market premium. There are several factors that can affect total grain N content including cultivar, amount of N applied, time of N application, amount of precipitation, rate of maturity, yield, and temperature during the growing season; especially during the grain fill period (Rao et al., 2000; Smith and Gooding, 1999). Generally, increased N fertilization and precipitation, split N applications, and cool temperatures during grain fill provide a higher total grain N content. Increased yield is gained from more kernels per given area. Thus, with higher grain yields, available N is divided between more kernels which in turn can reduce the grain N content (Jamieson and Semenov, 2000).

Feekes 5 Forage Nitrogen

Forage N is the measure of accumulated N in plant biomass. The stage of plant maturity influences N content. Younger plants tend to have higher N concentrations than older plants since N is concentrated in a smaller plant area (Surber et al., 2003).

Feekes 5 Forage Nitrogen Uptake

Forage N uptake is the product of forage N content and biomass. Increasing N uptake results in improved N use efficiency. Jamieson and Semenov (2000) believe that the factors limiting N uptake are moisture level in the soil and amount of N that is supplied.

Feekes 5 Dry Biomass

Biomass is the vegetative mass that is produced by a plant. Plants that are provided with ample water, nutrients, temperature, and sunlight will produce larger quantities of biomass than plants living in less favorable conditions (Rao et al., 2000). According to Fischer (1993) biomass production is known to be highly correlated with grain yield.

Normalized Difference Vegetative Index

Normalized difference vegetative index is a vegetative index that ranges from 0 to 1 and is useful for measuring plant growth characteristics. According to Karlsen et al. (2007) the formula for calculating NDVI is (near infrared reflectance – red light reflectance) / (near infrared reflectance + red light reflectance). Oklahoma State University and N-Tech Industries developed the GreenSeeker active handheld optical sensor that is currently used to estimate mid-season N rates in cropping systems and predict crop yields using NDVI. Normalized difference vegetative index readings are determined by the amount of biomass and greenness of the area sensed. Vegetation that has more biomass and is darker in color will have a larger numerical NDVI reading. Lower NDVI values correspond to plants that have less biomass and are lighter colored.

CHAPTER III

OBJECTIVES

The first objective of this research was to evaluate the relationships between Feekes 5 (F5) tiller density, forage N content, forage N uptake, dry biomass, F5 and F7 NDVI, grain N content, and final grain yield measured at three NRs (0, 56, and 112 kg ha^{-1}) and three SRs (63, 120, and 176 kg ha^{-1}) to improve mid-season yield predictions in winter wheat. The grain N content could not be measured mid-season, but this information was used after harvest to aid in connecting the dots between the other variables in order to find plant characteristics that were highly correlated with grain yield. The second objective was to correlate these plant characteristics with grain yield to determine which could be used mid-season to improve current wheat N fertilizer recommendations.

CHAPTER IV

MATERIALS AND METHODS

A two year field experiment was initiated in 2009 to evaluate the relationships between Feekes 5 (F5) tiller density, F5 forage N content, F5 N uptake, F5 biomass, F5 NDVI, F7 NDVI, and grain N content on final grain yield and determine which can be used mid-season to predict final grain yield. A randomized complete block design with four replications and nine treatments was implemented at two Oklahoma locations for a total of four site-years. The treatment structure is reported in Table 1. The locations were at the North Central Research Station near Lahoma and near Hennessey, OK. Both sites are rain fed locations. The Lahoma location was on a Grant silt loam, 1 to 3 percent slopes (Fine-silty, mixed, superactive, thermic Udic Argiustolls). The Hennessey location was on a Bethany silt loam, 0 to 1 percent slopes (Fine, mixed, superactive, thermic Pachic Paleustolls). Plot size was 3.05 m wide by 6.1 m long. Both trials were conventionally tilled prior to planting with a chisel plow and cultivator. The N source, urea ammonium nitrate (UAN), was applied pre-plant at three rates (0, 56, and 112 kg ha^{-1}) with a 3.05 m boom width equipped with streamer nozzles attached to a four wheeler one week before planting and incorporated into the soil with a cultivator. In 2009, winter wheat was planted on October 6 at Hennessey to Overley and October 7 at Lahoma to OK Bullet. In 2010, Hennessey was planted October 1 to Centerfield and Lahoma was planted October 6 to OK Bullet. Winter wheat was sown with a Kinkaid 3-point conventional drill with 15.24 cm row spacing. The drill was calibrated in the field for each of the three SRs (63, 120, and 176 kg ha^{-1}). At the F5 growth stage, tiller counts, NDVI, and forage biomass were collected. To count tillers, two 0.6 X 0.6 meter metal frames were constructed and randomly placed within plots. Only tillers with two unfolded leaves were counted. The two frames were averaged and converted to 1 m^2. Normalized difference vegetative index readings were taken from each frame with a GreenSeeker Handheld Sensor and averaged per plot. One of the 0.6 X 0.6 meter areas from each plot was randomly chosen for biomass collection. Forage biomass was cut at the soil surface and dried in an air forced oven at 65^0 Celsius, followed by recording the dry biomass weight. Dry biomass was ground with a Wiley Mill, rolled in glass bottles with stainless steel pins for 18 hours to ensure sample homogeneity and fineness, and analyzed for total N with a LECO Dry Combustion Analyzer (Schepers et al., 1989). Two GreenSeeker readings were taken down the length of each plot and averaged at both F5 and F7 growth stages to obtain NDVI. The center 10.97 m^2 of each plot were harvested in mid June with an experimental 8XP Massey Ferguson Combine and 400 gram grain subsamples were taken from each plot. The grain was then dried, ground, rolled, and analyzed for total grain N. SAS (2003) regression, correlation, and analysis of variance were used to determine the degree to which each variable was able to predict final grain yield.

CHAPTER V

RESULTS

Response of the dependent variables measured in this study differed by location and year, thus independent location and year analysis was performed and reported accordingly. Results are divided by location in an effort to better understand those factors that control and influence each site. Outcomes for the 2009-2010 cropping season at Hennessey and Lahoma are reported in Tables 2 and 3 and Figures 1 and 2, respectively. Results for the 2010-2011 cropping season at Hennessey and Lahoma are reported in Tables 4 and 5 and Figures 3 and 4, respectively.

Hennessey 2009-2010

Grain Yield

Grain yields ranged from 1942 to 4120 kg ha^{-1}, with an average of 3095 kg ha^{-1}(Table 2). The maximum yield was obtained at the high NR (112 kg ha^{-1}) and SR (176 kg ha^{-1}). The NR was significant, but the SR was not. With the high yield levels recorded at this location we expected the higher SRs to have a positive effect on grain yield, especially with higher N. There was an increase in grain yield as SR increased; however, the greatest yield increase occurred at the low NR rather than the high NR. This could have occurred because the wheat did not receive enough moisture to fully utilize the N at the high NR (Figure 1).

Tiller Count

Similar to that reported for yield, NR significantly increased the number of tillers (Table 2). Also, increasing the SR resulted in higher tiller counts. Therefore, the high NR and high SR yielded the most tillers with 1844 m^{-2}, while the least tillers were observed at the low NR and low SR with 807 m^{-2}. Although increased SR and NR often led to increased tillering and grain yield, it is important to note that increased tillering did not always lead to increases in grain yield. This suggests that although seeding rates could impact tillers, grain yields are not totally influenced by tillering at the Feekes (F) 5 growth stage. However, tillering at Hennessey was still highly correlated with final grain yield (r^2 = 0.55) as was also observed by Girma et al. (2006). Winter wheat can tiller profusely, but if the environment is not conducive to higher grain yields, many tillers will abort (Rickman and Klepper, 1991). At much higher yield levels, we expect that the wheat plant's resilience to produce more grain might have been realized, and the added tillers from the higher SRs could have been beneficial. However, with the yield levels reported here, this effect was not observed.

Total Grain Nitrogen

The largest total grain N value (20 g kg^{-1}) was observed at the high NR and low SR (Table 2). There was a trend for grain N to decrease with increasing SR at the high NR. A negative relationship between total grain N content and grain yield was observed, indicating that as grain N content decreased there was an increase in yield. This demonstrates that in order to improve wheat grain N content, and therefore, protein content, producers should apply higher amounts of N and or reduce SR. Grain N had some correlation with grain yield (r^2 = 0.24).

Feekes 5 Forage Nitrogen

Similar to total grain N, at the highest NR (112 kg ha^{-1}) forage N decreased as the SR increased (Table 2). This was most likely due to higher amounts of vegetation at the higher SR, and a dilution of total forage N. A tendency was noted for grain yield to increase as the forage N content decreased. Forage N at F5 was correlated with grain yield (r^2 = 0.31). For this site and year, this suggests that forage N determined at F5 could be used to predict final grain yield.

Feekes 5 Forage Nitrogen Uptake

Forage N uptake was positively correlated with grain yield (r^2 = .74) (Table 2). At the low NR (0 kg ha^{-1}), there was a trend for forage N uptake to increase with increasing SR, which corresponded to an increase in grain yield. As was expected, the highest forage N uptake occurred at the high NR due to a larger supply of N. Furthermore, at each SR the impact of NR nearly doubled the forage N uptake when comparing the low and medium NRs. Whereas, increases in N uptake were less pronounced when the medium and high NR were compared. These results follow the law of diminishing returns, where F5 forage N uptake followed an increasing linear trend at lower N inputs, while F5 forage N uptake was less responsive to changes at higher levels of N.

Feekes 5 Dry Biomass

Dry biomass at F5 was also well correlated with grain yield for Hennessey during the 2009-2010 growing season (r^2 = 0.62) (Table 2). The high NR (112 kg ha^{-1}) and high

SR (176 kg ha^{-1}) was the only treatment that had a significant increase in biomass production over the other treatments. The synergistic effect of NR and SR was evident with a biomass yield of (5336 kg ha^{-1}). At the low and medium NR, the highest biomass production occurred at the medium SR. Based on these results, in order to maximize biomass yield, graze-out and dual purpose (both grazing and grain production) producers should sow wheat at the high NR (112 kg ha^{-1}) and the high SR (176 kg ha^{-1}).

Feekes 5 and Feekes 7 NDVI

Feekes 5 NDVI values ranged from 0.46 to 0.67 with an average of 0.58 while F7 NDVI ranged from 0.37 to 0.67 and averaged 0.53 (Table 2). The average F5 NDVI was larger than the F7 NDVI because the wheat was becoming N deficient at the later growth stage. There was a trend for NDVI values to increase with increasing NR and SR. The NDVI increased with higher NR because of the increased vegetative growth, while SR increased NDVI because of higher plant counts which contributed more biomass. This was expected since NDVI can be a good measure of total dry biomass (Freeman et al., 2007). Both F5 and F7 NDVI values were well correlated with grain yield with r^2 values of 0.77 and 0.79, respectively.

Lahoma 2009-2010

Grain Yield

Grain yields ranged from 1350 to 2770 kg ha^{-1}, with an average of 2042 kg ha^{-1} at Lahoma for the 2009-2010 growing season (Table 3). The largest grain yield was observed at the high NR and high SR. At the medium NR, the highest grain yields were observed at the medium SR. Similarly, at the low NR, the highest yields were obtained at the low SR. Therefore, as NR is increased, SR should also be increased in order to obtain full grain potential. This increase in grain yield was expected since higher planting populations can lead to higher plant densities and more kernel bearing heads (Coventry et al., 1993).

Tiller Count

The SR at Lahoma was significant in 2010 for tiller count (Table 3). Tiller counts ranged from 773 to 1253 tillers per m^{-2} with an average of 1034. Tiller counts had a low correlation (r^2 = 0.02) with grain yield and there was a trend for tillering to decrease with increasing SR, most likely due to increased competition for moisture, nutrients, and light. It was also interesting that for each SR the medium NR produced the most tillers. This suggests that there was not enough moisture in this environment to utilize the amount of N supplied at the highest NR. The main effect of NR was not significant for number of tillers.

Total Grain Nitrogen

As SR and NR increased, there was a trend for total grain N to decrease with increased grain yields (Table 3). This demonstrates the negative relationship between grain yield and grain N content that has been reported by others (Acreche and Slafer, 2009). As grain yields increased, N was partitioned between more kernels, thereby resulting in a lower grain N content. Grain N was poorly correlated with grain yield (r^2 = 0.03).

Feekes 5 Forage Nitrogen

Feekes 5 forage N content ranged from 25 to 43 g kg^{-1} with an average of 32 g kg^{-1} (Table 3). The highest forage N contents occurred at the low SR. Across all NRs, forage N content followed a linear trend; decreasing with increasing SR. Alternatively, at each SR, forage N content increased with increased NR. The F5 forage N was correlated (r^2 = 0.26) with final grain yield. Larger grain yields occurred when the forage N content was lower.

Feekes 5 Forage Nitrogen Uptake

Feekes 5 forage N uptake trended slightly upward with increased SR (Table 3). Forage N uptake followed a strong linear trend to increase with increased NR, independent of SR. Final grain yield also increased as forage N uptake increased. It is noteworthy that increased SR competition did not lower yield, but actually allowed for improved N use efficiency and grain yield at the high NR. Forage N uptake at F5 was also highly correlated with final grain yield (r^2 = 0.52). Since forage N uptake is a function of dry biomass and forage N content, it followed the same trend as dry biomass.

Feekes 5 Dry Biomass

Feekes 5 biomass weights ranged from 532 to 1986 kg ha^{-1} with an average of 1072 kg ha^{-1} (Table 3). Seeding rate and NR were both contributing factors in increasing biomass production. Increases in F5 biomass corresponded to an increase in grain yield (r^2 = 0.36). These findings suggest that maximum biomass is obtained with the high NR and high SR.

Feekes 5 and Feekes 10 NDVI

Feekes 5 NDVI values ranged from 0.35 to 0.48 with an average of 0.43 while F10 NDVI ranged from 0.46 to 0.72 with an average of 0.61 (Table 3). F10 NDVI, readings were taken since the weather was not conducive at F7. As SR and NR increased the F5 and F10 NDVI values decreased. This can be explained by the increased N demand at higher plant densities. F5 and F10 NDVI values were both highly correlated with final grain yields and had r^2 values of 0.37 and 0.85, respectively. These findings are consistent with Solie et al. (2002), that F5 NDVI was correlated with final grain yield.

Hennessey 2010-2011

Grain Yield

Grain yields ranged from 1097 to 1830 kg ha^{-1}, with an average of 1495 kg ha^{-1} (Table 4). The maximum yield was obtained at the high NR (112 kg ha^{-1}) and medium SR (120 kg ha^{-1}). The NR was significant, but SR was not significant at all levels. This year's wheat crop was severely limited by moisture, especially during the spring as is seen when comparing Figures 1 and 3. Therefore, the high N rate did not increase grain yields as much as last year. In fact, the high N rate at the low SR actually reduced the grain yield since the N fertilizer supplied was too high for the amount of moisture received and actually burnt the wheat, resulting in yield loss.

Tiller Count

The SRs and NRs both positively influenced the tiller counts in this year's environment (Figures 3 and 4). The temperatures remained warm late into the fall allowing for immense tiller accumulations per plant with an average of 2415 tillers m^{-2}

(Table 4). As was seen last year, increasing the SR resulted in higher tiller counts again this year. The medium NR produced many more tillers than the low NR, but the high NR did not always increase tiller production when compared with the medium NR. However, the high NR had longer and wider leaves than the lower NRs. The dry spring caused many tillers to abort, but the plants with more tillers at F5 still had higher grain yields than plants with less tillers earlier in the season. Due to the abortion of tillers, the grain yield was very poorly correlated with tillering at F5. If sufficient rainfall was received we would have had enormous grain yields with the amount of tillers produced at this location.

Total Grain Nitrogen

The largest total grain N value (27 g kg^{-1}) was observed at the high NR and both the high and low SRs (Table 4). This can be explained by the fact that N was oversupplied and thus underutilized in the high N treatments. Grain N followed a linear pattern again this year with higher levels seen at higher NRs. Grain N content remained relatively steady across all SRs and N rate was the main factor that influenced grain N content. Therefore, varying the SR was not a large factor in determining grain N content. Grain N had little correlation with grain yield (r^2 = 0.23).

Feekes 5 Forage Nitrogen

Forage N tested at F5 trended downward with increasing SR and increased with increasing NR (Table 4). This downward trend with SR was most likely due to higher amounts of vegetation at the higher SR splitting the N between more plant biomass. A tendency was noted for grain yield to increase as the forage N content increased. Forage N at F5 was decently correlated with grain yield (r^2 = 0.50).

Feekes 5 Forage Nitrogen Uptake

Forage N uptake was positively correlated with grain yield ($r^2 = 0.45$) (Table 4). As SR increased the forage N uptake increased, but the NR was the major factor that increased forage N uptake. As the N rate increased, the forage N uptake increased. The largest N uptake occurred at the high NR and high SR, as was expected, since there was more N available and more plants in place to take up the N.

Feekes 5 Dry Biomass

Dry biomass at F5 was also correlated with final grain yield for Hennessey ($r^2 = 0.28$) (Table 4). Similar to tillering, Hennessey produced a large amount of biomass in the 2010-2011 growing season due to the ample fall soil moisture and late fall. This extra biomass depleted much moisture early in the season and limited grain production due to the below average moisture that was received late in the season. There was a trend for dry biomass to increase as the SR and NR increased. The high NR and SR produced the most biomass with 7482 kg ha^{-1}. The average biomass yield was 5516 kg ha^{-1}.

Feekes 5 and Feekes 7 NDVI

Feekes 5 NDVI values ranged from 0.60 to 0.75 with an average of 0.69 while F7 NDVI ranged from 0.51 to 0.73 and averaged 0.63 (Table 4). The average F5 NDVI was larger than the F7 NDVI because the wheat was N deficient. There was a trend for NDVI values to decrease with increasing SR. The NDVI increased with increasing NR, as was expected, as additional N produces lusher, larger leaves. Both F5 and F7 NDVI values were well correlated with grain yield with r^2 values of 0.58 and 0.59 for F5 and F7, respectively.

Lahoma 2010-2011

Grain Yield

Grain yields ranged from 1410 to 2803 kg ha^{-1}, with an average of 2068 kg ha^{-1} at Lahoma for the 2010-2011 growing season (Table 5). The largest grain yield was observed at the high NR and medium SR. This means that the wheat was not lacking in N fertilizer. As is noted by comparing Tables 1-4 the limiting element was water. Ample temperatures and moisture were received in the fall to produce above average biomass and tillers. In fact, the number of tillers in place this fall would have produced extremely high yields if average spring rains were received. However, the moisture did not come, causing tillers to abort and yields were suppressed. Increasing the SR at the low NR lowered grain yield. This was caused by too much N for the amount of moisture that was received.

Tiller Count

The SRs and NRs at Lahoma were significant in 2011 for tiller count (Table 5). Tiller counts ranged from 1144 to 1639 tillers per m^{-2} with an average of 1393. The highest NR and SR produced the most tillers, while the lowest NR and SR yielded the least tillers. Tiller counts had a positive correlation (r^2 = 0.42) with grain yield. However, the correlation was lower than expected due to the drought conditions that were encountered after the tiller counts were taken. There was a trend for tillering to increase with increasing SR. This was unexpected since more competition usually decreases tillering.

Total Grain Nitrogen

As SR increased, there was a trend for total grain N to decrease (Table 5). Grain N content increased as the NR increased. As the grain N content increased the grain yield trended upward. This was unusual since grain N content and grain yield are normally inversely related. Grain N was poorly correlated with grain yield ($r^2 = 0.37$).

Feekes 5 Forage Nitrogen

Feekes 5 forage N content ranged from 15 to 27 g kg^{-1} with an average of 22 g kg^{-1} (Table 5). The highest forage N content occurred at the low SR. Across all NRs, forage N content followed a linear trend, decreasing with increasing SR. Alternatively, at each SR, forage N content trended upward with increased NR. The F5 forage N was correlated ($r^2 = 0.53$) with final grain yield.

Feekes 5 Forage Nitrogen Uptake

The highest and lowest Feekes 5 forage N uptake levels were seen at the medium SR (Table 5). The lowest uptake (34 kg ha^{-1}) was recorded at the lowest NR and the highest NR had the greatest uptake (106 kg ha^{-1}). It is interesting that the highest uptake did not occur at the highest SR since ordinarily more plants per given area will increase the N uptake. Forage N uptake followed a strong linear trend to increase with increased NR, independent of SR. Final grain yield also increased as forage N uptake increased. Forage N uptake at F5 was highly correlated with final grain yield ($r^2 = 0.74$).

Feekes 5 Dry Biomass

Feekes 5 biomass weights ranged from 2243 to 4435 kg ha^{-1} with an average of 3113 kg ha^{-1} (Table 5). NR significantly increased the quantity of dry biomass that was produced. The larger NRs tended to produce more biomass. The SR was also significant for biomass production. Increases in F5 biomass corresponded to an increase in grain yield (r^2 = 0.52). These findings demonstrate that maximum F5 biomass was produced at the high NR and medium SR.

Feekes 5 and Feekes 7 NDVI

Feekes 5 NDVI values ranged from 0.40 to 0.61 with an average of 0.52, while F7 NDVI ranged from 0.36 to 0.63 with an average of 0.50 (Table 5). As NR increased, the F5 and F7 NDVI values increased. This increase in NDVI, from increased N, is due to more biomass production and a greener leaf canopy. F5 and F7 NDVI values were both highly correlated with final grain yields and had r^2 values of 0.74 and 0.67, respectively.

CHAPTER VI

DISCUSSION

Grain Yield

Both Hennessey and Lahoma obtained maximum grain yields for 2009-2010 with the highest NR and SR. However, in 2010-2011, both locations reached their highest grain yields at the high NR and medium SR. This difference in optimal SR was due to a lack of moisture in the 2010-2011 season that did not allow the higher SR to maintain the tillers that were put on in the fall. Grain yields at Lahoma in the first growing season were considerably lower due to reduced rainfall, leaf rust, and a late season hailstorm which hit Lahoma, but missed Hennessey. Fungicide was applied at Lahoma in the spring of 2010, but the leaf rust still limited yield. These factors could also account for the reduced plant characteristic correlations with grain yield at Lahoma compared to Hennessey seen in the 2009-2010 growing season (Tables 1-4). Monthly rainfall and temperatures are displayed in Figures 1-4.

Tiller Count

Hennessey averaged more tillers than Lahoma in both growing seasons. This is most likely due to environmental conditions. Lahoma received less rain (Figures 1 and 3) and had slightly lower temperatures than Hennessey (Figures 2 and 4). There was a stronger correlation between tiller count and grain yield at Hennessey in 2009-2010 than Lahoma, but an improved correlation with grain yield was observed at Lahoma in 2010-2011 (Tables 1-4). The poor correlation at Lahoma in 2009-2010 was due to leaf rust and late-season hail damage. The large accumulation of tillers at Hennessey in 2010-2011 followed by a severe drought caused the poor correlation there.

Total Grain Nitrogen

The total grain N values were higher at Lahoma in 2009-2010, but higher at Hennessey in 2010-2011 due to lower grain yields; this resulted in lower inter-grain competition. As indicated by these results, producers concerned with increasing grain N content and therefore, protein content should increase the NR and or decrease the SR.

Feekes 5 Forage Nitrogen

The F5 forage N content decreased as the SR and NR were increased. This is due to a dilution affect that occurred when the additional plants per given area divided the available N between larger and more plants. Correlation of forage N and grain yield were high at all sites in all years.

Feekes 5 Forage Nitrogen Uptake

Three out of the four trials had increased F5 forage N uptake when the SR increased. This demonstrates that wheat is capable of gaining a higher N use efficiency when higher SRs are utilized.

Feekes 5 Dry Biomass

The average F5 biomass weights were much larger at Hennessey than Lahoma during both growing seasons. Again, this was caused by more moisture and higher temperatures at Hennessey than Lahoma.

Normalized Difference Vegetative Index

The NDVI trended upward as the NR was increased. This was due to the greater leaf area and greener vegetation accumulated from extra N. The NDVI trended downward as SR was increased. This was caused by a dilution of the available N among more plants. Results from these trials show that NDVI is significant in explaining F5 biomass and ultimately grain yield. These findings coincide with Raun et al. (2001), who found that NDVI readings could successfully explain and predict winter wheat grain yields.

CHAPTER VII

CONCLUSIONS

The first objective for completing this experiment was to evaluate the relationships between Feekes 5 (F5) tiller density, forage N content, forage N uptake, dry biomass, F5 and F7 NDVI, grain N content, and final grain yield measured at three NRs (0, 56, and 112 kg ha^{-1}) and three SRs (63, 120, and 176 kg ha^{-1}) to improve mid-season yield predictions in winter wheat. Over two growing seasons, it was observed that tillering in the fall is advantageous, however, these tillers can abort if drought stress occurs and in these instances are not associated with increased grain yield. Larger accumulations of biomass in the fall also led to higher grain yields.

F7 NDVI and F5 NDVI mid-season measurements predicted grain yield the best (r^2 = 0.68 and 0.62, respectively) over the environments observed in both growing seasons. Nitrogen uptake, biomass, and forage N were variables that also predicted wheat grain yields reasonably well (r^2 = 0.61, 0.44, and 0.40 respectively) and should be used with F5 and F7 NDVI to aid in determining the ideal mid-season top dress N rate.

This study was conducted for two years. Environments were totally different each year, very wet with moderate temperatures the first year and very dry with extreme low and high temperatures the second year. Added studies should be conducted to solidify and verify these conclusions. For future experimentation, it would be interesting to use two wheat varieties at each location and implement the same nine treatments that were employed in this study. This would allow for a comparison of plant variables between different varieties that may have different growth habits, such as erect or prostrate growth patterns and varieties that produce large quantities of biomass in the fall for grazing, verses grain only varieties.

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TABLES

Table 1. Treatment structure employed at The North Central Research Station near Lahoma, Oklahoma, and Hennessey, Oklahoma; Winters 2009-2010 and 2010-2011 to evaluate the ability of wheat characteristics to predict final winter wheat grain yield.

TRT	Seeding Rate (lbs. / acre)	(kg / ha)	Nitrogen Rate (lbs. / acre)	(kg / ha)
1.	56	63	0	0
2.	56	63	50	56
3.	56	63	100	112
4.	107	120	0	0
5.	107	120	50	56
6.	107	120	100	112
7.	157	176	0	0
8.	157	176	50	56
9.	157	176	100	112

Table 2. Analysis of variance, mean squares, and means for NDVI at Feekes (F) 5, and F7, dry biomass at F5, forage nitrogen (N) and N uptake at F5, grain N, tillers per m^2, and grain yield, for winter wheat grown with various nitrogen and seeding rates, Hennessey, Oklahoma 2009-2010.

			F5 NDVI	F7 NDVI	F5 Dry Biomass	F5 Forage Nitrogen	F5 Forage N Uptake	Grain Nitrogen	Tillers m^{-2}	Grain Yield
Source of Variation		df	(mean squares)							
Replication		3	0.0024	0.0076*	368435	23†	765	4	26643	268337
Seeding Rate (SR)		2	0.0012	0.0014	1220834	8	78	3	325456**	288659
Nitrogen Rate (NR)		2	0.1227**	0.2026**	25743336**	49*	16247**	15	796868**	10266194**
SR*NR		4	0.0001	0.0065†	648812	27*	361	2*	147062*	159544
Residual Error		24	0.0022	0.0030	811530	8	269		2 40916	156820
			(means)							
Treatments	NR	SR			($kg\ ha^{-1}$)	($g\ kg^{-1}$)	($kg\ ha^{-1}$)	($g\ kg^{-1}$)	($\#\ m^{-2}$)	($kg\ ha^{-1}$)
1	0	63	0.4550	0.3675	1387	19	27	17	807	1983
2	56	63	0.6050	0.5025	2945	21	62	17	1199	2973
3	112	63	0.6525	0.6725	4203	27	113	20	1278	3895
4	0	120	0.4750	0.3700	1819	18	33	17	918	1942
6	112	120	0.6700	0.6325	4100	23	93	19	1185	4009
7	0	176	0.4750	0.4350	1682	23	37	17	1081	2550
8	56	176	0.6300	0.5250	3431	20	68	16	1297	3105
9	112	176	0.6600	0.6450	5336	21	111	18	1844	4120
SED			0.0332	0.0387	637	2	12	1	143	280
r^2			0.77	0.79	0.62	0.31	0.74	0.24	0.55	1
CV, %			8	10	28	13	24	9	17	13

SED – standard error of the difference between two equally replicated means

df– degrees of freedom

†, *, **, significant at the .10, .05, and .01 probability levels, respectively

NR – nitrogen rate in $kg\ ha^{-1}$

SR – seeding rate in $kg\ ha^{-1}$

r^2 –correlation coefficient for each variable versus grain yield

Table 3. Analysis of variance, mean squares, and means for NDVI at Feekes (F) 5, and F10, dry biomass at F5, forage nitrogen (N) and N uptake at F5, grain N, tillers per m², and grain yield, for winter wheat grown with various N and seeding rates, Lahoma, Oklahoma 2009-2010.

			F5 NDVI	F10 NDVI	F5 Dry Biomass	F5 Forage Nitrogen	F5 Forage N Uptake	Grain Nitrogen	Tillers m^{-2}	Grain Yield
Source of Variation		df	(mean squares)							
Replication		3	0.003	0.012	138236	14	138	12**	25508	280177
Seeding Rate (SR)		2	0.016	0.007	991138**	230**	256	18**	290209*	1571
Nitrogen Rate (NR)		2	0.011	0.154**	3199742**	197**	4040**	7**	121534	3281163**
SR*NR		4	0.003	0.004	304366†	14	197	3*	16326	241541
Residual Error		24	0.010	0.009	123808	11	106	1	64379	209019
			(means)							
Treatments	NR	SR			($kg\ ha^{-1}$)	($g\ kg^{-1}$)	($kg\ ha^{-1}$)	($g\ kg^{-1}$)	(# m^{-2})	($kg\ ha^{-1}$)
1	0	63	0.448	0.540	532	31	19	24	1151	1781
2	56	63	0.443	0.610	793	36	29	23	1253	1872
3	112	63	0.468	0.718	934	43	39	25	1118	2435
5	56	120	0.478	0.650	1215	32	38	22	1151	2242
6	112	120	0.460	0.720	1741	35	60	23	1081	2550
7	0	176	0.345	0.455	548	25	14	23	784	1494
8	56	176	0.390	0.565	1398	28	38	20	1042	1887
9	112	176	0.415	0.713	1986	30	60	21	773	2770
SED			0.071	0.067	249	3	7	1	179	323
r^2			0.37	0.85	0.36	0.26	0.52	0.03	0.02	1
CV, %			24	15	33	11	30	4	25	22

SED – standard error of the difference between two equally replicated means

df– degrees of freedom

†, *, **, significant at the .10, .05, and .01 probability levels, respectively

NR – nitrogen rate in $kg\ ha^{-1}$

SR – seeding rate in $kg\ ha^{-1}$

r^2 –correlation coefficient for each variable versus grain yield

Table 4. Analysis of variance, mean squares, and means for NDVI at Feekes (F) 5, and F7, dry biomass at F5, forage nitrogen (N) and N uptake at F5, grain N, tillers per m^2, and grain yield, for winter wheat grown with various nitrogen and seeding rates, Hennessey, Oklahoma 2010-2011.

			F5 NDVI	F7 NDVI	F5 Dry Biomass	F5 Forage Nitrogen	F5 Forage N Uptake	Grain Nitrogen	Tillers m^{-2}	Grain Yield
Source of Variation		df	(mean squares)							
Replication		3	0.0080**	0.0061	1073297	22*	1669	3	50284	94800
Seeding Rate (SR)		2	0.0038†	0.0007	2853775*	15	697	4†	179135†	10281
Nitrogen Rate (NR)		2	0.0490**	0.1115**	18326444**	307**	33940**	161**	738906**	854767**
SR*NR		4	0.0003	0.0004	944529	4	312	2	16375	57718
Residual Error		24	0.0013	0.0027	730904	7	759		1 63682	94211
			(means)							
Treatments	NR	SR			(kg ha^{-1})	(g kg^{-1})	(kg ha^{-1})	(g kg^{-1})	(# m^{-2})	(kg ha^{-1})
1	0	63	0.6320	0.5383	3987	19	76	20	1990	1307
2	56	63	0.7223	0.6503	5623	24	136	24	2404	1659
3	112	63	0.7530	0.7185	5472	30	165	27	2456	1619
4	0	120	0.6150	0.5120	4261	17	72	19	2128	1097
5	56	120	0.6993	0.6358	5819	24	137	24	2681	1513
6	112	120	0.7500	0.7268	6520	27	178	26	2498	1830
7	0	176	0.6045	0.5248	4141	18	76	20	2271	1169
8	56	176	0.6700	0.6353	6383	23	145	22	2668	1628
9	112	176	0.7273	0.7040	7482	26	199	27	2635	1629
SED			0.0255	0.0367	605	2	19	1	178	217
r^2			0.58	0.59	0.28	0.50	0.45	0.23	0.06	1
CV, %			5	8	15	12	21	5	10	21

SED – standard error of the difference between two equally replicated means

df– degrees of freedom

†, *, **, significant at the .10, .05, and .01 probability levels, respectively

NR – nitrogen rate in kg ha^{-1}

SR – seeding rate in kg ha^{-1}

r^2 –correlation coefficient for each variable versus grain yield

Table 5. Analysis of variance, mean squares, and means for NDVI at Feekes (F) 5, and F7, dry biomass at F5, forage nitrogen (N) and N uptake at F5, grain N, tillers per m^2, and grain yield, for winter wheat grown with various N and seeding rates, Lahoma, Oklahoma 2010-2011.

			F5 NDVI	F7 NDVI	F5 Dry Biomass	F5 Forage Nitrogen	F5 Forage N Uptake	Grain Nitrogen	Tillers m^{-2}	Grain Yield
Source of Variation		df	(mean squares)							
Replication		3	0.002	0.004	830620	22	709	10*	57052	333193
Seeding Rate (SR)		2	0.005	0.012	2326951*	31	1006	34**	199710*	388406
Nitrogen Rate (NR)		2	0.095**	0.131**	6871889**	121**	6715**	42**	160412†	3743173**
SR*NR		4	0.009	0.009	701493	33†	1063†	7†	64640	375356†
Residual Error		24	0.005	0.006	544167	15	444	3	54378	171019
			(means)							
Treatments	NR	SR			(kg ha^{-1})	(g kg^{-1})	(kg ha^{-1})	(g kg^{-1})	(# m^{-2})	(kg ha^{-1})
1	0	63	0.473	0.465	2339	20	50	23	1144	1651
2	56	63	0.510	0.498	2555	24	61	21	1372	1661
3	112	63	0.605	0.628	3182	27	84	26	1221	2494
4	0	120	0.403	0.358	2264	15	34	19	1224	1410
6	112	120	0.590	0.575	4435	24	106	22	1625	2803
7	0	176	0.400	0.365	2243	20	48	19	1433	1501
8	56	176	0.478	0.430	3319	18	61	19	1391	1870
9	112	176	0.610	0.610	3669	23	83	24	1639	2614
SED			0.05	0.05	522	3	15	1	165	292
r^2			0.74	0.67	0.52	0.53	0.74	0.37	0.42	1
CV, %			14	15	24	18	30	8	17	20

SED – standard error of the difference between two equally replicated means

df– degrees of freedom

†, *, **, significant at the .10, .05, and .01 probability levels, respectively

NR – nitrogen rate in kg ha^{-1}

SR – seeding rate in kg ha^{-1}

r^2 –correlation coefficient for each variable versus grain yield

FIGURES

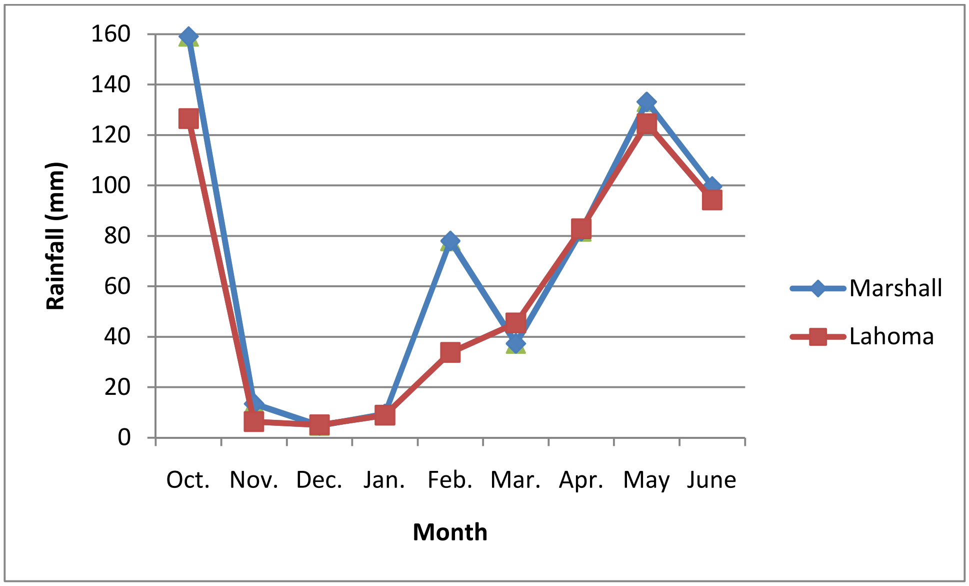

Figure 1. Total monthly rainfall during the 2009-2010 winter wheat growing season at Marshall (nearest Mesonet weather station to Hennessey) and Lahoma, Oklahoma.

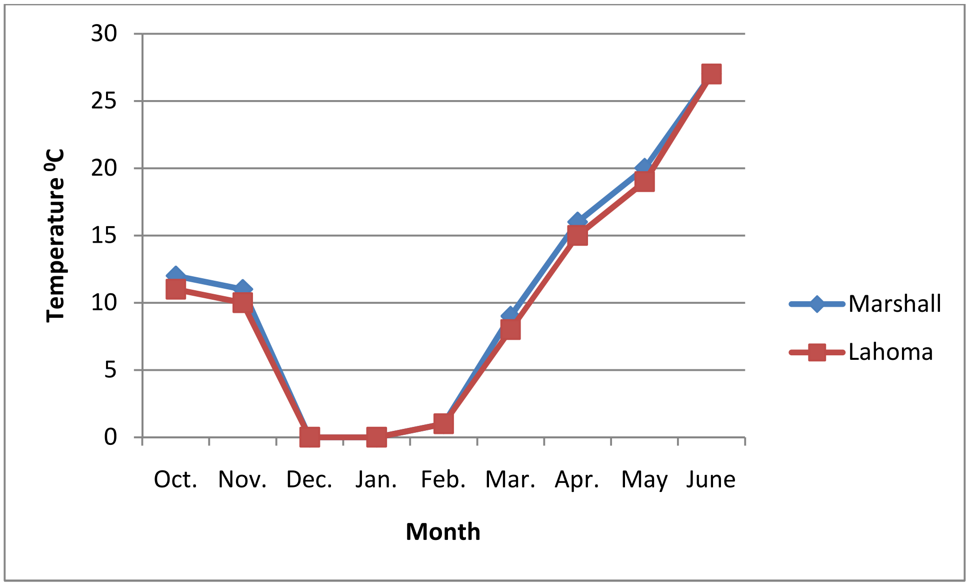

Figure 2. Average monthly air temperatures during the 2009-2010 winter wheat growing season at Marshall (nearest Mesonet weather station to Hennessey) and Lahoma, Oklahoma.

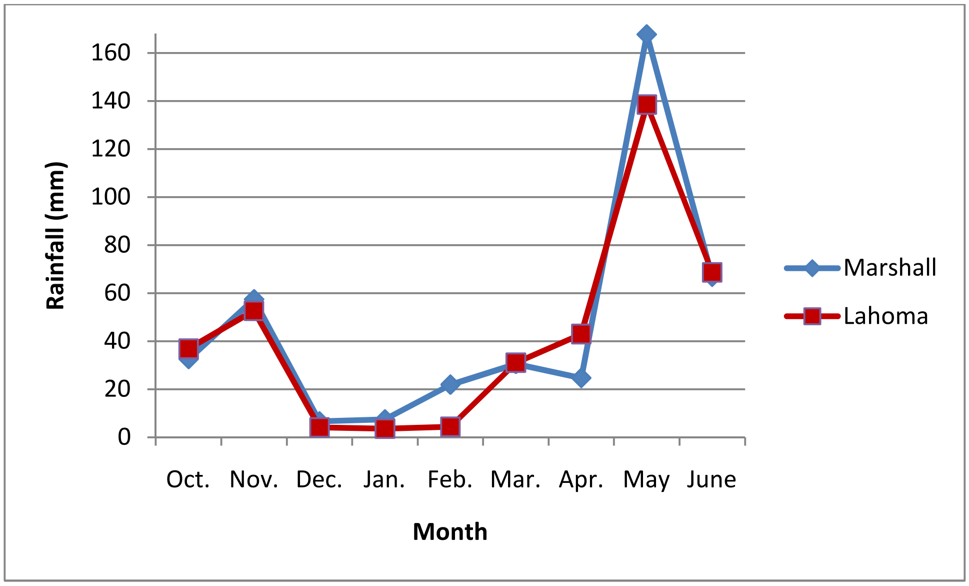

Figure 3. Total monthly rainfall during the 2010-2011 winter wheat growing season at Marshall (nearest Mesonet weather station to Hennessey) and Lahoma, Oklahoma.

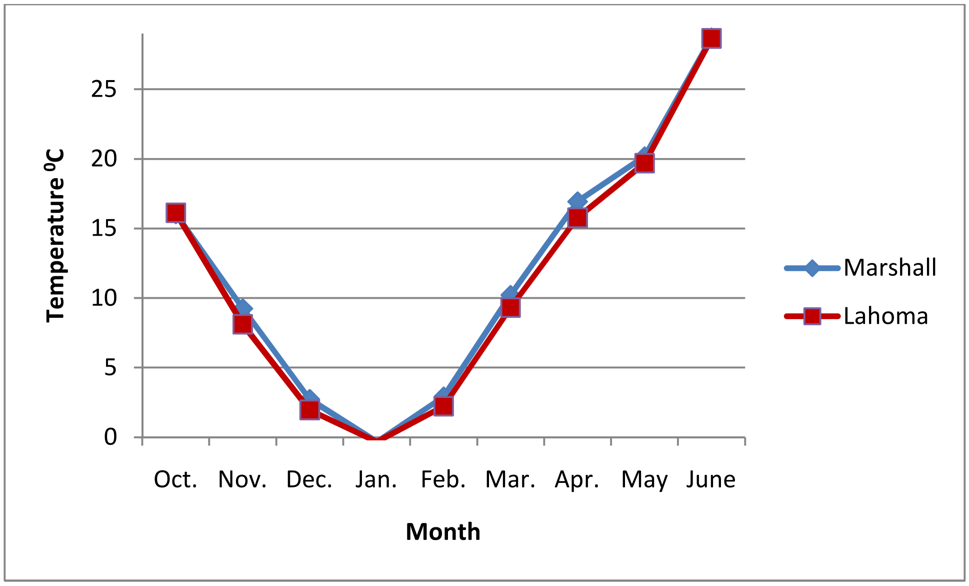

Figure 4. Average monthly air temperatures during the 2010-2011 winter wheat growing season at Marshall (nearest Mesonet weather station to Hennessey) and Lahoma, Oklahoma.

VITA

Kevin Mark Waldschmidt

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF PLANT POPULATION AND NITROGEN RATE ON SPECTRAL PROPERTIES AND GRAIN YIELD OF WINTER WHEAT (*TRITICUM AESTIVUM* L.)

Major Field: Plant and Soil Sciences

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Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: EFFECTS OF PLANT POPULATION AND NITROGEN RATE ON SPECTRAL PROPERTIES AND GRAIN YIELD OF WINTER WHEAT (*TRITICUM AESTIVUM* L.)

Pages in Study: 38 Candidate for the Degree of Master of Science

Major Field: Plant and Soil Sciences

Scope and Method of Study:

Predicted grain yields enable producers to more accurately apply the needed top-dress nitrogen (N) which leads to improved N use efficiencies and increased profit. This study was implemented to correlate and determine the relationships between winter wheat (*Triticum aestivum* L.) plant characteristics and grain yield to better predict grain yields mid-season. A two year, randomized complete block design field experiment, with three seeding rates (63, 120, and 176 kg ha^{-1}) and three N rates (0, 56, and 112 kg ha^{-1}), was established at two locations (Hennessey and Lahoma, Oklahoma) in the fall of 2009. Regression, correlations, and analysis of variance were used to determine the degree to which each variable was able to predict final grain yield.

Findings and Conclusions:

Fall tillering is important, but wheat can overcome poor fall tillering and produce an adequate yield. Early season biomass accumulation partially due to higher seeding rates, resulted in increased grain yields, and N use efficiency. Feekes 5 and 7 NDVI proved to be the best mid-season predictors of grain yield with r^2 = 0.62 and 0.68, respectively. Nitrogen uptake, biomass, and forage N were also well correlated with grain yield (r^2 = 0.61, 0.44, and 0.40 respectively) and should be used with F5 and 7 NDVI to aid in determining the ideal mid-season top-dress N rate.

ADVISER'S APPROVAL: Dr. William Raun