MAIZE GRAIN YIELD RESPONSE TO MISSES AS INFLUENCED BY NITROGEN AND PLANT POPULATION.
WINTER WHEAT GRAIN YIELD RESPONSE TO POTASSIUM IN TWO LONG-TERM EXPERIMENTS

By

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CHAPTER I

MAIZE GRAIN YIELD RESPONSE TO MISSES AS INFLUENCED BY NITROGEN AND PLANT POPULATION

Abstract

Maize (*Zea mays* L.) grain yield decline under low-input production environments has been linked to different kinds of management practices. The impact of plant spacing and plant population on grain yield has been well documented over time. However, limited research has been conducted to quantify the effects of misses or blanks on final grain yield. The objective of this study was to evaluate maize grain yield response to misses or blanks as influenced by nitrogen (N) rate and plant population. Field experiments were conducted at two locations (EFAW and LCB) over two years (2018 and 2019) in Oklahoma. The experimental design was a randomized complete block design with 3 replications. The treatment structure included eight treatments, at a target plant population of 44,460 seeds ha^{-1}. Plant spacing was 25cm, and where two N rates (0 and 70 kg ha^{-1}), and four different planting sequences (XXXXX, XX0XX, X0X0X and X000X) were evaluated. Grain N uptake, grain yield and NUE data were collected. Statistical analysis was carried out using SAS 9.4. Results from this study suggest that there is some latitude for having skips or misses within in a 5-plant sequence. Over years and experimental sites, the mean grain yield decreased significantly at 3-plant misses (X000X). With the exception for LCB 2018, plant sequences XXXXX, XX0XX and X0X0X were not significantly different when N was applied.

1.1. INTRODUCTION

Maize (*Zea mays* L.), is one of the most important food crops used worldwide alongside rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L). Maize provides about 30% of the food calories to more than 4.5 billion people in 94 countries in the developing world (Shiferaw et al., 2011). According to FAOSTAT (2013), the average maize production in the USA is 9.9 Mg ha^{-1} while in the developing countries, the average maize production is 1.8 Mg ha^{-1}. In 2013, maize production in the world exceeded one billion metric tons (FAOSTAT, 2015). Today, about 67% of the world maize production takes place in developing countries and are usually dominated by middle and/or low income farmers. This is in part why maize is regarded as one of the most important staple food crops for the livelihoods of billions of people in the developing world.

The world population projected to reach 9.8 billion by 2050 with the majority in developing countries (Bureau, 2007), requires a greater effort to improve crop production and productivity. This, therefore, suggests that there will be a significant increase in global food demand that can only be matched by improved agronomic practices. Maize production in the developing world will clearly not be an exception. Thus, yield will need to be doubled in order to sustainably feed the growing world population (Rosegrant et al., 2009). In addition to being a vital stable food crop for humans in many countries across the globe, maize is also an important source of animal feed especially in poultry, and livestock production (Delgado, 2003).

Furthermore, maize is an important source of nutritional security for millions of people in the developing world, especially in Africa and Latin America (Ranum et al., 2014; Shiferaw et al., 2011).

The nutritional value and a higher yield ceiling, makes maize generally more attractive to famers in areas with land scarcity and densely populated regions of the world. Interestingly, in many regions of the developing world, maize production is cultivated completely by hand (planting and harvesting) which leads to an average yield of about 1.8 Mg ha^{-1} (FAOSTAT, 2015). One of the reasons why the average yield in the developing world hovers near 2.0 Mg ha^{-1} may be attributed to farm size on these marginal landscapes that can be as small as 0.1 to 2 ha (Ibeawuchi et al., 2009). Also, maize planting in most developing nations is primarily achieved through the use of traditional implements such as hoes, stick planters and dribble sticks that are labor intensive, and present various health challenges (Adjei et al., 2003). While 60% of the yield improvement in maize can be attributed to the genetic characteristics of seeds, 40% of yield is still dependent on the types of management practices used (Duvick, 1992).

Globally, profit is an important concern for many produces despite the environmental factor that is somewhat unpredictable. Today, many producers have prioritized optimum yield with modest amounts of agricultural inputs. Nonetheless, misses or blanks are a common source of uneven spacing and often caused by the inability of planters to drop seeds, during planting or due to late emergence. Misses or blanks within the plant stand can be attributed to issues like soil compaction, seed quality, planting depth and soil moisture level (Diaz-Zorita et al., 2005; Gupta et al., 1988). Previous studies have revealed that plant stand is vital to determine final grain yield (Tollenaar and Wu, 1999), hence plant uniformity during the growing season may serve as an advantage for higher grain yields under good management practices. The importance of homogeneous plant stand establishment cannot be over emphasized for achieving maximum corn grain yield. The Oklahoma State University (OSU) Greenseeder hand planter was used for this experiment. The Greenseeder hand planter singulates seeds for increased plant-stand-homogeneity, unlike the heterogeneity found when 2 to 3 seeds are planted per strike using metal tipped sticks and that is common throughout the developing world. Although, this hand planter was designed to meet food demands for developing countries where maize production is mostly carried out on a small scale and lower yields, it is unique and its ability to drop one seed at a time made it a viable tool for this study.

The Greenseeder hand planter is designed in a way that it places one seed at a time per planting hole (singulation). It is made up of polyvinyl chloride round pipe (PVC) with a diameter of 5.8 cm attached to a metering delivery system (Omara et al., 2016). The metering system consists of aluminum, internal plastic housing, catchment drum, spring and brush. On the end of the metering system is the tip in a shovel shape, which can penetrate into the soil (5cm depth) depending on the force applied by the operator. The Greenseeder hand planter offers several advantages over the traditional hand planters including reduced producer exposure to chemically treated seeds, decreased soil surface erosion due to increased homogeneity of plants, and mid-season N placement among others (Dhillon et al., 2018). The OSU Greenseeder hand planter can also lead to increased N uptake via placing the fertilizer immediately adjacent to each plant when N is applied mid-season. It is important to place the fertilizer beneath the surface where immediate fertilizer-soil contact takes place. The most commonly used N source in many nations is urea (46-0-0) and it is primarily broadcast applied to the soil surface. This conventional method increases the likelihood of N loss via ammonia volatilization (Terman, 1980). This loss can be reduced by using OSU Greenseeder planter which places N below the soil surface. Use of the Greenseeder hand planter can also assist with increasing grain yields thus improving N use efficiency (Dhillon et al., 2018).

1.2. OBJECTIVE

The objective of this study was to examine maize grain yield response to misses or blanks as influenced by N rate and plant population.

1.3. LITERATURE REVIEW

In order to meet the growing demand for maize and increase crop productivity under a variable and changing climate, more holistic approaches need to be defined (Shiferaw et al., 2011). In the past, many scientists and researchers have evaluated various approaches on how to increase or maximize maize grain yield through many management practices. Unlike some crops, plant-to-plant spacing for maize significantly influences grain yield (Omara et al., 2016). Mattera et al. (2013), described seed spacing as the spatial distribution of plants which affects plant canopy structure, light interception, radiation use efficiency, biomass and grain production. Wade et al. (1988), reported that the nutrient uptake and grain yield of maize is dependent on the plant population per square meter and the spacing of plants within a square meter. (Wade et al., 1988) further observed and reported that an uneven plant spacing compared to uniform spacing at the same population density can significantly reduce grain yield. However, depending on the management practices during planting, plant spacing can pose a negative or positive threat to yield.

1.3.1. Effect of Plant Spacing and Misses on Maize Grain Yield.

In the past, researchers have shown that one of the factors affecting yield of maize is plant spacing. As a result of uneven plant spacing, an average of 158 kg ha^{-1} yield loss was found for every 2.54 cm increase in standard deviation of within row plant distribution (Nielsen, 1991). In contrast, Lauer and Rankin (2004) found the effects of plant spacing (unevenness) on corn yield to be insignificant. Also, a steady decrease in grain yield was reported as a result of increased plant spacing variability (Krall et al., 1977).

The diverse outcomes regarding grain yield response to plant spacing may be attributed to plant density and the actual plant to plant spacing measurement.

Misses or blanks is a common source of uneven spacing, and often caused by the inability of planters to drop seeds during planting or failure of seed to form a plant. Johnson and Mulvaney (1980) reported high reduction in grain yield when variability occurred due to big gaps (plant spacing) rather than smaller gaps, and yields were similarly low under low plant population compared to higher populations. Similar results were recorded by Lauer and Rankin (2004) where grain yield was reduced at 1.06% cm^{-1} standard deviation as plant spacing variation increases above 12.0 cm. Nonetheless, the effect of misses or blanks on maize grain yield should be estimated more accurately due to inconsistent findings from previous research work.

1.3.2. Effect of Nitrogen Fertilizer on Maize Grain Yield

The effects of N in increasing grain yields cannot be overstated. Research has shown that the proper application of N fertilizer (urea) can increase N use efficiency and can also increase crop yields. According to Ciampitti and Vyn (2011), N uptake in maize during the growing season strengthens the crop through the vegetative stage and reaches a maximum close to silking. Dietz and Harris (1996) reported that maize has a high N requirement and further concluded that the high N rate requirements can increase the chance of N loss if not applied properly. The global N use efficiency for cereal crops and that includes maize has been estimated to be 33% (Raun and Johnson, 1999). Also, Francis et al. (1993) reported 73% of the total N applied to maize can be lost through different pathways. However, in order to maximize grain yields, and reduce environmental risk, the adoption of best management practices is needed. This is also attributed to the 4Rs application concept; the application of the right nutrient source, applying at the right time, applying at the right place and applying at the right time (Bruulsema et al., 2009; Roberts, 2010).

1.4. MATERIALS AND METHODS

1.4.1. Study Area and Weather Features

Field experiments were conducted at two locations in Oklahoma (OK), EFAW and Lake Carl Blackwell. EFAW is located in Stillwater, OK (36°08'12.46"N, 97°06'26.55"W) on an Ashport silty clay loam (fine-silty, mixed, superactive, thermic Fluventic Haplustoll). Lake Carl Blackwell is located eight miles west of Stillwater on Highway 51 (36°08'51"N, 97°17'20"W) and is a Port silt loam soil (fine-silty, mixed, thermic Cumulic Haplustoll). Average temperature and total rainfall at each location for the growing seasons (April to September) in 2018 and 2019 were obtained from Mesonet (www.mesonet.org). EFAW received a total of 604 and 1075mm of rainfall in 2018 and 2019 growing seasons respectively, while LCB received 635 and 1032 mm of rainfall in 2018 and 2019 respectively (Table 1.1). Air temperature averaged 23 and 24°C in 2018 and 2019 at EFAW respectively, while at LCB location, average temperature was 23°C in both 2018 and 2019 from planting to harvest (Table 1.1).

1.4.2 Experimental design and management

This experiment was carried out using a randomized complete block design, eight treatments with three replications (Figure 1). The eight treatments used in this study consisted of two levels of N fertilizer (0 and 70 kg N ha^{-1}) and -5-plant sequences at four levels of missing pattern (XXXXX, XX0XX, X0X0X and X000X). This 5-plant sequence was a planting scenario where the check treatment received complete planting (XXXXX) without any misses; ‘X’ represents a planted seed and ’0’ represents a miss or skip (Figure 1). Maize was planted in the summer of 2018 using the OSU hand planter at different plant spacing and sequences to evaluate the maize grain yield response to misses. The plot size for this experiment was 3.048 x 6.096 m and an alley of 1.524 m and each plot consisted of four rows of which the two middle rows were harvested. The plant population was 52,632 seeds ha^{-1}, 76cm row spacing and a plant spacing of 25cm.

Maize planting was carried out manually in order to effectively observe the impact of misses. Nitrogen was broadcast applied at 70 kg N ha^{-1} to four of the treatments while the other four received 0 kg N ha^{-1}.

1.4.3. Data Collection and Analysis

Plant harvest was accomplished manually by hand, the middle two rows of each plot were harvested. Maize ears were dried using a forced air-dry oven maintaining 75 °C for 7 days. The dried ears with the grain were shelled using a hand mechanical sheller. Grain yield for each plot was adjusted to 12.5% moisture content and recorded before grinding and milling for further N analysis. Dried maize grain was ground via being rolled in a glass bottle having stainless steel rods mixed in with the sample for 24 hours to obtain a sample material fine enough to pass a 1 mm sieve. The ground grain sample was then taken to the laboratory for N analysis.

The total N in the grain was determined using LECO Truspec CN dry combustion analyzer (Schepers et al., 1990). Approximately 150 mg from each treatment was sampled, weighed and wrapped in an aluminum foil for combustion in the LECO analyzer at a temperature of about 950℃ to obtain grain N concentration (%). For each treatment, grain N uptake was then determined by multiplying the grain N concentration with the grain yield (Equation 1)

Grain N uptake = Harvested yield (HY) x Percent grain N content (%NC) Equation 1

Nitrogen use efficiency was calculated using the difference method (Raun and Johnson 1999) which utilizes the following formula (Equation 2):

$$NUE\ (\%) = \frac{(Grain\ N\ uptake\ treated - Grain\ N\ uptake\ control)}{N\ \ applied} \times 100$$

Equation 2

Statistical analysis was accomplished using SAS (2012) 9.4 Analysis of variance was performed using PROC GLM to analyze the effect of misses on maize grain yield, N content, N uptake and NUE. Treatment means were separated using LSD ($\boldsymbol{\alpha}$ = 0.05).

1.5. RESULTS AND DISCUSSION.

1.5.1. Maize Grain Yield

Analysis of variance (ANOVA) for maize grain yield in 2018 and 2019 indicated a significant difference (P<.0001) between treatments (Table 1.2). Similarly, ANOVA also showed a significant difference between years (P=0.0041), location (P<.0001) and the interaction between year and location (P=0.0003) for maize grain yield (Table 1.2). No significant difference was observed between replications (Table 1.2).

In 2018 at LCB, ANOVA showed that there was a significant effect of planting sequence and N rate on maize grain yield (p=0.0009; Table 1.3). At this location, the planting sequence significantly affected grain yield (p<.0001) (Table 1.2). The treatment combination with the highest yield was a complete sequence (XXXXX) at an N rate of 70 kg ha^{-1} (Table 1.3). This yield was 36.1% higher than the yield for a treatment combination that had the same sequence but with no N applied (0-N) (Table 1.3). The lowest yield was found with a sequence of 3-misses (X000X) and 0-N, and had a yield that was 29% lower than the yield for a similar sequence but with 70 kg N (Table 1.3). Overall, Grain yields ranged between 2.97 and 7.63 Mg ha^{-1} at LCB in 2018 (Table 1.3). The effect of N on grain yield was observed at this site in most of the planting sequences where N was applied.

In 2018 at EFAW, overall ANOVA showed that there was a significant effect of sequence (p=0.0170) on maize grain yield (Table 1.3). The complete sequence with 70 kg N ha^{-1} combination observed the highest yield at about 5.57 Mg ha^{-1}, and where this yield was 25%

higher than the same sequence at 0 kg N ha^{-1}(Table 1.3). The lowest yield (3.03 Mg ha^{-1}) was found with a sequence of 3-misses (X000X) and at N rate of 70 kg ha^{-1}.

Overall, maize grain yield ranged from 3.03 to 5.57 Mg ha^{-1} (Table 1.3). Maize grain yield was lower at this site compared to LCB, and this low yield can be attributed to a difference in soil type at LCB being medium textured, and may allow it to be well-drained and promote growth of maize roots when compared to fine-textured silty clay loam at EFAW or perhaps differences in rainfall received at both locations. (Table 1.1).

In 2019, overall ANOVA revealed that there was a significant effect of planting sequence and N rate on maize grain yield at LCB (p<.0001; Table 1.3). The treatment combination with the highest yield (7.61 Mg ha^{-1}) was observed with a complete sequence (XXXXX) and at an N rate of 70 kg ha^{-1} (Table 1.3) This yield was 30% higher than the yield for a treatment combination that encompassed the same sequence at 0 kg N ha^{-1} (Table 1.3). The lowest yield (3.12 Mg ha^{-1}) was found with a sequence of 3-misses (X000X) and 0 kg N ha^{-1} combination, however this yield was not significantly different for a similar sequence (X000X) at 70 kg N (Table 1.3). The wider spacing between plants showed only limited differences. Overall, Grain yields had a range of 3.12 to 7.61 Mg ha^{-1} at LCB in 2019 (Table 1.3).

At EFAW, overall ANOVA indicated that there was a significant effect of planting sequence and N rate on maize grain yield in 2019 (p=0.0064; Table 1.3). The treatment combination with the highest yield (4.12 Mg ha^{-1}) was observed with a complete sequence (XXXXX) and at N rate of 70 kg ha^{-1} (Table 1.3) This yield was 46% higher than the yield for a treatment combination that encompassed the same sequence at 0 kg N ha^{-1} (Table 1.3). The lowest yield (2.22 Mg ha^{-1}) was found with two different treatments, a complete sequence (XXXXX) and 3-misses (X000X) at 0 and 70 kg N ha^{-1} respectively (Table 1.3). Overall, grain yields ranged between 2.22 and 4.12 Mg ha^{-1} at EFAW in 2019 (Table 1.3). This result mirrored LCB 2019 except where the lowest grain yield was obtained with the 3-misses plant sequence (X000X) at 70 kg N ha^{-1}.

In general, these findings indicated that maize grain yield increased with a complete sequence (XXXXX) when N was applied at 70 kg N ha^{-1}. The highest grain yield across sites and years was notably associated with this sequence. As would be expected this suggests that over the cropping years and sites, sequence XXXXX was the best planting sequence when N is applied at 70 kg N ha-^{1}. However, looking at the general significant level among sequences where N was applied at 70 kg ha^{-1} with the exception of LCB 2018, treatments 5 (XXXXX), 6 (XX0XX), and 7 (X0X0X) were not significantly different. This could imply that a producer with sufficient N availability may not need to replant with these levels of plant sequence and plant population.

The N influence on yield could be linked with previous studies that have been documented showing the ability of N fertilization to increase maize grain yield (Oyebiyi et al., 2019; Wienhold et al., 1995). On the other hand, findings also revealed with exception to 2019 LCB, that maize grain yield increased with a 1-miss sequence (XX0XX) when N was not applied (0 kg N ha^{-1}). This suggests that producers living in regions with zero or no N availability may optimize maize grain yield with this plant sequence (XX0XX). This is to a certain degree similar to findings from Lauer and Rankin (2004) and Liu et al. (2004) that reported the value of neighboring plants and the compensation for skips or misses (gaps), thus reducing the negative impact of no emergence on maize grain yield.

1.5.2. Maize Grain N Concentration (%)

Combined ANOVA did not show a significant difference in grain N concentration (GNC) between the different planting sequences (p=0.09) (Table 1.2). However, at EFAW ANOVA in 2018 indicated a significant difference in GNC between planting sequences (p=0.01). Optimum maize GNC was observed with X0X0X planning sequence at 70 kg N ha^{-1} though there were no significant differences between plant sequences that received 70 kg N ha^{-1} (Table 1.4). The lowest GNC was recorded with a complete plant sequence (XXXXX) at 0 kg N ha^{-1}. As yields were higher there was likely a dilution effect whereby N concentration decreased with the higher biomass produced.

In 2019, overall ANOVA showed a significant effect of treatment on grain N (p=0.0009) (Table 1.4). The highest grain N was recorded with "X000X" plant sequence at 70 kg N ha^{-1} while the lowest grain N was observed with a complete plant sequence (XXXXX) at 0 kg N ha^{-1}. Grain N concentration for X000X and 70 kg N ha^{-1} was 34% greater than the result observed under XXXXX and 0 kg N ha^{-1} These findings in 2019 mirrored the 2018 results (Table 1.4).

At LCB, ANOVA in 2018 indicated that there was no significant difference in GNC among the plant sequences (p=0.9935) (Table 1.4). The highest maize GNC was observed with XX0XX plant sequence at 70 kg N ha^{-1} though there were no significant differences between plant sequences either at 0 or 70 kg N ha^{-1} (Table 1.4). Carryover N may have been responsible for the level of grain N recorded in treatments that had received 0 kg N ha^{-1} (Table 1.4). The similar GNC observed across the different treatments averaged 1.1%.

In 2019, overall ANOVA showed no significant differences in GNC (p=0.02) between plant sequences (Table 1.4). The highest grain N was observed with "X000X" plant sequence at 70 kg N ha^{-1} while the lowest GNC was observed with a complete plant sequence (XXXXX) at 0 kg N ha^{-1}. Again, these findings were consistent with results from EFAW in 2018 and 2019 (Table 1.4).

1.5.3. Grain N Uptake

At LCB, ANOVA in 2018 for grain N uptake indicated an overall significant difference (p=0.0099) between planting sequences (Table 1.5). The highest grain N uptake was observed with the complete plant sequence (XXXXX) at 70 kg N ha^{-1}. At this level, N uptake was 41% higher than a similar sequence without N application (Table 1.5). The lowest grain N uptake was obtained with the plant sequence (X000X) at 0 kg N ha^{-1}. This grain N uptake was 63% lower than the highest grain N uptake obtained at this site in 2018.

In 2019, ANOVA at LCB for grain N uptake showed an overall significant difference (p<.0001) between planting sequence (Table 1.5). Results for this year were similar to those of 2018, where the highest grain N uptake was obtained with a complete sequence at 70 kg ha^{-1} and the lowest with the plant sequence (X000X) at 0 kg N ha^{-1}.

At EFAW, ANOVA in 2018 for grain N uptake indicated a significant difference (p=0.0170) between planting sequence (Table 1.5). The highest grain N uptake was observed with the complete plant sequence (XXXXX) at 70 kg N ha^{-1}. At this level, N uptake was 37% higher than a similar sequence without N application that had a grain N uptake of ……kg ha^{-1} (Table 1.5). The lowest grain N uptake was obtained with the plant sequence (X000X) at 70 kg N ha^{-1}. This grain N uptake was similar to the one obtained at same plant sequence (X000X) but with no N applied (Table 1.5).

In 2019, ANOVA at EFAW for grain N uptake indicated an overall significant difference (p=0.0064) between planting sequence (Table 1.5). The highest grain N uptake was observed with the complete plant sequence (XXXXX) at 70 kg N ha^{-1}. At this level, N uptake was 58% higher than a similar sequence without N application (Table 1.5). Also, the lowest grain N uptake was obtained with this same plant sequence (XXXXX) at 0 kg N ha^{-1}. In general, low grain N uptake was observed at EFAW compared with LCB, and this was true for both years (2018 and

2019). This low grain N uptake may be attributed to within site variability (Solie et al., 1996) or perhaps soil type and environmental factors.

1.5.4. Grain N Use Efficiency

The overall analysis of variance for both locations showed a significant difference (p=0.003) in N use efficiency (NUE) between sequence in 2018 and 2019 (Table 1.2). However, in 2018 and 2019, analysis of variance did not indicate a significant difference (p=0.0652 and p=0.4085 respectively) in NUE between planting sequence at LCB (Table 1.6). In contrast to LCB, ANOVA showed a significant effect of sequence on NUE at EFAW in 2018 and 2019 (p=0.0335 and p=0.0470 respectively) in NUE between planting sequence. The complete sequence (XXXXX) and 1-miss sequence (X0X0X) obtained the highest NUE at both sites in 2018 and 2019 (Table 1.6).

1.6. CONCLUSION

The main purpose of this chapter of the dissertation was to evaluate maize grain yield response to misses or blanks as influenced by N rate and plant population. Data were collected and analyzed for plant spacing of 25cm, and where two N rates (0 and 70 kg ha^{-1}), and four different planting sequences (XXXXX, XX0XX, X0X0X and X000X) were examined. Results from the study showed that the complete sequence (XXXXX) combined with N application (70 kg N ha^{-1}), obtained the highest maize grain yield across all sites and years. However, this highest yield was not significantly different from sequence XX0XX and X0X0X when N was applied. These findings suggest that producers may not necessarily have to replant at these levels of misses when fertilizer N is not limited. Additionally, the sequence with one miss (XX0XX) obtained the highest grain yield among other plant sequences at 0 kg N ha^{-1} across most sites and cropping seasons. Producers living in regions with limited access to fertilizer N may still benefit by having homogenous stands with limited number of misses. Furthermore, results suggest that there is some latitude for having only one miss. Lower populations should likely be evaluated based on these observations. Similarly, grain N uptake appears to be higher for a complete sequence with 70 kg N ha^{-1} applied. This was, however, similar to grain N uptake associated with other sequences that received the same N rate with the only exception being X000X. This implies that having one or two misses per 5-plant sequence might not substantially reduce grain yield and N uptake when N is applied at the right amount. These findings also revealed a possibility of saving seeds by reducing plant population while maintaining maize grain yield levels.

Table 1.1. Total rainfall and average temperature during the growing season (April to September) in 2018 and 2019 at EFAW, Stillwater and Lake Carl Black well (LCB) Oklahoma.

Month	Rainfall (mm)		Temperature ^{0}C	
	2018	2019	2018	2019
		EFAW, Stillwater		
April	52.3	134.4	12.3	16.1
May	98.6	439.4	24.0	20.1
June	151.6	106.9	26.6	26.5
July	79.2	19.3	27.8	28.2
August	142.0	209.8	26.2	27.0
September	79.8	165.4	22.9	26.1
		LCB		
April	51.1	111.0	12.0	15.6
May	75.7	413.5	23.7	19.7
June	214.9	102.6	26.3	26.1
July	71.4	33.3	27.1	27.9
August	151.1	208.0	25.9	26.6
September	70.6	163.6	22.6	22.3

Table 1.2: General ANOVA table for the effect of treatments, N rates, year, locations and their interactions on maize grain yield, grain N, grain N uptake, and NUE at EFAW and LCB in 2018 and 2019

SoV	Grain yield		Grain N		Grain N uptake		NUE	
	F	P	F	P	F	P	F	P
Sequence	13.98	<.0001	1.88	0.0932	9.05	<.0001	6.22	0.003
Replication	2.55	0.0854	3.23	0.0445	1.13	0.3306	0.92	0.4121
Year (Y)	8.86	0.0041	17.05	<.0001	12.18	0.0009	0.03	0.864
Location (L)	63.25	<.0001	72.94	<.0001	87	<.0001	6.7	0.0164
Y x L	14.45	0.0003	113.4	<0.001	37.76	<.0001	2.85	0.105

SoV - Source of Variance

Table 1.3. Mean maize grain yield for planting sequence and N fertilizer at LCB and EFAW Stillwater, Oklahoma 2018 and 2019.

Treatment	N Rate ($kg\ ha^{-1}$)	Plant sequence	Grain Yield ($Mg\ ha^{-1}$) at LCB				Grain Yield ($Mg\ ha^{-1}$) at EFAW			
			2018		2019		2018		2019	
			mean	±S.E	mean	±S.E	mean	±S.E	mean	±S.E
1	0	XXXXX†	4.83^{BC}‡	0.22	5.32^{CD}	0.34	4.17^{AB}	1.07	2.22^{D}	1.08
2	0	XX0XX§	5.37^{BC}	0.21	4.95^{D}	0.66	4.66^{AB}	0.39	3.56^{AB}	0.30
3	0	X0X0X	5.52^{BC}	0.52	4.31^{ED}	0.29	3.75^{AB}	1.68	3.05^{BCD}	0.34
4	0	X000X	2.97^{D}	0.01	3.21^{E}	0.24	3.51^{AB}	1.06	2.48^{DC}	0.38
5	70	XXXXX	7.63^{A}	0.07	7.61^{A}	0.68	5.57^{A}	0.67	4.12^{A}	0.53
6	70	XX0XX	4.68^{BC}	0.21	6.20^{BC}	0.65	5.34^{A}	1.03	3.41^{ABC}	0.47
7	70	X0X0X	5.72^{B}	0.97	6.80^{AB}	0.62	5.10^{AB}	0.70	3.7^{AB}	0.60
8	70	X000X	4.20^{C}	0.96	3.60^{E}	0.85	3.03^{B}	1.01	2.22^{D}	0.18
Pr > F			0.0009		<.0001		0.0170		0.0064	
C.V (%) ¶			10.40		10.88		23.61		18.21	

† X- represents one seed in a linear sequence of maize plants
‡ Means followed by the same letters within a column were not significantly different.
§ 0-represents a miss or lack of a maize plant within the specified 5-plant sequence
¶ C.V is the coefficient of variation.

Table 1.4. Mean maize grain N concentration for planting sequence and N fertilizer at LCB and EFAW Stillwater, Oklahoma 2018 and 2019.

Treat ment	N Rate (kg ha^{-1})	Plant sequence	Grain N (%) at LCB		Grain N (%) at EFAW	
			2018	2019	2018	2019
			mean	mean	mean	mean
1	0	XXXXX†	1.30^{A}‡	1.35^{C}	1.22^{C}	0.90^{CD}
2	0	XX0XX§	1.27^{A}	1.45^{ABC}	1.23^{C}	1.08^{B}
3	0	X0X0X	1.33^{A}	1.39^{BC}	1.32^{BC}	0.89^{D}
4	0	X000X	1.37^{A}	1.40^{BC}	1.31^{BC}	1.14^{AB}
5	70	XXXXX	1.36^{A}	1.52^{AB}	1.44^{AB}	1.04^{BC}
6	70	XX0XX	1.37A	1.56^{AB}	1.50^{A}	1.01^{BCD}
7	70	X0X0X	1.35^{A}	1.58^{A}	1.53^{A}	1.13^{AB}
8	70	X000X	1.35^{A}	1.61^{A}	1.51^{A}	1.24^{A}
Pr > F			0.9935	0.0150	0.0008	0.0009
C.V (%) ¶			12.08	6.0364	6.1728	7.7032

† X- represents one seed in a linear sequence of maize plants
‡ Means followed by the same letters within a column were not significantly different.
§ 0-represents a miss or lack of a maize plant within the specified 5-plant sequence
¶ C.V is the coefficient of variation.

Table 1.5: Mean Grain N uptake for planting sequence and N fertilizer at LCB and EFAW Stillwater, Oklahoma 2018 and 2019.

Treatment	N Rate ($kg\ ha^{-1}$)	Plant sequence	Grain N uptake ($kg\ ha^{-1}$) at LCB				Grain N uptake at ($kg\ ha^{-1}$) EFAW			
			2018		2019		2018		2019	
			mean	±S.E	mean	±S.E	mean	±S.E	mean	±S.E
1	0	XXXXX †	65.29^{CB}‡	0.22	73.08^{C}	5.14	50.60^{B}	5.99	18.01^{D}	4.61
2	0	XX0XX§	72.35^{B}	7.02	71.65^{C}	4.22	57.22^{AB}	3.27	37.42^{ABC}	1.61
3	0	X0X0X	75.21^{B}	0.79	59.86^{CD}	4.43	49.08^{B}	12.21	27.09^{DC}	2.55
4	0	X000X	40.25^{C}	4.47	47.38^{D}	3.49	46.28^{B}	9.12	28.57^{DC}	4.33
5	70	XXXXX	110.80^{A}	14.5	115.69^{A}	6.63	80.88^{A}	9.78	42.68^{A}	2.44
6	70	XX0XX	65.23^{CB}	4.89	93.163^{B}	7.23	79.97^{A}	8.61	34.76^{ABC}	4.06
7	70	X0X0X	77.66^{B}	2.33	105.56^{AB}	3.42	77.96^{A}	4.52	41.92^{BA}	4.58
8	70	X000X	57.82^{CB}	6.24	58.45^{CD}	7.35	45.29^{B}	7.50	30.25^{BC}	1.96
Pr > F			0.0099		<.0001		0.0170		0.0064	
C.V (%) ¶			16.18		11.85		23.61		18.21	

† X- represents one seed in a linear sequence of maize plants
‡ Means followed by the same letters within a column were not significantly different.
§ 0-represents a miss or lack of a maize plant within the specified 5-plant sequence
¶ C.V is the coefficient of variation.

Table 1. 6. Mean nitrogen use efficiency (NUE) for planting sequence and N fertilizer at LCB and EFAW Stillwater, Oklahoma 2018 and 2019.

Treatment	N Rate (kg ha^{-1})	Plant sequence	NUE (%) at LCB		NUE (%) at EFAW	
			2018	2019	2018	2019
			mean	mean	mean	mean
1	0	XXXXX†	-	-	-	-
2	0	XX0XX§	-	-	-	-
3	0	X0X0X	-	-	-	-
4	0	X000X	-	-	-	-
5	70	XXXXX	53.40^{A}‡	65.81^{A}	43.26^{A}	38.71^{A}
6	70	XX0XX	39.10^{A}	25.73^{A}	44.64^{A}	-3.31^{B}
7	70	X0X0X	52.58^{A}	63.26^{A}	41.26^{A}	21.19^{AB}
8	70	X000X	32.65^{A}	34.78^{A}	-1.41B	2.40^{B}
Pr > F			0.0652	0.4085	0.0335	0.0470
C.V (%) ¶			57.85	48.21	53.87	89.82

† X- represents one seed in a linear sequence of maize plants
‡ Means followed by the same letters within a column were not significantly different.
§ 0-represents a miss or lack of a maize plant within the specified 5-plant sequence
¶ C.V is the coefficient of variation.

Plant Sequence Trial

Plot Size: 10’ x 20’
Alley: 10’
Crop: Maize
Population: 52,632 seeds/ha
Row Spacing: 30’’ (76cm)
Plant Spacing:11.6’’(25cm)

Treatment	5-plant Sequence	N, kg/ha	Population seeds/ha
1	XXXXX	0	53,000
2	XX0XX	0	35,000
3	X0X0X	0	26,000
4	X000X	0	13,000
5	XXXXX	70	52,632
6	XX0XX	70	35,000
7	X0X0X	70	26,000
8	X000X	70	13,000

Rep 3	8	5	2	7	4	6	9	1	3	10	12	11
Rep 2	4	9	5		2	1	10	6	3	8	11	12
Rep 1	2	9	6	1	3	10	4	8	5	7	12	11

Figure 1.1: Plot plan illustrating both field layout and treatment structure

CHAPTER II

WINTER WHEAT (*TRITICUM AESTIVUM* L.) GRAIN YIELD RESPONSE TO POTASSIUM IN TWO LONG-TERM EXPERIMENTS

Abstract

Potassium (K) is the third most important plant nutrient element after nitrogen (N) and phosphorus (P). Surface and subsurface layers of the soil within the profile contain about 3 to 100 Mg ha^{-1} of total K, much of which (98%) is bound in mineral form, while only 2% is in soil solution and exchangeable form. In winter wheat, many studies have been conducted on grain yield response to K fertilization as affected by soil properties, methods of applications and the availability in soils. However, little information is available on the relationship of wheat grain yields response to K fertilization in a long-term experiment. The aim of this study was to examine winter wheat grain yield in long term experiments as influenced by K. Data from two long-term experiments 502 and 222 located at Lahoma and Stillwater OK, respectively were used. Two treatments (10 and 12) from experiment 502 (E502) and four treatments (8, 9, 11 and 12) from experiment 222 (E222) were evaluated. These treatments were also examined for K response to water stressed conditions. Statistical analysis was accomplished using SAS 9.4, and orthogonal contrasts were used to determine the effect of K on grain yield. Results revealed soil K is currently at sufficient levels and any additional K fertilization might not be of any benefit for this region.

2.1 INTRODUCTION

Potassium (K) is the seventh most abundant element in earth's crust and remains an important nutrient for all living organisms. In plants, K is the third most essential nutrient after N and P (Manning, 2010). Potassium is well-known for its function in cell division, growth, disease resistance and drought tolerance in plants. This unique quality as an essential plant nutrient may be attributed to its ability to form free, positively charged K^+ ions. In cropping system, K increases water use efficiency, support plant biological systems and fiber properties such as micronaire, length, and strength (Brar and Tiwari, 2004). Potassium plays a major part in photophosphorylation, turgor maintenance, photo assimilate transport from spring tissues via phloem to sink tissues, stress tolerance and enzyme activation in plants (Usherwood, 2000). In addition, K is mobile in plants and can be translocated against solid electrical and chemical gradients (Brar and Tiwari, 2004). During crop development and growth, K can boost water uptake in plants and maintain cell turgor, stomatal opening and closing, and osmoregulation (Cakmak, 2005; De La Guardia and Benlloch, 1980).

In soil, among the major and secondary elements, K is also the most abundant (Reitemeier, 1951). Soil K content often depends on agricultural activities, and leaching of K especially in sandy soils (Rengel and Damon, 2008). The concentration of K in the soil differs, and constitutes approximately 2.5% of the lithosphere. The concentration of K in soils ranges from 0.04 to 3% (Sparks and Huang, 1985). However, the majority of K in the soil is not plant available. Potassium uptake or availability can be classified in four categories; soil solution K, structural K, exchangeable K and non-exchangeable K (Syers, 1998).

However, the exchangeable K among different pools of the soil largely depends on the concentration of other macronutrients in the bulk solution (Yanai et al., 1996). Nonetheless, the discharge of transferrable K to the bulk solution is prolonged in comparison to the rate of K^+ acquisition by plants (Sparks and Huang, 1985). In wheat (*Triticum aestivum* L), many studies have been reported on grain yield response to K fertilization as affected by soil properties, methods of application and the availability in soil (Huang et al., 2009; Schneider et al., 2003; Vyn and Janovicek, 2001; Zhang et al., 2011). However, little information is available on the relationship between wheat grain yield and K fertilization in long-term continuous winter wheat experiments. Das et al. (2019); De-shui et al. (2007) demonstrated that long-term application of K could be beneficial for improving winter wheat grain yield. Das et al. (2019) also noted that continuous farming without K fertilization depletes K stock in the soil, making it insufficient to meet crop requirement. However, evidence elsewhere showed that it is possible to sustain yield without application of K due to the inherent ability of some soils to supply enough K to meet winter wheat demand (Kunzová and Hejcman, 2009). These seemingly contradictory studies provide further ground for exploration of winter wheat response to K application. This could potentially lead to unearthing of evidence necessary to build the wealth of knowledge regarding the benefit of K fertilization under long-term winter wheat experiments.

1.2 OBJECTIVE

The objective of this study was to examine wheat grain yield response to long term K fertilization under rain-fed conditions.

2.2. LITERATURE REVIEW

2.2.1. Role of Potassium in Plants and Soil

According to the International fertilizer association (IFA, 2005), global utilization of K has improved at an average rate of 4.4% yearly over the period of 1999 to 2005. About 2.1 to 2.3% of the total earth's crust is estimated to be K, making it the seventh most abundant element (Havlin et al., 2005; Schroeder, 1978; Zörb et al., 2014). Approximately 3.7 billion tons of K as a K_2O equivalent are remaining in the reserves worldwide (Jasinski, 2008). However, the higher application of nitrogen (N) and phosphorus (P) fertilizers often yield to an imbalance of N, P, and K in plant and soil systems (Dobermann et al., 1996). Considering all macronutrients, K is applied at much lower rates, and often only 35% of the total K assimilated is returned to the soil (Smil, 1999).

One of the major benefits of K in plants and soil is its efficiency to assist with pest and disease resistance, improving photosynthesis, and interestingly, withstand stability between monovalent and divalent cations (Brar and Tiwari, 2004). Additionally, K helps with plant turgor, stress tolerance, enzyme stimulation, plant mobility, is vital for all living organisms, and is needed for crop growth and development (Marschner, 1995).

2.2.2. Potassium Deficiency

Severe deficiency of potassium often leads to numerous plant physiological conditions, low plant growth and progress and that impact crop grain yield and fiber quality.

While laboratory testing remains one of the best ways to detect K deficiency, one might also visibly identify a K deficiency on the spot. Potassium deficiency on plant leaves looks like a yellowish-white mottling to a light-yellowish-green color at the early stage to a reddish brown as symptoms progresses. This is generally noticed on the outer edges of the leaf. Plant growth can be negatively influenced as a result of K deficiency (Pettigrew, 2008). Globally, K deficiency is often found in soils as a result of continuous agricultural production practices with inadequate or no K fertilization. According to a report by Steven (1985), K deficiency significantly decreases photosynthesis through a reduction in both leaf area and CO_2 fixation. However, one of the major reasons behind K deficiency is the continuous removal of biomass from the soil in the form of harvested grains, straw, or hay (Smil, 1999). Also, erosion and leaching have further contributed to K deficiencies in soils (Rengel and Damon, 2008). Acidic sandy soil, waterlogged soils, and saline soils were reported as types of soil which are often K deficient (Mengel et al., 2001).

In recent years, scientists have reported an increase in K deficiency worldwide. In China, one-fourth of arable soils and three-fourth of paddy soils are reported to be K deficient (Rengel and Damon, 2008; Römheld and Kirkby, 2010). In India, about 72% of the total agricultural land are K deficient and require immediate K fertilization to improve crop production (Yadav and Sidhu, 2016). In Australia, an increase in K deficiencies were found in wheat production research experiments (Rengel and Damon, 2008). Potassium deficient plants are highly sensitive to high light intensity, and as such, crops grown under environmental stress or high light intensity over long periods of time, have a higher internal requirement for K than plants exposed to lower light intensities during growth (Cakmak, 2005). Additionally, Cakmak (2005) further reported that low K supplies pose an environmental risk to plants.

2.2.3. Potassium in Wheat

Potassium use efficiency (KUE) for cereal crops in the world was estimated to be 19% (Dhillon et al., 2019), thus, fertilization methods and optimization needs to be improved in order to meet the growing population and demand for food globally. Studies show, that whenever soils test high for exchangeable K, wheat grain yield increases (Fixen et al., 1986; Sweeney et al., 2000). Potassium fertilization continues to play a major part in the structural integrity of cereal crops, osmoregulation and photosynthesis (Pettigrew, 2008), and together with fungicide application, becomes a vital approach for reducing disease and increasing winter grain yields (Sweeney et al., 2000).

In a study evaluating the effects of K nutrition in wheat, foliar application of K was found to increase both the biological and grain yields when solutions of 2 g K/liter were applied (Hosinkhani et al., 2013). In wheat, K follows N and P according to nutrient hierarchy (Pettigrew, 2008) and K accounts for about 1.5 and 3% of the wheat shoot dry weight (Grabov et al., 2005). According to Koch and Mengel (1977), K fertilization was found to stimulate an increase in wheat grain protein and amino acid content. On the contrary, Boquet and Johnson (1987) found that K fertilization had no effect on grain protein content and mineral composition in soft red winter wheat. Some of this was also influenced by the application of N and K (Widdowson et al., 1963).

2.2.4. Potassium Response to water stressed in Winter Wheat

Water stress is a common factor restricting crop development and efficiencies globally. Water insufficiency may strengthen cellular membrane permeability, subsequent to potassium outflow. Water shortage is a major limitation to agricultural production in many nations around the world, thus affecting the value, development and production of crops (Ahmad et al., 2015). Furthermore, drought has been reported to be a leading cause of yield loss (approximately 50%) in agriculture

(Wang et al., 2003). Levitt (1980) also emphasized that both the biological and metabolic processes in crops are affected by water scarcity and as a result leads to a substantial decline in development, chlorophyll, and where different florescence factors are changed (Ahmad et al., 2017; Yang et al., 2006). Carbon dioxide CO_2 plays an important role in plant growth, however the effect of drought on plants during the growing season can lead to the closure of stomata and ultimately stop the assimilation of CO_2 (Yang et al., 2006). Potassium is recognized for its major role in the functions of stomata during photosynthesis and transpiration through the maintenance of plant turgor and transportation of photo-assimilates (Pettigrew, 2008).

Shahzad et al. (2017), reported an increase in maize grain yield under drought conditions as a result of foliar K application. Similarly, positive response of K improving drought stress in winter wheat was reported in a controlled hydroponics experiment (Wei et al., 2013). Correspondingly, Shahzad et al. (2017) observed a growth deficiency in winter wheat due to drought stress conditions, and that was alleviated by K application. The application of K fertilizer by site specific need, or recommended quantity is capable of increasing crop grain yield, forage color, fruit size and general productivity (Kanai et al., 2007) and can lessen the losses caused by drought (Raza et al., 2013). In addition, a study that was carried out by Wei et al. (2013), where it was concluded that drought-tolerant wheat combined with sufficient K fertilization is key for winter wheat growth in arid and semi-arid regions. Generally, wheat grain yields in rain-fed agricultural systems, especially the Southern Great Plains region (Kansas, Oklahoma and Texas) face limitations due to water availability (Bushong et al., 2014). The southern great plains region often encounters periods of prolonged drought, asymmetrical rainfall, and variable temperatures (Baath et al., 2018). Drought stress conditions undoubtedly remain a serious challenge in the agricultural world. Nonetheless, K is the major element and nutrient necessary for optimum plant development in all agricultural cropping systems. Foliar application at the recommended level can alleviate the extreme losses imparted by the water stress (Ahmad et al., 2018).

2.3. MATERIALS AND METHODS

2.3.1. Study Area and Location

Two long-term continuous winter wheat experiments; Experiment 222 (E222) and Experiment 502 (E502) were used to achieve the objective of this study. Experiment 222 was established in 1969 and it is located at the Agronomy research station in Stillwater, OK. The soil type at this location is a Kirkland Silt Loam (fine, mixed, thermic Udertic Paleustoll). Experiment 502, established in 1970, is located in Lahoma, OK. The soil at this location is classified as a Grant Silt Loam (fine-silty, mixed, superactive, thermic, Udic Argiustoll).

2.3.2. Experimental Design and Management

A randomized complete block design with four replications was used at both locations (E222 and E502). Treatment structure and design is reported in Table 2.1. Both experiment stations were managed under conventional tillage until the year 2010 when they were converted to no-tillage systems. Wheat has been planted every fall season of each year since the inception of these experiments using varieties common to each region. Experiment 502 and E222 have 14 and 13 treatments, respectively. To achieve the objective of this study, two treatments (10 and 12) were selected from E502, and four treatments (8, 9, 11 and 12) were selected from E222 (Table 1). Treatment 8 and 9 had constant N and P application rates of 90 kg N ha^{-1} and 29 kg P ha^{-1}. Treatment 8 has not received any K fertilizer since the trial was started 50 years ago. Nonetheless, treatment 9 received 74 kg K ha^{-1} annually.

Similarly, treatment 11 and 12 had a constant N and P rate for both treatments (135 kg N ha^{-1} and 44 kg P ha^{-1} respectively) but differed for their K rate. For treatment 11, 74 kg K ha^{-1} was applied while 0 kg K ha^{-1} was applied on treatment 12. (Table 2.1). At E502, treatment 10 and 12 received equal rates of N and P (67 and 29 kg ha^{-1} accordingly) and different rates of K. For treatment 10, 56 kg K ha^{-1} was applied while 0 kg K ha^{-1} was applied on treatment 12 (Table 2.1).

2.3.3. Data Analysis

Statistical analysis was accomplished using SAS 9.4 (SAS, 2009). Analysis of variance was achieved using PROC GLM to analyze the winter wheat grain yield response to K. Treatment means – and associated standard errors – were generated and separated using LSD at 0.05 probability level. Single-degree-of-freedom, non-orthogonal contrasts were also employed to further evaluate differences among specific treatment levels.

2.4. RESULTS AND DISCUSSION.

2.4.1. Grain Yield

For experiment 222, when N was applied at 135 kg ha^{-1}, the analysis of variance (ANOVA) revealed that there was a significant effect of K application on winter wheat grain yield (P = 0.03; Table 2.2). Grain yield was higher at the high rate of K application. Grain yield at 74 kg K ha^{-1} was 10.1% higher than 1.91 Mg ha^{-1} obtained when no K was applied (Table 1.3). In this case, the soil K supply could have been inadequate to meet crop demand for K resulting in the lower grain yield when compared to the plot where 74 kg K ha^{-1} was applied. Similarly, single degree of freedom contrasts indicated a significant difference (P = 0.03) (Table 1.3) between yield obtained when K was applied at 0 and 74 kg ha^{-1}. This provided evidence that K fertilizer plays an important role in improving grain yield by increasing the concentration of K in the bulk solution and root surface sorption zone to sufficiency level (Das et al., 2019).

However, at 90 kg N ha^{-1} application rate, ANOVA did not show a significant effect of K application on winter wheat grain yield (P = 0.12; Table 2.2). Grain yield was similar at both 0 and 74 kg K ha^{-1}. At these rates, grain yield averaged 2.0 Mg ha^{-1} (Table 1.3). Analysis of mean differences using a single degree of freedom contrasts did not reaffirm the similarities in grain yields between the two K rates of 0 and 74 kg ha^{-1} (P = 0.170; Table 1.3). This similarity in yield between 0 and 74 kg K ha^{-1} following the application of 90 kg N ha^{-1} suggests the need for correctly estimating N rate that will allow for maximization of wheat yield potential.

Application of a sufficient amount of K to the soil without adequate supply of N may not lead to the maximization of yield potential of a given crop growing environment as evidenced at this N rate (Raun et al., 1998; Raun et al., 2002) In Oklahoma, at least 90 kg N ha^{-1} is required to maximize grain yield when P and K are non-limiting Thomason et al. (2000). If N and/or K are limiting, then there is a potential that grain yield obtained may not be statistically different from each other regardless of how much K was applied. This may explain why in this study grain yield in the unfertilized check plot was similar to the one that received 74 kg K ha^{-1} (for N applied at 90 kg ha^{-1}). For experiment 502 (E502), application of K at different rates did not have a noted effect on winter wheat grain yield (P = 0.58; Table 2.2). This result is similar to one of the scenarios observed in E222 where there was no grain yield difference between the two K rates (0 and 74 kg K ha^{-1} with both receiving 90 kg N ha^{-1}). Single degree of freedom contrasts indicated that there was no statistical grain yield difference 0 and 56 kg K ha^{-1} (P = 0.57; Table 1.3). At both K rates, grain yield averaged 2.9 Mg ha^{-1} (Table 1.3). This suggests that despite no K application for treatment 12 since the trial began, soil K supply was still sufficient for attaining similar wheat grain yields. Soil test K (mg/kg) in treatments 10 and 12 were 660 and 412 at the start of 2018 when this work was implemented.

Like previously explained for E222, the N rate could have also influenced the observed grain yields. With N at just 67 kg ha^{-1}, similar yield may be observed for both K rates since a sufficient level of soil K does not necessarily mean grain yield maximization. This N rate is below the 90 kg ha^{-1} recommended rate for winter wheat grown in Oklahoma (Thomason et al., 2000) especially in years with poor mineralization of soil organic matter.

2.4.2. Grain Yield Response to Potassium during water stressed conditions.

The average rainfall at E222 and E502 was 922 and 771 mm from 1994 to 2018 (Dhillon et al., 2020). However, rainfall data retrieved from Mesonet.org, E222 showed a relatively low amount of rainfall in the year 2001, 2005, and 2014 (375, 374, and 282mm respectively) and high rainfall in the year 1998, 2004 and 2015 (912, 775, and 792mm correspondingly) (Table 2.4). Looking at E222 where 4 treatments (treatment 8, 9, 11 and 12) were examined under drought conditions, we observed an inconsistent trend of crop response to K. Under drought conditions (low rainfall) and higher rainfall, treatment 8 and 9 (at 90 kg N ha^{-1} application rate) both showed a trend for increased grain yield over time (Figure 1.2 and Figure 1.3). Average yield for treatment 8 and 9 was 2.1 and 2.2 Mg ha^{-1} respectively during the drought season. In this same season (low rainfall), treatment 9 which received 74 kg K ha^{-1} yielded similarly to treatment 8 where there was no K applied over the years. Results indicate no economic benefit for applying 74 kg K ha^{-1} when N was also applied and was likely to be adequate for maximizing yield. This result suggests that initial soil test K levels were 100% sufficient for winter grain yield. However, for the high rainfall season, treatment 9 average grain yield was 33% higher than 2.2 Mg ha^{-1} that was obtained from treatment 8 where 0 kg K ha^{-1} was applied. This is assumed to have been an effect of rainfall influencing yield. Similar trends were observed for treatment 11 and 12, where treatment 11 received 74 kg K ha^{-1} and was 11% higher than 2.06 Mg ha^{-1} recorded for treatment 12 at 0 kg K ha^{-1} during a more water stressed season (Table 2.4). The effect of rainfall could also be linked with the slight increase in grain yield in treatment 11 (2.96 Mg ha^{-1}) compared with 2.58 Mg ha^{-1} in treatment 12 at 0 kg K ha^{-1}.

For experiment 502 (E502) (Table 4.2), a downward trend was observed for both treatments 10 and 12 during a drought season (Figure 2.0), where winter grain yield declined over time. Possible reasons may be attributed to the low rainfall received. However, treatment 12, where no K was applied recorded the highest grain yield over time (all instances, Figure 2.3) compared to treatment 11 that received 56 kg K ha^{-1} annually. A possible interpretation to this finding might be the availability of soil K for plant uptake during drought stress conditions. Similarly, treatment 12 (No K applied) also yielded the most when rainfall was high (Table 4.2).

2.5. CONCLUSION.

Long-term field experiments are an indispensable tool for the derivation of site and cropping oriented fertilizer recommendations. Significant response of grain yield to applied K was only seen in E222 (treatment 11 vs treatment 12) but not in E502 where soil test K levels were higher. There were some inconsistencies across site years and this restricted combined analysis of the data. Overall, results from this study indicated that after many decades of continuous K fertilization, K is possibly at a sufficient level in the soil and that any additional K fertilization might not be of any benefit for this region. A re-evaluation of each site fertilization effect on N and K ratio and soil K buildup under the current NPK rate are likely needed.

Table 2.1: Treatments included for Experiment 222, Stillwater , and Experiment 502, Lahoma, OK used for this study.

Experiment	Treatment	Fertilizer rate (kg ha^{-1})		
		N	P	K
E222	8	90	29	0
	9	90	29	74
	11	135‡	44	74
	12	135‡	44	0
E502	10	67	29	56
	12	67	29	0

‡N rate split to 67.5 N kg applied in fall and 67.5 N kg applied in Spring. N, P, and K – Nitrogen, Phosphorus, and Potassium applied as Urea (46-0-0), Triple Super Phosphate (0-22-0) and Potassium Chloride (0-0-52), respectively. Complete treatment structure for each site reported in Table 2.1a and 2.1b.

Table 2.1a. Complete treatment structure with pre-plant N, P and K rates at experiment 222 in Stillwater, Oklahoma.

Treatment	N rate (kg N ha $^{-1}$)	P rate (kg P ha^{-1})	K rate (kg K ha^{-1})
1	0	29	37
2	45	29	37
3	90	29	37
4	135‡	29	37
5	90	0	37
6	90	15	37
7	90	44	37
8†	90	29	0
9†	90	29	74
10	0	0	0
11†	135‡	44	74
12†	135‡	44	0
13	90	29	37

N, P, and K – Nitrogen, Phosphorus, and Potassium applied as Urea (46-0-0), Triple Super Phosphate (0-22-0) and Potassium Chloride (0-0-52), respectively. †; Treatments used in this study because they all have constant N and P rates. ‡N rate split to 67.5 N kg applied in Fall and 67.5 N kg applied in Spring

Table 2.1b. Complete treatment structure with pre-plant N, P and K rates at experiment 502 in Lahoma, Oklahoma.

Treatment	N rate (kg N ha^{-1})	P rate (kg P ha^{-1})	K rate (kg K ha^{-1})
1	0	0	0
2	0	20	56
3	22	20	56
4	45	20	56
5	67	20	56
6	90	20	56
7	112	20	56
8	67	0	56
9	67	10	56
10†	67	29	56
11	67	39	56
12†	67	29	0
13	112	39	56
14	67	20	56

N, P, and K – Nitrogen, Phosphorus, and Potassium applied as Urea (46-0-0), Triple Super Phosphate (0-22-0) and Potassium Chloride (0-0-52), respectively. †; Treatments used in this study because they all have constant N and P rates.

Table 2.2: Analysis of variance, mean squares in Experiments 222 and 502

Source of Variation	Df	Mean Squares	F value	Pr > F
E222				
K at 90 kg N ha^{-1} (Treatment 8 vs 9)				
Rep	3	0.8522	1.18	0.226
Treatment	1	1.7706	2.44	0.119
Error	367	0.7247	1.49	
K at 135 kg N ha^{-1} (Treatment 11 vs 12)				
Rep	3	0.4645	0.54	0.656
Treatment	1	4.2158	4.89	0.028
Error	367	0.8616	1.63	
E502				
Rep	3	0.6277	0.60	0.615
Treatment	1	0.3214	0.31	0.579
Error	363	1.0438	0.53	

Df- degree of freedom, N – nitrogen, K – potassium

Table 2.3. Treatment means for Grain K uptake (kg ha^{-1}) and single-degree-of-freedom non-orthogonal contrasts between treatments at E222 (Stillwater) and E502 (Lahoma) Oklahoma

Treatment	K rate (kg ha^{-1})	Grain Yield (Mg ha^{-1})
E222		
K at 90 kg N ha^{-1} (Treatment 8 vs 9)		
8	0	1.80
9	74	1.95
MSE		0.725
SED		0.852
CV, %		45.37
Contrasts		PR>F
8 vs 9		0.119
K at 135 kg N ha^{-1} (Treatment 11 vs 12)		
11	74	2.13
12	0	1.91
MSE		0.86
SED		0.464
CV, %		46.30
Contrasts		PR>F
11 vs 12		0.028
E502		
10	56	2.92
12	0	2.95
MSE		1.04
SED		0.50
CV, %		34.58
Contrasts for K rates		
Trt10 vs Trt11		0.57

Table 2.4: Experiment 222 Grain Yield Response to K Fertilization at Average Low Rainfall and High Rainfall

Low Rainfall					
	No K applied		K applied		
Year	Trt 8	Trt 12	Trt 9	Trt 11	Average Rainfall
2001	1.81	1.88	1.78	2.23	375
2005	2.07	2.02	2.17	2.36	374
2014	2.43	2.28	2.51	2.35	282
Average	2.10	2.06	2.16	2.32	344
High Rainfall					
1998	1.28	1.86	1.42	1.94	912
2004	2.34	2.79	2.93	3.51	775
2015	3.03	3.08	3.26	3.43	792
Average	2.21	2.58	2.54	2.96	826

“Trt” indicates treatment, NPK rates for treatments are represented on table 1.

Table 2.5: Experiment 502 Grain Yield Response to K Fertilization at Average Low Rainfall and High Rainfall

Year	K ~applied	No K^ applied	Average Rainfall
Low Rainfall			
2003	6.14	6.29	545
2004	3.86	4.28	511
2006	2.46	2.72	458
Average	4.16	4.43	504
High Rainfall			
1995	2.87	2.90	954
1997	2.44	2.78	1039
1999	3.08	3.01	1030
Average	2.80	2.90	1008

~ indicates Treatment 10, with an N, P and K rates of 67, 29, and 56 kg ha^{-1} respectively. ^ indicates Treatment 12 with N, P and K rates of 67, 29, and 0 kg ha^{-1} respectively

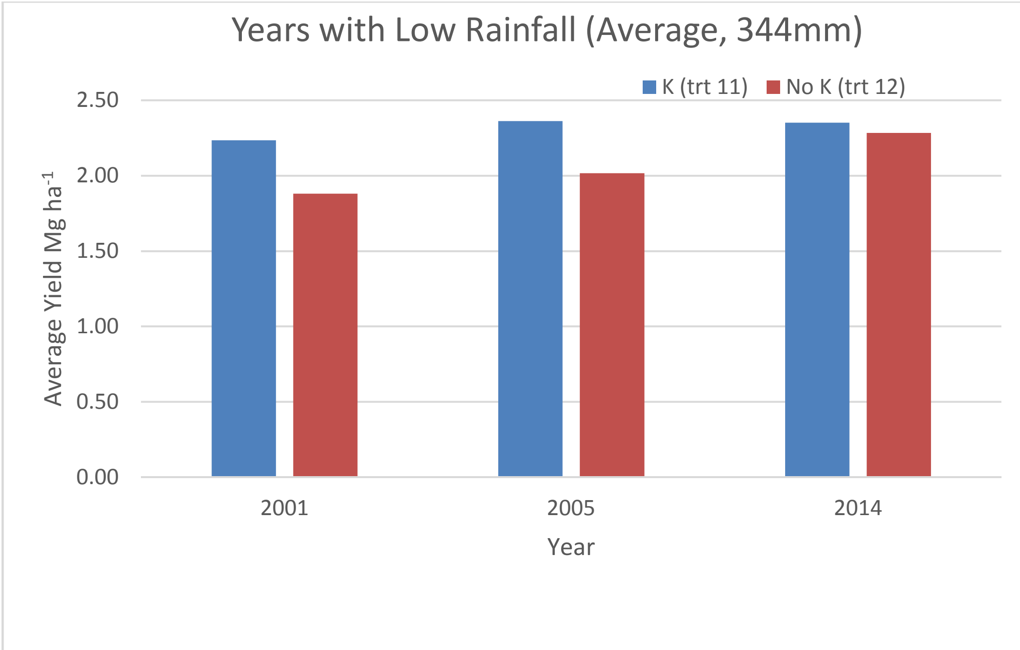

Figure 2.1: Experiment 222 Grain Yield response to low rainfall, treatment 11 and 12.

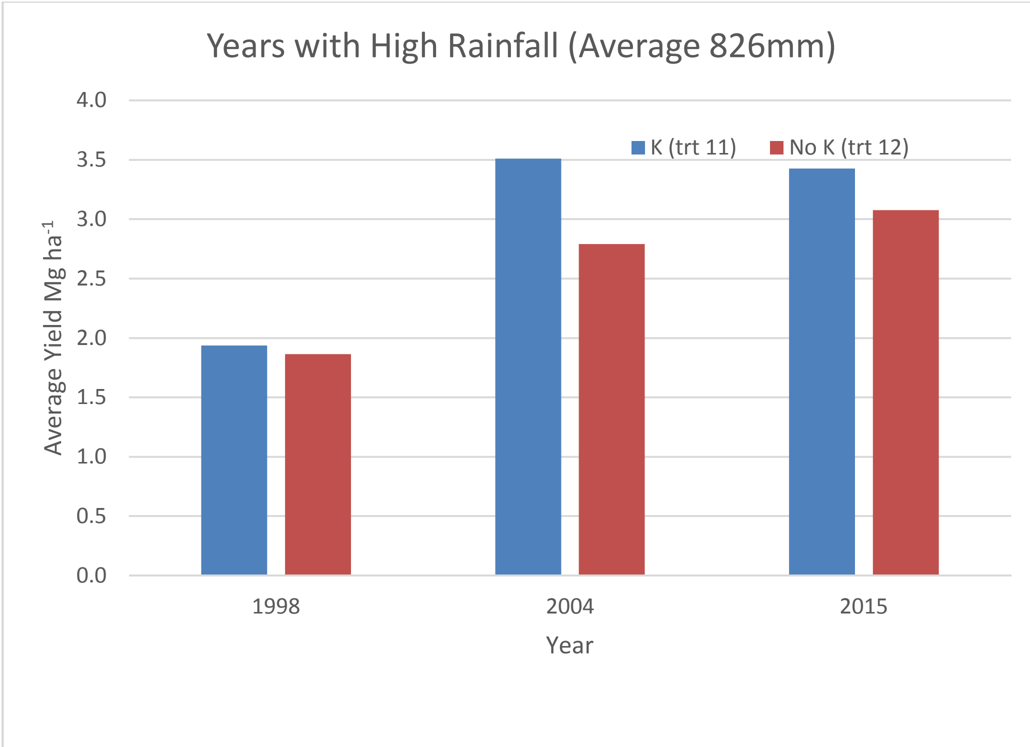

Figure 2.2: Experiment 222 Grain Yield response to high rainfall, treatment 11 and 12.

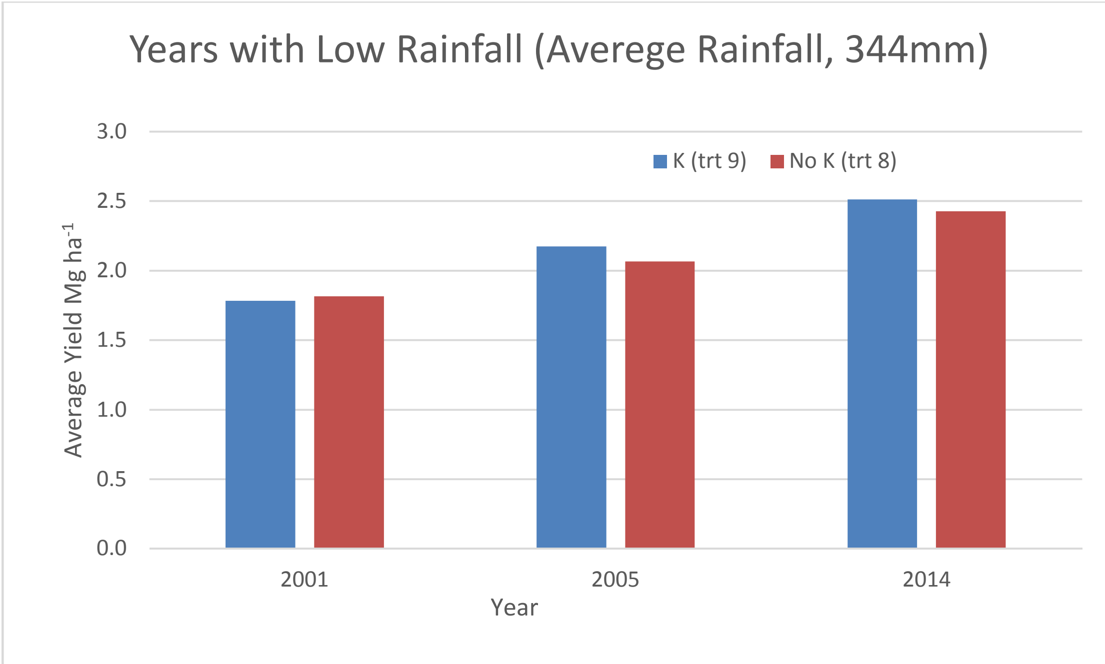

Figure 2.3: Experiment 222 Grain Yield response to low rainfall, treatment 8 and 9.

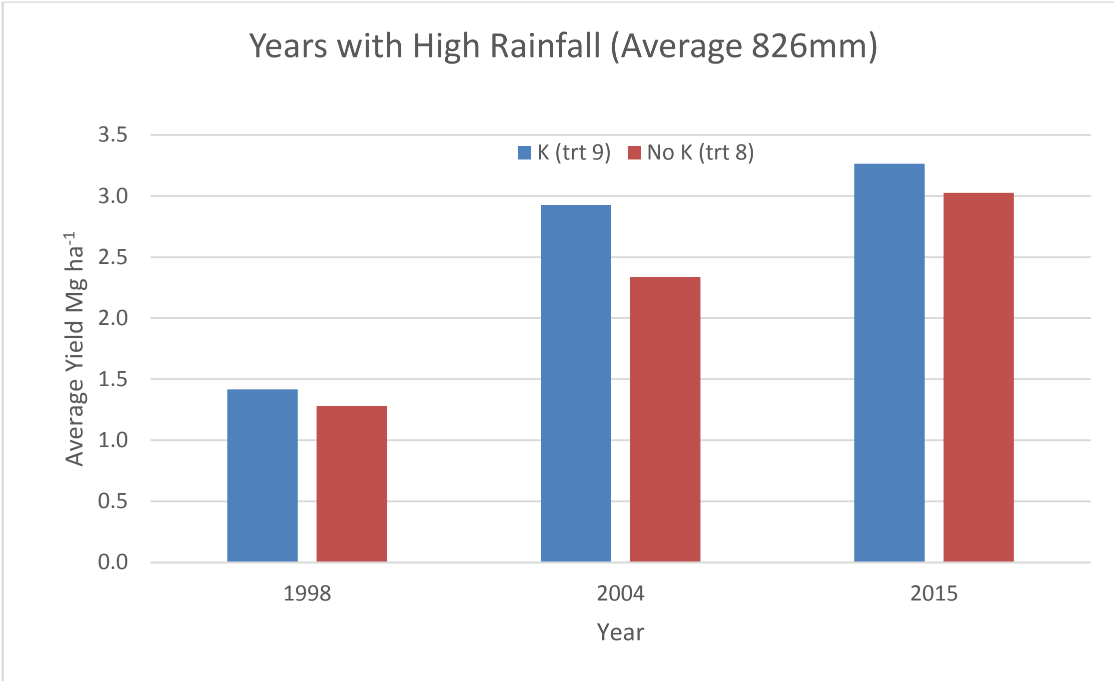

Figure 2.4: Experiment 222 Grain Yield response to high rainfall, treatment 8 and 9.

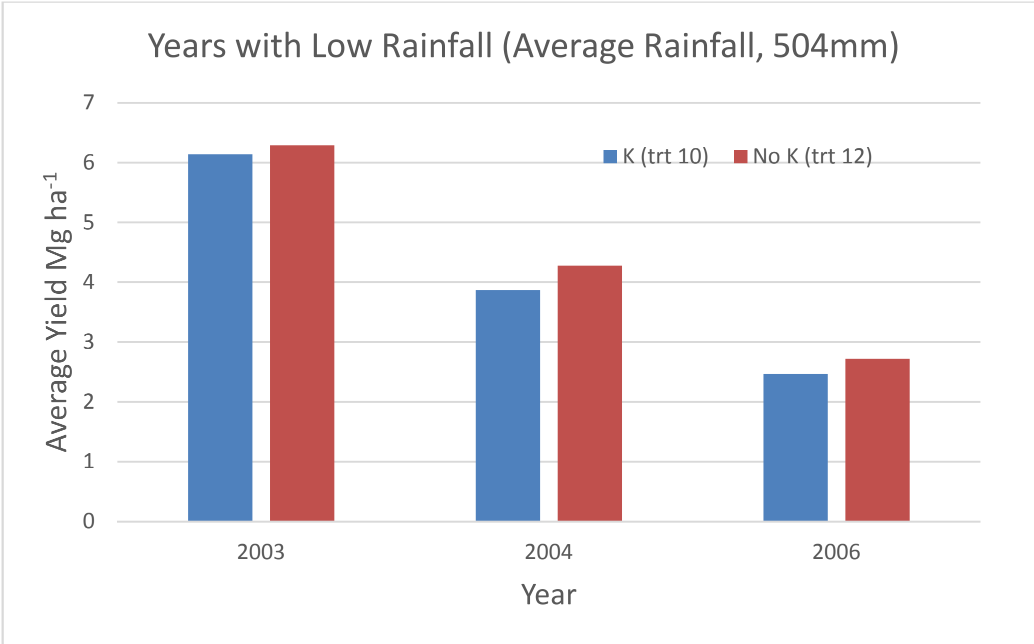

Figure 2.5: Experiment 502 grain yield response to low rainfall, treatment 10 and 12.

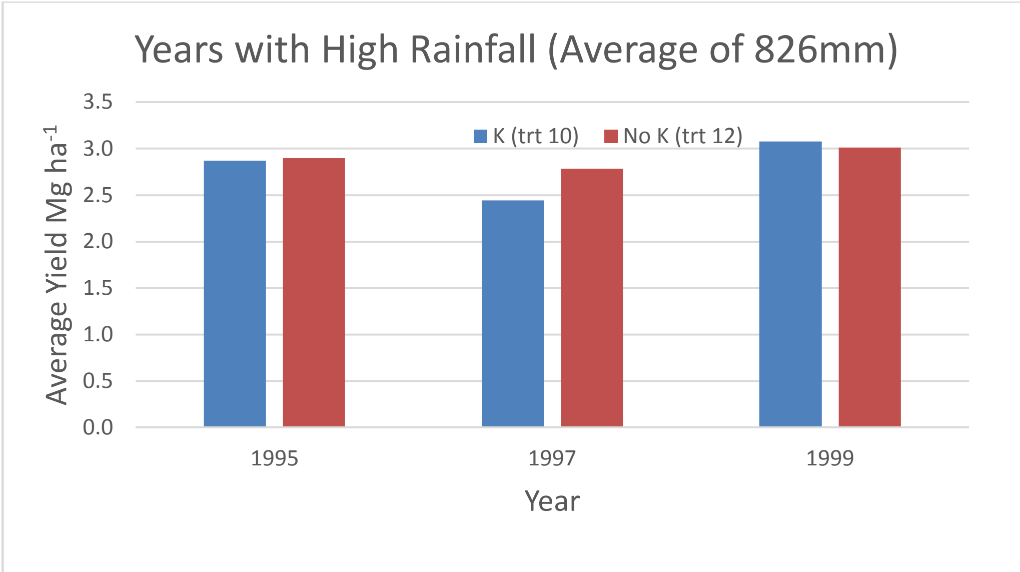

Figure 2.6: Experiment 502 grain yield response to high rainfall treatment 10 and 12.

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APPENDICES

1.1 Field experiment at the Lake Carl Blackwell evaluating different plant sequence at two N rates

1.2: Close up picture at the Lake Carl Blackwell experiment station at or near the 6 leaf maize growth stage.

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1.3: Close up picture at the Lake Carl Blackwell Experiment Station at the 3 – leaf maize growth stage

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