EFFECT OF ROW SPACING, PLANT DENSITY, NITROGEN RATE, AND PLANTING METHOD ON MAIZE (ZEA MAYS L) GRAIN YIELD

By

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ABSTRACT

Narrow row spacing often results in increased plant density and reduced variability. This study was conducted to determine how narrow row spacing and increased plant density influence corn yield, harvest count, cob weight, stalk lodging and test weight. Two field experiments were conducted for two years, at Lake Carl Blackwell (Port silt loam) and Perkins (Teller sandy loam-fine-laomy, mixed, thermic Udic Argiustolls), Oklahoma. Fourteen treatments were evaluated at each location using a randomized complete block experimental design. Treatments included two different row spacing's (0.51m, 0.76m), four different plant densities (43,859 65,359 87,719, and 130,718 seeds/ha plants/ha), three different nitrogen (N) application rates (0, 60, 120 kg N/ha), two plant-to-plant spacing's (0.15m, 0.30m) and two different planting methods (Greenseeder hand planter vs Indigenous planter). Results were evaluated using grain yield, harvest count, cob weight, and stalk lodging as dependent variables. Narrow row spacing (0.51m) resulted in higher grain yields compared to the wide row spacing (0.76m) at both locations. This was likely due to increased plant population at the narrow spacing.

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CHAPTER I

THE EFFECT OF ROW SPACING, PLANT DENSITY, NITROGEN RATE, AND PLANTING METHOD ON MAIZE (ZEA MAYS L) GRAIN YIELD

INTRODUCTION

It is well known that global population is gradually on the rise. By 2030, our current population is expected to increase from 7.3 billion to 8.5 billion (UN, 2015). This figure is expected to further increase to about 9.6 billion by 2050 and 12.3 billion by 2100 (Gerland, 2014). The majority of this increase is expected to come from Africa, because of the increase in fertility rate (Gerland, 2014). Between 5 and 170 million people will be at risk of hunger by 2080 (Schmidhuber et al. 2007). Climate change also imparts a significant threat to agriculture and food production through drought, increased atmospheric carbon dioxide, and resultant flooding and/drought (Ali et al., 2017). Thus, there is a need to increase food production around the world in a sustainable manner.

Maize

In developing nations, cereals are consumed as an important staple food. Maize (*Zea mays. L.*) for example, is one of the most important staple foods in most African countries (M'mboyi et al., 2010) and consumed by over 900 million people, of which 15% is consumed by poor farmers (CIMMYT and IITA 2010). Apparently, in Sub Saharan Africa, 50% of the countries consume maize as a staple food (FAO, 2011). Thus, an increase in maize production may be an important contributor for combating hunger in this region, as it is consumed in various forms in the diet (IITA, 2001). In-order to increase maize production, it is important to develop efficient farming tools and fertilizer application practices for maize cultivation, and to improve nitrogen use efficiency, crop quality and yield.

The production of maize in the world surpassed 1 billion metric tons in 2013 (FAOSTAT, 2013) which is the most tonnage produced by any cereal crop. Maize supplies 30% of the food calories other than rice and wheat, to over 4.5 billion people in 94 countries (Shiferaw et al., 2011).

Hand Planter

According to (FAOSTAT, 2016), 29 M ha of maize is planted by hand in developing countries and the average yields are approximately 1.8 Mg ha^{-1}, while the average maize production in the United States is 9.9 Mg ha^{-1}. Many factors account for these high yields in the U.S, specifically highly advanced agricultural mechanization not available in developing countries. Over the last two decades, the Division of Agriculture at Oklahoma State University has worked to develop an improved hand planter, for subsistence farmers in developing countries (Omara et al., 2016; Dhillon et al., 2017; Dhillon et al., 2018). Farming practices in developing countries are often subsistent ranging from 0.1 to 2 ha, and they typically lack resources (Ibeawuchi et al., 2009). Thus, resource poor farmers use stick planters, machete, dibbler or hoe for planting corn, and these methods are highly labor intensive (Adjei et al., 2003; Tweneboah, 2000). Omara et al. (2016) reported that when corn is planted by hand, there is a tendency to drop/plant two or more seeds per hill and covered with soil. This leads to the emergence of multiple seeds and uneven germination. This in turn can lead to seed rotting because of deep planting and loss of seed due to inappropriate covering (Aikins et al., 2010). Many studies have reported the relevance of homogenous crop stand in-order to attain higher yields (Nafziger et al., 1991; Ford and Hicks, 1992; Nielson, 2004; Liu et al., 2004; Tollenaar et al., 2006; Rutto et al., 2014). Homogeneity of crops have the ability to increase water use efficiency, nutrient use efficiency, and solar radiation, which ultimately affects yields. Crop homogeneity is a problem in many different countries due to poor planting practices. Increasing homogeneity has the ability to improve water efficiency, nutrient use efficiency, and solar radiation that ultimately influences yield. However, homogeneity of plant stands are lacking in many developing countries, because two or three seeds are planted per hill, resulting in stand heterogeneity and decreased yields. Subsequently, researchers have invested time, energy, and resources to develop a hand planter for smallholder farmers in developing countries. Continued focus targets maize singulation for each planter strike. Aikins et al. (2010) compared hand planters with various maize varieties. He reported that 70% of the time, planters deliver greater or less than 3 seeds while 53% of the time, planters deliver less than or greater than 2 seeds per hill. Therefore, there is a need to develop a planter that can deliver one seed per hole to attain homogeneity within the plant stand.

Oklahoma State University (OSU) has developed a maize planter, which has 80% singulation efficiency and 20% multiple seed delivery using different seed types (Omara et al., 2016). This is an important discovery that will benefit small farmers. Using the Greenseeder hand planter, chemically treated seed is removed from the hands of farmers, and it can decrease the rate of soil erosion by improving plant spacing. Furthermore, by simply changing the internal drum this planter can facilitate mid-season application of urea-N fertilizer, placing urea below the soil surface hence reducing NH_3 losses, and fertilizer runoff (Dhillon et al., 2018).

The current planter comprises a polyvinyl chloride round pipe (PVC) with a diameter of 5.8 cm connected to an inner barrel containing a drum to collect seeds, housing, brush, and internal rotating drum. The Greenseeder hand planter consists of a sharp metal tip, which opens the soil for proper seed placement. Depending on the operator and soil conditions, the Greenseeder hand planter can place seed 5 cm deep in the soil. Proper use of the hand planter can deliver single seeds per strike into the soil. The best way to operate the hand planter is by striking the soil leaning forward, keeping the tip in the soil, and then moving the handle forward. The planter tip is removed as the operator steps further forward and the tip comes out of the ground, at the same time, a seed is being dropped. Current work continues to optimize brush placement/angle for improved singulation.

Recently, Harman et al. (2017) evaluated seven different planters for yield, economic viability, usability and plant population establishment. The seeders tested were a dibble stick (Each Farms, Mt. Gilead, USA), OSU Greenseeder (Oklahoma State University, Stillwater, USA), Li Seeder (Yunfan Machinery Manufacturing Co., LTD, Fushun, China), Brazilian Jab (Fitarelli Aratiba, Brazil), Haraka rolling (Esen Equip, Potchefstroom, South Africa), CA-Seeder 1000 (Morrison Seeders, Unicoi, USA) and John Deere MaxEmerge Conservation Planter (John Deere, Moline, IL, USA). Results showed that the OSU Greenseeder hand planter had the lowest weight of 1.9 kg, the highest crop height at 59.5 cm, it also achieved the highest mean grain yield at 4.83 Mg ha^{-1}, and had the highest number of ears/stalk near 0.93. The Greenseeder planter also provided the least mechanization, ease in handling seed, usability, and transport and emerged as the top ranked planter compared to the other seeders (Harman et al., 2017).

Row Spacing

Recent studies on narrow row spacing for maize production have produced inconsistent results. Results are varied concerning the relationship between narrow spacing and yield (Farnham, 2001; William et al., 2002). At present limited work has tested different row spacing combined with plant-to-plant spacing with the Greenseeder hand planter. Optimal plant density level and row width for maize grain yield may vary with location, primarily latitude.

Nitrogen Use Efficiency

The worldwide consumption of N fertilizer reported by FAO (2001) was 85,529,551 Mg in 1999, while 60% or 51,317,730 Mg was accounted for by cereal production (FAO, 1995). Worldwide nitrogen use efficiency (NUE) for cereal crops (maize, rice, sorghum, barley, millet, oat and rye) is approximately 33% (Raun and Johnson 1999). Therefore, 67% of the applied N is lost and unavailable, costing $15.9 billion dollars yearly loss of N fertilizer (Raun and Johnson, 1999). Improved NUE is needed to attain maximum yields and the optimum N fertilizer needed by plants. A 1% increase in NUE could be worth $200,000,000 (Raun and Johnson 1999). Tilman (1999) reported that food production has increased 6.87 fold in the last 34 years. This increase was partly due to a 3.48-fold increment in phosphorus (P) fertilizer, 6.87-fold increase in N, 1.68-fold increase in irrigated crop area and 1.1 fold increment in the total area cultivated. He further reported that for agricultural food to double, N and P have to increase 3 fold, irrigated land area has to double and land under production has to increase by 18% worldwide. The proper nitrogen use efficiency of maize is economically and environmentally important, and could be increased by reducing row spacing and increasing plant density (Shapiro et al., 2006).

The increase in N fertilizer costs has led to the implementation of different N management practices such as the use of the normalized difference vegetative index (NDVI). This index combined with climatological data can be used to predict yield potential in the middle of the season. The predicted yield potential is then employed to decipher appropriate mid-season fertilizer N rates that can maximize yields and use efficiency (Lukina et al., 2001).

Normalized Difference Vegetative Index

The normalized difference vegetation index (NDVI) is computed as (NIR – VIS) / (NIR+VIS), where VIS stands for the spectral reflectance measurements taken in the visible red while NIR in near infrared regions of the spectrum. The NDVI sensor readings can be obtained from the Greenseeker sensor. The Greenseeker sensor is an active optical sensing device developed by Oklahoma State University (reference?). It can sense an area between 0.6 to 1.0m from the target to the surface. Normalized Difference Vegetation Index readings can be superficially graphic with the ability to decipher healthy vegetation on several different scales. NDVI measurement comprises multispectral incident light in the 671 $\pm$ 6 and 780 $\pm$ 6 nm bandwidths. NDVI index has the ability to predict the amount of total plant N uptake from mid-season readings, collected from actively growing plant canopies (Hatfield and Prueger, 2010).

Filella et al. (1995) determined that sensing leaves could provide a rapid estimate of wheat N status. They tested different empirical reflectance indices of pigment content at 450nm, 550 nm, 680 nm, and red-edge wavelengths. From the result, there was a significant relationship between canopy chlorophyll A content and R550, R680 and all the red parameters. Thus, the optical sensing technique had a potential to determine N status of wheat. Similarly, Raun et al. (2001) reported that NDVI measurements could be used to predict potential grain yield from mid-season sensor readings. This can be determined through reflectance of red and near infrared by dividing NDVI by the cumulative growing degree days from the time the crop was planted to the time the readings were collected. They also noticed that it is possible to predict top-dress N rates depending on the predicted yield. Also, Lukina et al. (2001) determined the ability of using an optical sensor measurement to predict early-season plant N uptake using the readings collected. They sensed the wheat plant at or near Feekes growth stage 5 from 3 experimental stations. This encumbered using passive sensors that measured reflectance in the red 671 $\pm$ 6 nm and near-infrared 780 $\pm$ 6 nm regions, using interference filters. From this, they determined that NDVI was an excellent predictor of N uptake for plants with a coefficient of determination near 0.75 (r^2). NDVI was calculated using the equation $[(NIR_{ref} / NIR_{inc} – Red_{ref} / Red_{inc})] / [(NIR_{ref}/NIR_{inc}) + (Red_{ref} / Red_{inc})]$. Subsequently, Raun et al. (2005) studied the use of optical sensors in the red and near infrared bands on how they can be used to predict yield and estimate fertilizer requirements. This work showed that mid-season prediction of yield was possible by dividing NDVI by the number of days from planting to sensing and could be used to predict yield potential over different years and locations. Also, this work reported that using mid-season fertilizer rates based on the predicted yield potential, could lead to an increase in NUE of 15% for winter wheat.

CHAPTER II

THE EFFECT OF ROW SPACING, PLANT DENSITY, NITROGEN RATE, AND PLANTING METHOD ON MAIZE (ZEA MAYS L) GRAIN YIELD

LITERATURE REVIEW

The effect of row spacing varies from a positive, neutral to negative relationship with yield. Widdicombe et al. (2002), analyzed different planting population densities (56,000, 65,000, 73,000, 81,000 and 90,000 plants per ha) and row spacing (0.38m, 0.56m, and 0.76m) of maize at different locations. Results showed that maize grain yield increased by 2 and 4% when row spacing was reduced from 0.76m to 0.56m and 0.38m, respectively. In addition, the highest plant density (90,000) had the highest grain yield. The harvest moisture decreased by a factor of 2.1% when the row width decreased from 0.76m to 0.56m to 0.38m. Average maize grain yields for the different row widths 0.76m to 0.56m to 0.38m, were 11,130, 11,350, and 11,551 kg ha^{-1}, respectively.

Similarly, Williams et al. (2002) reported on a study on using different row spacing (0.76m, 0.56m, and 0.38m) and plant population (64,200, 79 000, and 88,900 plants ha^{-1}) on forage maize yield. They noted that there was an increase in yield of 1.4 and 2.8 Mg ha^{-1} when row spacing decreased from 0.76m to 0.56m and 0.38m respectively. Dry matter yield levels for row spacing (0.38m, 0.56m, 0.79m) were 23.5, 22.5, and 21.0 Mg ha^{-1} respectively. In addition, dry matter yield increased by 1.6 Mg ha^{-1} when plant density increased from 64,200 to 88,900 plant ha^{-1}. Different plant densities (64,200, 79,000, 88,900 plants ha^{-1}) produced yields 19.2, 20.3 and 20.8 Mg ha^{-1} respectively. Furthermore, Bruns et al. (2002) evaluated maize planted under five different densities

(43,000, 48,000, 54,300, 64,000, and 76,500 plants ha^{-1}) using 101.6 cm row spacing. They noticed that with higher plant densities, yield levels were higher. On average the yield produced at 43,000 plants ha^{-1} was 9 Mg ha^{-1} while at 76,500, the yield produced was 10.55 Mg ha^{-1}. Thus, there was a 17% increase in yield from the lowest plant density to the highest plant density. Also, Shapiro et al. (2006), compared the effect of two row spacings (0.76 vs 0.51m), three plant densities (61,800, 74,160 and 86,520 plant ha^{-1}) and four N rates (0, 84, 168 and 252 kg ha^{-1}). By reducing the row spacing from 0.76 to 0.51 this resulted in an average increase in yield (8.44 vs 8.98 Mg ha^{-1}). Therefore, decreasing row spacing resulted in a 6% increase in yield. However, total dry matter yield did not change with altered plant density. The lowest yield was found at the lowest plant density. Nitrogen rate had little effect on yield. However, the highest yield (11.57 Mg ha^{-1}) was attained when 84 kg N ha^{-1} of fertilizer was applied. Application of N resulted in a 24% increase in grain yield. Similarly, Cox et al. (2001) evaluated the effect of different row spacing, plant density, and N rates on maize silage. They examined two row spacings (0.38 and 0.76 m), two harvest densities (80, 000 and 116,000 plants ha^{-1}), and six N rates (0, 50, 100, 150, 200, and 250 kg ha^{-1}). This was further used to decipher interactions between row spacing, N rates and plant density. Their work showed that yields were greater at 0.38m than 0.76 m at 20.3 Mg ha^{-1} and 18.9 Mg ha^{-1} respectively. Nitrogen rates had an effect on dry matter yield at 150 kg N ha^{-1} which had the highest yield of 20.6 Mg ha^{-1} for the 0.38 m row spacing. Plant density had only small differences in yield with the highest yield of 22.0 Mg ha^{-1} when planted at a population of 116,000 seeds per ha, while the lowest yield was 15.9 Mg ha^{-1} at 80,000 plants ha^{-1}. In conclusion, narrow row spacing resulted in a 7.5% increase in yield. Barbieri et al. (2012) evaluated the effect of row spacing on water use efficiency based on yield. They used two different row spacings (35 and 70cm) and two rates of N (0 and 180 kg ha^{-1}). Under irrigation and without fertilization, narrow row spacing had a significantly higher yield (5.51 Mg ha^{-1} vs 4.49 Mg ha^{-1}) while significant differences were also observed in a rain-fed system. Narrow row spacing performed better with yields of 9.04 and 7.74 Mg ha^{-1} and when not fertilized, 4.16 vs 3.48 Mg ha^{-1}. In addition, N rate application resulted in higher yields when row spacing was 35 cm. Most grain yields were significantly higher when 180 kg N ha^{-1} was applied especially with narrow row spacing. Also, Pablo et al. (2008) evaluated the effect of narrow row spacing and nitrogen use in maize. The experiment consisted of three different row spacings (70, 52 and 35cm) and four N rates (0, 90, 140, and 180 kg N ha^{-1}). Grain yield was significantly increased at two different N rates (0 and 140 kg N ha^{-1}) when row spacing was reduced from 70cm to 35cm with an average of 9.05 and 10.72 Mg ha^{-1}. Nitrogen rate also had a significant effect on grain yield with an average of 11.84 and 7.93 Mg ha^{-1} for 140 and 0 kg N ha^{-1}, respectively. On the other hand, Dale (2001) evaluated the effect of narrow row spacings (0.76cm and 0.38cm) and population densities (59,000, 69,000, 79,000, and 89,000 plants ha^{-1}) on maize grain yield. He conducted this study across six locations in Iowa over 3 years. He observed that the average yield across all locations between 0.76cm and 0.38cm row spacing was 10.5 and 10.3 Mg ha^{-1} respectively. Also, the highest grain yield was recorded at a seeding population of 89,000 and that delivered a yield of 11.7 Mg ha^{-1}. Also, Brent et al. (2001) evaluated the impact associated with three narrow row spacings (0.76 0.56, and 0.38 m) and three plant population densities (59,300, 72,900, and 83,900 plants ha^{-1}) on maize grain yield. From these studies, no yield differences were observed for row spacings of 0.38, 0.56 and 0.76m (10.61, 10.64, 10.56 Mg ha^{-1}, respectively). However, plant population density (59,300, 72,900 and 83,900 plants ha^{-1}) had an effect on yield at 10.22, 10.75 and 10.86 Mg ha^{-1} respectively. For this work higher plant densities resulted in higher maize yields.

Marianna et al. (2012) studied the effect of different row spacing and multiple plant densities of maize hybrids. The two row spacings used for this study were 76cm and 20cm with four different plant densities (69,000 81,000 93,000, and 105,000 plant ha^{-1}). No relationship was found between plant density and yield. Also, row spacing did not affect maize yield. Similarly, Pablo et al. (2000) studied the effect of row spacing and different rates of N availability (0 and 120 or 140 kg ha^{-}) in maize. It was a two-year experiment consisting of two row widths (0.35m and

0.70m) and three different N rates (0 and 120 or 140 kg ha^{-1}) at a constant plant density. The results showed that narrow row spacing significantly increased kernel number per unit area and grain yield of maize. The average response of yield to row spacing was 14.5 and 20.5% for kernel and yield respectively. The average yield in 1995 for 0.35m and 0.70m row spacing's were 11,135 kg ha^{-1} and 9120 kg ha^{-1} respectively while for 1996 the average yield was 10,715 kg ha^{-1} and 9055 kg ha^{-1} respectively. In addition, 27 to 46% of the grain yield increase was obtained under narrow row spacing and N- deficient maize crops.

Marsalis et al. (2010) evaluated the effect of different planting densities and N application on maize. The planting densities were partitioned into the following categories; high (74,100 plants ha^{-1}), medium (66,690 plants ha^{-1}) and low (55,575 plants ha^{-1}) while the N rates were 106 and 140 kg ha^{-1}. From these results, the medium plant density had the highest average forage yield of 25.2 Mg ha^{-1} followed by low (24.6 Mg ha^{-1}) and high (23.6 Mg ha^{-1}). The main effect of N rate was not significant. Another study by Paulo Sergio Le Silva et al. (2007) evaluated five different plant densities (30,000, 40,000, 50,000, 60,000 and 70,000 plants ha^{-1}) on green ear yield. Row spacing (1.0 m) was the same amongst all planting densities. From the result, the green ear yield increased with plant density with an average yield of 14.9 Mg ha^{-1} and the maximum yield was recorded at a population of 50,000 plants per hectare.

OBJECTIVES AND HYPOTHESIS

The objective of this experiment was to evaluate the effect of row spacing and plant population under different rates of N applied using the OSU Greenseeder planter and a simulated farmer practice. Two different row spacings were evaluated at each site with four different plant populations, three N rates and two plant-to-plant spacings. The hypotheses were; (1) reduced row spacing will result in increased grain yield; (2) higher maize populations will lead to higher yields; (3) decreased plant-to-plant spacing will increase yield levels; (4) increased applied N will produce higher yields; (5) OSU Greenseeder planter will perform better than the simulated farmer practice. The rationale for developing the Greenseeder planter was to reduce the time spent in the field by smallholder farmers, remove chemically treated seeds from the hands of producers and deliver single seeds per planter strike, and deliver improved fertilizer placement.

CHAPTER III

THE EFFECT OF ROW SPACING, PLANT DENSITY, NITROGEN RATE, AND PLANTING METHOD ON MAIZE (ZEA MAYS L) GRAIN YIELD

METHODOLOGY

Experimental site

To accomplish the objective of this study, four maize trials were conducted at two locations in 2017 and 2018. The first location was the Perkins Experiment Station (Perkins, OK) which is located near Stillwater and the soil type described as a Teller sandy loam, fine, mixed, thermic Udic Argiustolls. A second location was at Lake Carl Blackwell (LCB), located 8 miles west of Stillwater on Highway 51 which is a Pulaski fine-sandy loam (coarse/ loamy, mixed non-acid, thermic, Typic, Ustifluvent) (USDA / NRCS soil taxonomy). Soil classification by site is described in Table 1**.**

Yield, emergence and ear count for both trials are reported in Tables 3 through 10**.** Plot management dates and activities for both years are reported in Table 2.

Experimental Layout and Management

A randomized complete block design with three replications and 14 treatments was used for both locations. No tillage and conventional tillage were employed at Efaw and Lake Carl Blackwell, respectively. The treatment structure consisted of two different planting methods; the OSU-Hand Planter (OSU-HP) and the Farmers Practice (FP), two different row spacings (0.51 0.76m), two different plant to plant spacings (0.15 and 0.30m), three different rates of N fertilizer application (0, 60, and 120 kg N ha^{-1}), and four different planting populations (43,859, 65,359, 87,719, and 130,718 seeds/ha) (figure 10). The plot size was 3.03m x 6.06m with an alley of 1.52m. Maize was planted 5 cm deep and plant to plant spacing was maintained by marking a string at 15cm or 30cm according to the treatment structure to ensure uniformity. Twenty one strikes and forty strikes were made in each row with 15m and 30m plant to plant spacing respectively. Two checks were included and planted with the simulated farmer practice (stick planter), where a hole was made by using the stick planter and two or three seeds were dropped per hole. Urea fertilizer was applied side-dress at three different rates 0, 60 and 120 kg N ha^{-1}. Emergence counts were collected for both locations and evaluated. The OSU-hand planter was used to side dress in accordance to the treatment structure while the simulated farmers practice, N was dribble applied next to each plant. NDVI sensor readings were collected at stages V6 using the OSU Greenseeker Hand Held sensor (Trimble, Ukiah, CA). At the Perkins station, forage samples were collected from a 1.5 x 6.0m area, dried and weighed accordingly. The cob count was collected for both trials and grain was shelled from collected cobs. Moisture content for final grain yield was adjusted to 15.5%. Plot subsamples were taken and then dried at 75°C for 2 days, ground to pass a 240-mesh screen and analyzed for total N using a LECO Truspec CN dry combustion analyzer (Schepers et al., 1989).

Climatic data including total rainfall, average monthly temperature for Lake Carl Blackwell (2017), Lake Carl Blackwell (2018), Perkins (2017), and Efaw (2018) and are shown in Figures 1, 2, 3 and 4 respectively.

Data Analysis

The data was analyzed using SAS version 9.3 (SAS Institute, Cary, NC, USA. PROC GLM) to determine the effects of row spacing on maize yield. Mean separation was performed using LSD (α = 0.05). Single-degree-of-freedom-contrasts were also used to partition treatment differences and overall response.

CHAPTER IV

THE EFFECT OF ROW SPACING, PLANT DENSITY, NITROGEN RATE, AND PLANTING METHOD ON MAIZE (ZEA MAYS L) GRAIN YIELD

RESULTS AND DISCUSSION

Lake Carl Blackwell 2017

Emergence as affected by spacing, planter type and N rate

The emergence of maize was recorded until plants reached the third leaf stage. There was a significant ($p < 0.05$) effect of row spacing, plant spacing and planter type on emergence (Table 3). The overall percent emergence was good for all treatments, however, maximum emergence count (treatment 7) (311 plants) was achieved with the combination of narrow row (0.51m), narrow plant to plant spacing (0.15m) and the farmers practice (FP) (Figure 5). This was a result of two or three seeds planted per hole in order to simulate the farmers practice used in developing countries. Meanwhile, a non-orthogonal, single-degree-of-freedom-contrast showed a significant difference in emergence count with different row spacing, plant spacing and planter used (contrast 0.51 vs 0.76m, Table 5). Narrow row spacing (0.51m) had significantly ($p < 0.05$) higher emergence counts than wider row spacing (0.71m) (Table 3). This was because with reduced row spacing four rows could fit in a plot while only two rows fit when wider row spacing was used. Furthermore, the farmer's practice had a higher emergence count than the hand planter (contrast HP vs FP, Table 3). This was due to the fact that the OSU-hand planter drops one seed per hole while for the FP two or three seeds were dropped per hole. Similarly, narrow plant spacing (0.15m) resulted in a higher emergence count compared to wide plant to plant spacing (0.30m) (contrast plant spacing 0.30 vs 0.15m, Table 3). This was because reduced plant spacing had more seeds planted per plot than increased plant spacing. Finally, N rate of 120 kg ha^{-1} resulted in higher emergence count compared to 60kg ha^{-1} (contrast 60 vs 120 kg N ha^{-1}, Table 3). Higher plant population resulted to high number of plant stand.

Ear count as influenced by spacing, planter type and N rate

There was a significant ($p < 0.05$) effect of spacing, N rate and planter type on ear count at Lake Carl Blackwell 2017 (Table 4).

The maximum number of ears were recorded from the combination of reduced plant to plant spacing (0.15m), reduced row spacing (0.51m) with farmers planting (FP) method at 120 kg N ha^{-1}. This was due to a higher plant density and high N rate. On the other hand, the minimum ear count was recorded from the combination of wide row spacing (0.76m), narrow plant to plant spacing (0.15m) and with the farmer practice (Table 4). This may be due to low plant density and no fertilizer applied. Moreover, a non-orthogonal, single degree of freedom contrast showed that narrow row spacing (0.51m) had significantly ($p<0.01$) higher ear counts than wider row spacing (0.76m) (Table 4). Similarly, the farmers practice resulted in higher ear count than the OSU hand planter. The N rate of 120 kg ha^{-1} showed significantly higher ear count compared to 60 kg ha^{-1}. Plant population of 65,359 seeds/ha produced the highest ear count compared to other plant populations.

Maize yield as affected by spacing, planter type N rate and plant population

Analysis of variance showed significant differences due to treatment on grain yield ($p < 0.05$) (Table 5). The maximum yield was recorded from the combination of narrow row spacing (0.51m), wide plant to plant spacing (0.3cm), with an N rate of 60 kg ha^{-1}. On the other hand, the lowest yield recorded was from the combination of wide row spacing (0.76m), narrow plant to plant spacing (0.15m) and 0 kg ha^{-1} N rate. Additionally, a non-orthogonal, single degree of freedom contrast showed a significant difference between narrow row spacing and wide row spacing ($p < 0.01$) (Table 5). Narrow row spacing resulted in higher yields than wider row spacing. However, plant to plant spacing, N rate and planter type were not significantly different. This might have been due to the brief drought period during the growing season. Similar results were achieved by Williams et al. (2002) who reported a 1.4 Mg ha^{-1} yield increase when row spacing was reduced from 0.76m to 0.56m. Plant population of 65,359 resulted to higher yields compared to all other plant populations.

Perkins (2017)

Emergence as affected by spacing, planter type and N rate

Analysis of variance showed a significant ($p < 0.05$) effect of row, plant to plant spacing, and planter type (Table 6).

The overall percent emergence was good among all treatments with the maximum recorded in the farmers practice while the minimum was from the OSU hand planter. Furthermore, emergence count was recorded and the maximum count was observed from the combination of narrow row (0.51m), narrow plant to plant spacing (0.15m) and farmers practice (FP) (Figure 6). Essentially, a non-orthogonal, single-degree-of-freedom-contrast showed a significant difference in emergence count with different row spacing, plant spacing and planter used (contrast 0.51 vs 0.76m, Table 6). Narrow row spacing (0.51m) had a significantly ($p < 0.01$) higher emergence count than increased row spacing (0.71m). Likewise, the farmer’s practice had higher emergence than the hand planter (contrast HP vs FP, Table 6). Also, narrow plant spacing (0.15m) resulted in a higher emergence count compared to wide plant to plant spacing (0.30m) (contrast plant spacing 0.30 vs 0.15m, Table 7). Finally, the contrast between the N rate of 120 kg ha^{-1} and 60 kg ha^{-1} was not significantly different (contrast 60 vs 120 kg/ha, Table 6). Plant population of 130,718 resulted to the highest number of plant stand due to increased plant population.

Ear count as affected by spacing, planter type and N rate

There was a significant ($p < 0.05$) effect of spacing, N rate and planter type on ear count (Table 7).

The maximum number of ears was recorded from the combination of reduced plant to plant spacing, and reduced row spacing at 60 kg N ha^{-1}. Alternatively, the lowest ear count was recorded from the combination of wider row spacing (0.76m), narrow plant to plant spacing (0.51m) with the farmers practice (Table 7). Furthermore, a non-orthogonal, single degree of freedom contrast showed that narrow row spacing (0.51m) had significantly ($p<0.01$) higher ear counts than wider row spacing (0.76m) (Table 7). Similarly, an N rate of 120 kg ha^{-1} showed significantly higher ear count compared to 60 kg ha^{-1}. Nonetheless, plant to plant spacing and planter type did not affect grain yield. Plant population of 65,359 seeds/ha resulted to higher ear count over all other plant populations.

Grain yield as affected by spacing and N rate

Analysis of variance showed that there were significant treatment differences in grain yield ($p < 0.01$) (Table 8). The highest yield of 4.47 Mg ha^{-1} ha was recorded from narrow row spacing (0.51m), wider plant-to-plant spacing (0.30m), and an N rate of 60 kg ha^{-1} using the hand planter. This was higher than the 2.66 Mg ha^{-1} observed in the check plot. The farmers practice (FP) had the lowest yield recorded for treatments at the same rate (Table 8). Comparison of treatments using non-orthogonal, single degree of freedom contrasts showed that narrow row spacing resulted in significantly higher yields compared to wide row spacing at (($p < 0.01$, Table 8). Furthermore, wider plant to plant spacing produced higher yields compared to narrow plant to plant spacing ($p < 0.05$). Similarly, the OSU hand planter produced higher yields compared to the farmers practice ($p < 0.1$). However, N rate was not significantly different (Table 8). Similar results were reported by Shapiro et al. (2006) who stated that narrow row spacing increased yield by 4%. In addition, the N rate of 84 kg ha^{-1} increased yields by 24%. Plant population of 65,359 seed/ha produced the highest grain yields compared to all other plant populations.

Forage as affected by spacing, planter type and N rate

The forage weight recorded at Perkins in 2017 showed that narrow row spacing resulted in higher forage yields compared to wider row spacing. The highest forage yield (8.17kg) was recorded from the combination of narrow row, and narrow plant to plant spacing with the OSU hand planter. Alternatively, the lowest forage weight (3.72kg) was recorded from the combination of wide row spacing, and wide plant to plant spacing with the farmers practice.

LCB (2018)

Emergence as affected by spacing and N rate

The overall percent emergence (wide row spacing, narrow plant to plant spacing with the hand planter) was 97%. Emergence was recorded and the maximum count was from narrow row spacing, narrow plant to plant spacing, N rate 60 kg ha^{-1}, and with the farmers practice. The lowest emergence was recorded from the combination of wide row spacing, wide plant to plant spacing, N rate of 120 kg ha^{-1} also with the hand planter. Furthermore, upon evaluation using non-orthogonal single-degree-of-freedom-contrasts, it was observed that there was a significant difference in emergence with different row spacing, plant spacing and planter used (contrast 0.51 vs 0.76m, Table 3). Reduced row spacing (0.51m) had a significantly higher emergence count than increased row spacing (0.71m). It was also observed that the farmers practice had better emergence than the OSU hand planter (contrast HP vs FP, Table 3). The simulated farmers practice had a significantly ($p<0.01$) higher emergence count compared to the OSU-hand planter. In addition, the contrast between narrow plant spacing of 0.15m compared to wide plant to plant spacing of 0.30m was significant at ($p<0.01$). Narrow plant spacing (0.51m) had higher maize emergence compared to wider plant to plant spacing (0.30m) (contrast plant spacing 0.30 vs 0.15m, Table 5). However, N rate had no effect on emergence count at this site. Highest plant population (130,718) resulted to the highest number of plant stand due to increased plant population.

Ear count as affected by spacing, planter type and N rate

The effect of spacing, and planter type on ear count was significant ($p<0.05$). The highest number of ears was recorded from narrow plant to plant spacing, and narrow row spacing using the hand planter at 120 kg N ha^{-1}. Alternatively, the lowest ear count was recorded from the combination of wide row spacing, narrow plant to plant spacing, and no N applied with the farmers practice (Table 4). Furthermore, a non-orthogonal single degree of freedom contrast (Row spacing 0.51 vs 0.76m, table 4) showed a significantly higher ear count with reduced row spacing compared to wider row spacing. This was a result of the reduced spacing. In addition, narrow and wide plant to plant spacing (contrast 0.30 vs 0.15m) was significant at ($p < 0.01$) (Table 4). Narrow plant spacing (0.15m) resulted to higher ear counts compared to wide plant spacing (0.30m). Likewise, the hand planter produced higher ear counts compared to the farmers practice at ($p < 0.01$) (Table 4). The N rates of 60 and 120 kg ha^{-1} were not significantly different. Sensor NDVI data was collected at V6 growth stage. There was a significant difference due to treatment for NDVI. Non orthogonal contrasts of row spacing, N rate and planter type showed a significant difference ($p < 0.01$) (Table 10). Plant population of 65,359 seed/ha produced the highest ear counts compared to all other treatments.

Grain yield as affected by Spacing and N rate

Analysis of variance showed significant differences due to treatment in grain yield ($p < 0.05$) (Table 5). The highest yield was recorded from the combination of narrow row spacing (0.51cm), wide plant spacing (0.3cm), and an N rate of 60 kg ha^{-1} . While the lowest yield was recorded from the combination of wide row spacing, narrow plant to plant spacing, 0 kg ha^{-1} with the farmers practice of 2.53 Mg ha^{-1}. Moreover, a non-orthogonal single degree of freedom contrast showed that narrow row spacing produced significantly higher grain yields compared to wide row spacing ($p < 0.01$) (Table 5). Similarly, narrow plant spacing showed a significantly higher grain yield versus wide plant spacing. In addition, grain yield was significantly higher at an N rate of 60 and 120 kg ha^{-1} compared to the check. Also, there were significant differences between N rates 60 and 120 kg ha^{-1}. The hand planter resulted to higher yields compared to the farmers practice. This was because of better plant stand homogeneity with the hand planter compared to the traditional farmers practice. Similarly, Cox et al. (2001) reported that narrow row spacing increased yields by 7.5%. Plant population of 65,359 resulted to higher grain yields compared to all other plant populations.

Efaw 2018

Emergence as affected by spacing, planter type and N rate

Analysis of variance showed that treatment influenced emergence ($p<0.05$). The overall percent emergence was good at this site. Furthermore, emergence count was analyzed and the highest emergence count was attained from reduced row spacing, plant spacing, 60 kg N ha^{-1} with the farmers practice (Table 6). While, the lowest emergence count was recorded from the combination of wide row spacing, wide plant-to-plant spacing, and 60 kg ha^{-1} N rate with the hand planter. A non-orthogonal single degree of freedom contrast showed that narrow row spacing had a significantly higher emergence count than wider row spacing. Also, narrow plant spacing had a significantly higher emergence count than increased plant spacing. In addition, the farmers practice resulted in higher emergence compared to the OSU hand planter. Likewise, 120 kg N ha^{-1} resulted in higher emergence compared to 60 kg ha^{-1}. Higher plant population (130,718 seeds/ha) produced higher number of plant stand due to increased plant population density.

Ear count as affected by spacing, planter type and N rate

The effect of spacing, planter type and N rate on ear count was significant ($p<0.05$). The highest number of ears was recorded from narrow plant to plant spacing (0.15m), narrow row spacing (0.51m) using the hand planter at 120 kg N ha^{-1}. On the other hand, the lowest ear count was recorded from the combination of wide row spacing (0.76m), narrow plant to plant spacing (0.15m), 60 kg N ha^{-1} and with the farmers practice (Table 7). Furthermore, a non-orthogonal single degree of freedom contrast (row spacing 0.51 vs 0.76m, Table 8) showed a significantly higher ear count with reduced row spacing (0.51m) compared to wider row spacing (0.76m). In addition, narrow and wide plant to plant spacing (contrast 0.30 vs 0.15m) was significant at ($p < 0.01$) (Table 7). Narrow plant spacing (0.15m) resulted in higher ear counts compared to wide plant spacing (0.30m). Likewise, the hand planter produced higher ear counts compared to the farmers practice ($p < 0.01$) (Table 7). The N rate of 120 kg N ha^{-1} resulted in higher ear counts compared to 60 kg N ha^{-1}. Plant population of 65359 seeds/ha produced higher ear counts compared to all other plant populations.

Grain yield as affected by spacing, planter type and N rate

Analysis of variance showed that there were significant differences due to treatment in grain yield ($p < 0.01$) (Table 8). The highest yield was recorded at the narrow row spacing (0.51m), wider plant spacing (0.30m), N rate of 120 kg ha^{-1} using the OSU hand planter (10.84 Mg ha^{-1}). The lowest yield was recorded from the check plot (1.76 Mg ha^{-1}, Table 8).

Treatment comparisons showed a significant difference between narrow row spacing and wider row spacing at ($p < 0.01$) (Table 8). Narrow row spacing resulted in higher grain yields compared to wider row spacing. Furthermore, wide plant to plant spacing produced a higher grain yield than narrow plant to plant spacing. Likewise, the hand planter resulted in a higher grain yield compared to the farmers practice. Finally, an N rate of 120 kg ha^{-1} produced significantly higher yields than 60 kg N ha^{-1}

The 60 kg N ha^{-1} rate accounted for the highest yield but was not significantly different from 120 kg N ha^{-1}. However, 60 kg N ha^{-1} was significantly different from the check ($p < 0.01$) (Table 8). Similar work by Barbieri et al. (2012) stated that narrow and wide row spacing resulted in yields of 5.51 and 4.49 Mg ha^{-1} respectively. Plant population of 65,359 seeds/ha resulted to the highest grain yields over all other treamtments.

Sensor NDVI data was collected at V6 growth stage. Non-orthogonal contrasts of row spacing, N rate and Planter type were not significant (Table 10).

CHAPTER V

THE EFFECT OF ROW SPACING, PLANT DENSITY, NITROGEN RATE, AND PLANTING METHOD ON MAIZE (ZEA MAYS L) GRAIN YIELD

CONCLUSIONS

Results from this study demonstrated that; (1) narrow row spacing (0.51m) at all locations resulted in higher maize grain yields compared to the wider row spacing (0.76m). At Perkins and Lake Carl Blackwell 2017, narrow row spacing resulted in a yield increase of 14% . Narrow row spacing increased maize grain yields by 20% and 18% respectively at Efaw and LCB. Likewise, (2) plant population of 65,359 seeds/ha produced the highest maize grain yields. Also, (3) wider plant spacing (0.30m) resulted in yield increases at all locations when compared to narrow plant spacing (0.15m). At Perkins and LCB 2017, wide plant spacing resulted in a yield increase of 6% and 8% respectively. While, at Efaw and LCB 2018, wider plant spacing increased yields by 18% and 12% respectively. Furthermore, at Perkins and LCB 2017, (4) the N rate of 60 kg ha^{-1} increased yields by 10% and 24% respectively while 120 kg N ha^{-1} increased yields by 11% and 25% respectively. At Efaw and LCB in 2018, the N rate of 60 kg ha^{-1} increased yields by 16% and 23% respectively versus the check, while 120 kg N ha^{-1} increased yields by 62% and 58% respectively. In addition, (5) the hand planter and the farmers practice were not significantly different in 2017. However, at LCB and Efaw 2018, the hand planter resulted in a yield increase of 10% and 26% respectively over the farmers practice. Finally, the combination of narrow row spacing and wide plant-to-plant spacing at Perkins and LCB 2017 resulted in a yield increase of 14% and 20% respectively.

Similarly, at Efaw and LCB 2018 yields were increased by 14% and 20% respectively for the narrow versus wide row spacing.

This data shows that maize producers in developing countries could use narrow row spacing with wide plant-to-plant spacing to increase grain yields. Also, the OSU hand planter can be used to increase maize grain yield through improved plant stand homogeneity. The OSU hand planter has the added benefit of being able to apply mid-season fertilizer by plant, thus increasing nitrogen use efficiency.

Because corn in the developing world is planted by hand, analysis should really focus on number of plants per unit area. Row spacing is something that producers seek, especially as they traverse across the terrain. Plant to plant spacing can certainly be taught, but the row spacing for working in and around the plants both for weeding and finally harvesting is somewhat fixed. This is also because some animal use requires navigation within the rows, and this could be prohibitive when too narrow.

TABLES

Table 1. Description of soil series at Stillwater, Efaw and Lake Carl Blackwell, OK.

Location	Soil Series
Perkins, OK	Konawa fine sandy loam (fine-loamy, mixed, thermic Ultic haplustalfs Paleustolls)
Efaw, OK	Ashport silty clay loam (fine-silty, mixed, superactive, thermic Fluventic Haplustolls)
LCB, OK	Port Silt Loam (fine-silty, mixed, thermic cumulic Haplustolls)

LCB – Lake Carl Blackwell

Table 2. Field activities for each location, 2017 and 2018.

	2017		2018	
Field Activity	Perkins	LCB	Efaw	LCB
Pre-plant N fertilization	April 11	May 5	April 25	April 25
Planting	April 19	May 9	April 30	May 1
Side-dress	June 22	June 23	June 14	June 15
Harvest	August 30	August 29	September 10	September 11

Perkins, Oklahoma Agricultural Experiment Station near Stillwater, OK;
Efaw, Oklahoma Agricultural Experiment Station near Stillwater, OK;
LCB, Oklahoma Agricultural Experiment Station west of Stillwater, OK near Lake Carl Blackwell

Table 3. Emergence means as influenced by sidedress N and plant-to-plant spacing, Lake Carl Blackwell, 2017-2018

Treatment	Side-dress N (kg/ha)	PPS (m)	RS (m)	Planter	Emergence (%)	
					LCB 2017	LCB 2018
1	0	0.15	0.51	FP	97	91
2	0	0.15	0.76	FP	96	94
3	60	0.15	0.51	HP	93	95
4	60	0.15	0.76	HP	88	93
5	60	0.30	0.51	HP	96	95
6	60	0.30	0.76	HP	100	90
7	60	0.15	0.51	FP	94	91
8	60	0.15	0.76	FP	100	95
9	60	0.30	0.51	FP	96	91
10	60	0.30	0.76	FP	98	86
11	120	0.30	0.51	HP	96	95
12	120	0.30	0.76	HP	100	90
13	120	0.15	0.51	HP	98	89
14	120	0.15	0.76	HP	95	97
SED					7.9	24
CV, %					7	33

Contrasts	**Treatments**		
Row spacing 60kg/ha 0.51 vs 0.76	3vs4 5vs6 7vs8 9vs10	*	*
Row spacing 120kg/ha 0.51 vs 0.76	11vs12 13vs14	*	*
HP vs FP	3 4 5 6 vs 7 8 9 10	*	*
Plant spacing 0.30 vs 0.15	11 12 vs 13 14	*	*
NRate 0 vs 60	1 2 vs 7 8	Ns	ns
NRate 60 vs 120	3 4 5 6 vs 11 12 13 14	***	ns
Population density 65359 vs 130718	3vs5 7vs9 11vs13	*	*
Population density 65359 vs 87719	4vs5 8vs9 11vs14	*	ns
Population density 65359 vs 43859	5vs6 9vs10 11vs12	*	*

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

CV, coefficient of variation, %

FP, farmer practice

HP, OSU Hand planter

ns, not-significant *, **, ***, significant at Pr>F, 0.01, 0.05 and 0.10 probability levels, respectively.

Table 4. Ear count means as influenced by sidedress N and plant-to-plant spacing, Lake Carl Blackwell, 2017-2018

Treatment	Side-dress N (kg/ha)	PPS (m)	RS (m)	Planter	Ear Count	
					LCB 2017	LCB 2018
1	0	0.15	0.51	FP	83	87
2	0	0.15	0.76	FP	67	78
3	60	0.15	0.51	HP	104	136
4	60	0.15	0.76	HP	94	102
5	60	0.30	0.51	HP	84	89
6	60	0.30	0.76	HP	71	136
7	60	0.15	0.51	FP	121	103
8	60	0.15	0.76	FP	105	112
9	60	0.30	0.51	FP	99	91
10	60	0.30	0.76	FP	85	121
11	120	0.30	0.51	HP	101	126
12	120	0.30	0.76	HP	80	86
13	120	0.15	0.51	HP	135	138
14	120	0.15	0.76	HP	104	109
SED					12.31	4.49
CV, %					16	5
Contrasts			**Treatments**			
Row spacing 60kg/ha 0.51 vs 0.76			3vs4 5vs6 7vs8 9vs10		**	*
Row spacing 120kg/ha 0.51 vs 0.76			11vs12 13vs14		*	*
HP vs FP			3 4 5 6 vs 7 8 9 10		**	*
Plant spacing 0.30 vs 0.15			11 12 vs 13 14		*	*
NRate 0 vs 60			1 2 vs 7 8		*	*
NRate 60 vs 120			3 4 5 6 vs 11 12 13 14		*	ns
Population density 65359 vs 130718			3vs5 7vs9 11vs13		*	*
Population density 65359 vs 87719			4vs5 8vs9 11vs14		ns	ns
Population density 65359 vs 43859			5vs6 9vs10 11vs12		**	*

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

CV, coefficient of variation, %

FP, farmer practice

HP, OSU Hand planter

ns, not-significant *, **, ***, significant at Pr>F, 0.01, 0.05 and 0.10 probability levels, respectively.

Table 5. Grain yield means as influenced by sidedress N and plant-to-plant spacing, Lake Carl Blackwell, 2017-2018

Treatment	Side-dress N (kg/ha)	PPS (m)	RS (m)	Planter	Grain yield, Mg ha^{-1}	
					LCB 2017	LCB 2018
1	0	0.15	0.51	FP	3.52	3.74
2	0	0.15	0.76	FP	2.36	2.53
3	60	0.15	0.51	HP	4.91	6.48
4	60	0.15	0.76	HP	3.77	4.66
5	60	0.30	0.51	HP	5.92	7.37
6	60	0.30	0.76	HP	4.52	5.26
7	60	0.15	0.51	FP	5.55	5.73
8	60	0.15	0.76	FP	3.88	4.02
9	60	0.30	0.51	FP	6.29	5.83
10	60	0.30	0.76	FP	5.03	4.15
11	120	0.30	0.51	HP	5.94	14.25
12	120	0.30	0.76	HP	4.22	8.67
13	120	0.15	0.51	HP	4.99	10.28
14	120	0.15	0.76	HP	3.70	7.88
SED					0.91	0.97
CV, %					24	18

Contrasts	**Treatments**		
Row spacing 60kg/ha 0.51 vs 0.76	3vs4 5vs6 7vs8 9vs10	*	*
Row spacing 120kg/ha 0.51 vs 0.76	11vs12 13vs14	**	*
HP vs FP	3 4 5 6 vs 7 8 9 10	ns	**
Plant spacing 0.30 vs 0.15	11 12 vs 13 14	ns	*
NRate 0 vs 60	1 2 vs 7 8	*	*
NRate 60 vs 120	3 4 5 6 vs 11 12 13 14	ns	*
Population density 65359 vs 130718	3vs5 7vs9 11vs13	***	*
Population density 65359 vs 87719	4vs5 8vs9 11vs14	*	*
Population density 65359 vs 43859	5vs6 9vs10 11vs12	**	*

SED, standard error of the difference between two equally replicated means
CV, coefficient of variation, %
FP, farmer practice
HP, OSU Hand planter
ns, not-significant *, **, ***, significant at Pr>F, 0.01, 0.05 and 0.10 probability levels, respectively.

Table 6. Plant emergence as affected by sidedress N and plant to plant spacing, Perkins 2017, Efaw 2018

Treatment	Side-dress N (kg/ha)	PPS (m)	RS (m)	Planter	Emergence (%)	
					Perkins 2017	Efaw 2018
1	0	0.15	0.51	FP	91	97
2	0	0.15	0.76	FP	83	100
3	60	0.15	0.51	HP	90	92
4	60	0.15	0.76	HP	96	98
5	60	0.30	0.51	HP	90	95
6	60	0.30	0.76	HP	78	100
7	60	0.15	0.51	FP	91	92
8	60	0.15	0.76	FP	92	96
9	60	0.30	0.51	FP	93	96
10	60	0.30	0.76	FP	96	96
11	120	0.30	0.51	HP	84	94
12	120	0.30	0.76	HP	90	90
13	120	0.15	0.51	HP	94	90
14	120	0.15	0.76	HP	88	97
SED					5.35	6.01
CV, %					8	6
Contrasts			**Treatments**			
Row spacing 60kg/ha 0.51 vs 0.76			3vs4 5vs6 7vs8 9vs10		*	*
Row spacing 120kg/ha 0.51 vs 0.76			11vs12 13vs14		*	*
HP vs FP			3 4 5 6 vs 7 8 9 10		*	*
Plant spacing 0.30 vs 0.15			11 12 vs 13 14		*	*
NRate 0 vs 60			1 2 vs 7 8		ns	*
NRate 60 vs 120			3 4 5 6 vs 11 12 13 14		ns	***
Population density 65359 vs 130718			3vs5 7vs9 11vs13		*	*
Population density 65359 vs 87719			4vs5 8vs9 11vs14		*	*
Population density 65359 vs 43859			5vs6 9vs10 11vs12		***	***

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

CV, coefficient of variation, %

FP, farmer practice

HP, OSU Hand planter

ns, not-significant *, **, ***, significant at Pr>F, 0.01, 0.05 and 0.10 probability levels, respectively.

Table 7. Ear count means as influenced by sidedress N and plant-to-plant spacing, Perkins 2017 and Efaw 2018.

Treatment	Side-dress N (kg/ha)	PPS (m)	RS (m)	Planter	Ear Count	
					Perkins 2017	Efaw 2018
1	0	0.15	0.51	FP	62	117
2	0	0.15	0.76	FP	56	81
3	60	0.15	0.51	HP	79	115
4	60	0.15	0.76	HP	74	87
5	60	0.30	0.51	HP	69	90
6	60	0.30	0.76	HP	65	67
7	60	0.15	0.51	FP	79	123
8	60	0.15	0.76	FP	73	99
9	60	0.30	0.51	FP	78	94
10	60	0.30	0.76	FP	68	75
11	120	0.30	0.51	HP	66	115
12	120	0.30	0.76	HP	60	103
13	120	0.15	0.51	HP	71	132
14	120	0.15	0.76	HP	64	103
SED					4.38	4.19
CV, %					8	5
Contrasts			**Treatments**			
Row spacing 60kg/ha 0.51 vs 0.76			3vs4 5vs6 7vs8 9vs10		*	*
Row spacing 120kg/ha 0.51 vs 0.76			11vs12 13vs14		**	*
HP vs FP			3 4 5 6 vs 7 8 9 10		ns	*
Plant spacing 0.30 vs 0.15			11 12 vs 13 14		ns	*
NRate 0 vs 60			1 2 vs 7 8		*	*
NRate 60 vs 120			3 4 5 6 vs 11 12 13 14		*	*
Population density 65359 vs 130718			3vs5 7vs9 11vs13		**	*
Population density 65359 vs 87719			4vs5 8vs9 11vs14		ns	ns
Population density 65359 vs 43859			5vs6 9vs10 11vs12		**	*

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

CV, coefficient of variation, %

FP, farmer practice

HP, OSU Hand planter

ns, not-significant *, **, ***, significant at Pr>F, 0.01, 0.05 and 0.10 probability levels, respectively.

Table 8. Grain yield means as influenced by sidedress N and plant-to-plant spacing, Perkins 2017 and Efaw 2018.

Treatment	Side-dress N (kg/ha)	PPS (m)	RS (m)	Planter	Grain yield (Mg ha^{-1})	
					Perkins 2017	Efaw 2018
1	0	0.15	0.51	FP	3.27	2.51
2	0	0.15	0.76	FP	2.66	1.76
3	60	0.15	0.51	HP	3.61	5.7
4	60	0.15	0.76	HP	2.67	3.79
5	60	0.30	0.51	HP	4.47	6.01
6	60	0.30	0.76	HP	3.03	4.57
7	60	0.15	0.51	FP	4.09	3.73
8	60	0.15	0.76	FP	3.25	2.07
9	60	0.30	0.51	FP	4.15	3.83
10	60	0.30	0.76	FP	3.13	2.06
11	120	0.30	0.51	HP	4.09	10.84
12	120	0.30	0.76	HP	3.41	7.12
13	120	0.15	0.51	HP	3.81	7.2
14	120	0.15	0.76	HP	2.87	5.24
SED					0.24	0.55
CV, %					8	11
Contrasts			**Treatments**			
Row spacing 60kg/ha 0.51 vs 0.76			3vs4 5vs6 7vs8 9vs10		*	*
Row spacing 120kg/ha 0.51 vs 0.76			11vs12 13vs14		*	*
HP vs FP			3 4 5 6 vs 7 8 9 10		***	*
Plant spacing 0.30 vs 0.15			11 12 vs 13 14		**	*
NRate 0 vs 60			1 2 vs 7 8		*	*
NRate 60 vs 120			3 4 5 6 vs 11 12 13 14		Ns	*
Population density 65359 vs 130718			3vs5 7vs9 11vs13		*	*
Population density 65359 vs 87719			4vs5 8vs9 11vs14		*	*
Population density 65359 vs 43859			5vs6 9vs10 11vs12		*	*

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

CV, coefficient of variation, %

FP, farmer practice

HP, OSU Hand planter

ns, not-significant *, **, ***, significant at Pr>F, 0.01, 0.05 and 0.10 probability levels, respectively.

Table 9. NDVI as affected by sidedress N and plant-to-plant spacing Perkins 2017 and Efaw 2018

Treatment	Side-dress N (kg/ha)	PPS (m)	RS (m)	Planter	NDVI V6	
					Perkins 2017	Efaw 2018
1	0	0.15	0.51	FP	0.62	0.83
2	0	0.15	0.76	FP	0.62	0.82
3	60	0.15	0.51	HP	0.64	0.82
4	60	0.15	0.76	HP	0.68	0.82
5	60	0.30	0.51	HP	0.65	0.76
6	60	0.30	0.76	HP	0.64	0.77
7	60	0.15	0.51	FP	0.61	0.79
8	60	0.15	0.76	FP	0.66	0.83
9	60	0.30	0.51	FP	0.61	0.80
10	60	0.30	0.76	FP	0.6	0.81
11	120	0.30	0.51	HP	0.65	0.79
12	120	0.30	0.76	HP	0.62	0.75
13	120	0.15	0.51	HP	0.63	0.80
14	120	0.15	0.76	HP	0.65	0.83
SED					5.51	0.07
CV, %					35	10
Contrasts			**Treatments**			
Row spacing 60kg/ha 0.51 vs 0.76			3vs4 5vs6 7vs8 9vs10		Ns	ns
Row spacing 120kg/ha 0.51 vs 0.76			11vs12 13vs14		Ns	ns
HP vs FP			3 4 5 6 vs 7 8 9 10		Ns	ns
Plant spacing 0.30 vs 0.15			11 12 vs 13 14		Ns	ns
NRate 0 vs 60			1 2 vs 7 8		Ns	ns
NRate 60 vs 120			3 4 5 6 vs 11 12 13 14		Ns	ns

SED, standard error of the difference between two equally replicated means
CV, coefficient of variation, %
FP, farmer practice
HP, OSU Hand planter
ns, not-significant *, **, ***, significant at Pr>F, 0.01, 0.05 and 0.10 probability levels, respectively.

Table 10. NDVI as affected by sidedress N and plant-to-plant spacing, Lake Carl Blackwell, 2017-2018

Treatment	Side-dress kg N ha^{-1}	PPS (m)	RS (m)	Planter	NDVI V6	
					LCB 2017	LCB 2018
1	0	0.15	0.51	FP	0.69	0.44
2	0	0.15	0.76	FP	0.68	0.47
3	60	0.15	0.51	HP	0.78	0.51
4	60	0.15	0.76	HP	0.74	0.51
5	60	0.30	0.51	HP	0.74	0.55
6	60	0.30	0.76	HP	0.72	0.58
7	60	0.15	0.51	FP	0.83	0.56
8	60	0.15	0.76	FP	0.82	0.59
9	60	0.30	0.51	FP	0.65	0.59
10	60	0.30	0.76	FP	0.7	0.63
11	120	0.30	0.51	HP	0.75	0.61
12	120	0.30	0.76	HP	0.76	0.74
13	120	0.15	0.51	HP	0.78	0.79
14	120	0.15	0.76	HP	0.8	0.85
SED					0.05	0.15
CV, %					10	31

Contrasts	**Treatments**		
Row spacing 60kg/ha 0.51 vs 0.76	3vs4 5vs6 7vs8 9vs10	ns	ns
Row spacing 120kg/ha 0.51 vs 0.76	11vs12 13vs14	ns	ns
HP vs FP	3 4 5 6 vs 7 8 9 10	ns	ns
Plant spacing 0.30 vs 0.15	11 12 vs 13 14	ns	ns
NRate 0 vs 60	1 2 vs 7 8	ns	ns
NRate 60 vs 120	3 4 5 6 vs 11 12 13 14	ns	ns

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

CV, coefficient of variation, %

FP, farmer practice

HP, OSU Hand planter

ns, not-significant *, **, ***, significant at Pr>F, 0.01, 0.05 and 0.10 probability levels, respectively

FIGURES

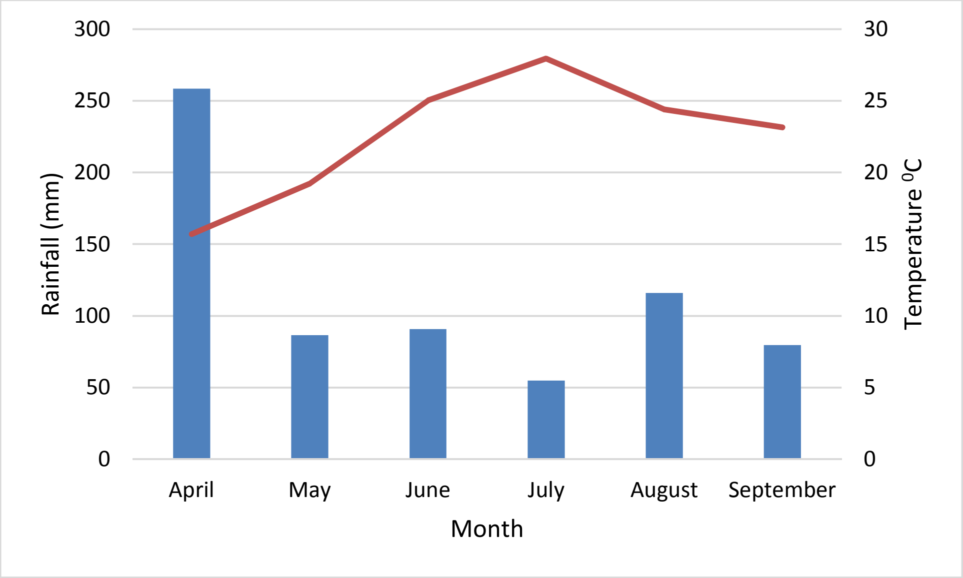

Figure 1: Amount of Rainfall from planting to harvest at Lake Carl Blackwell in 2017

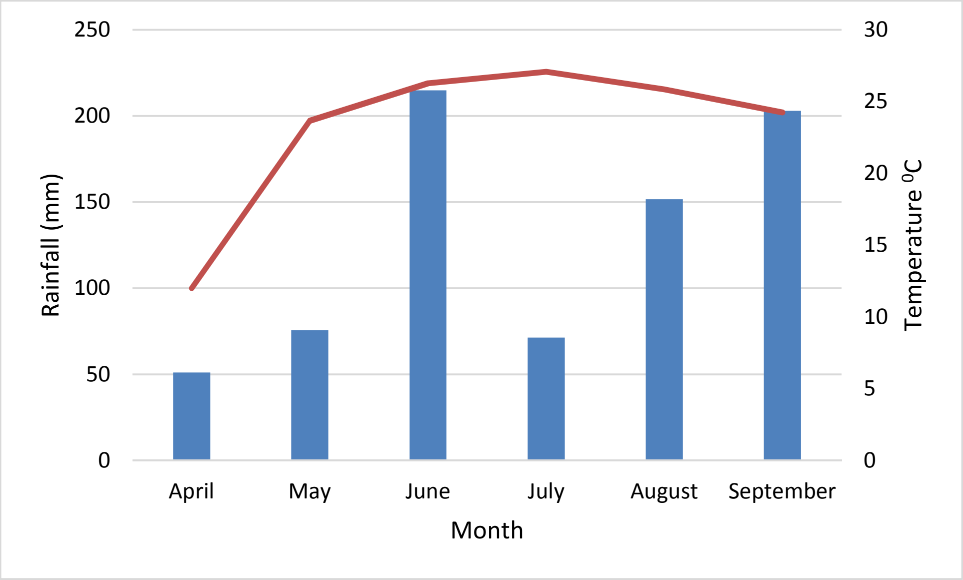

Figure 2: Amount of Rainfall from planting to harvest at Lake Carl Blackwell in 2018

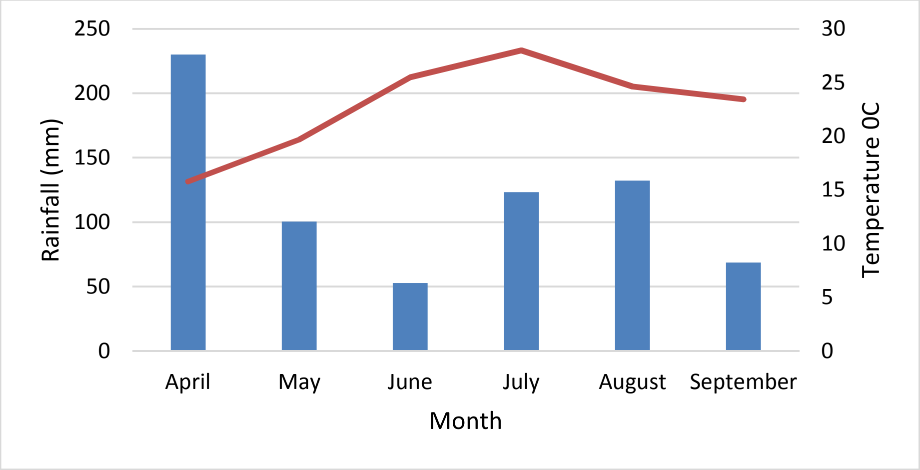

Figure 3: Amount of Rainfall from planting to harvest at Perkins in 2017

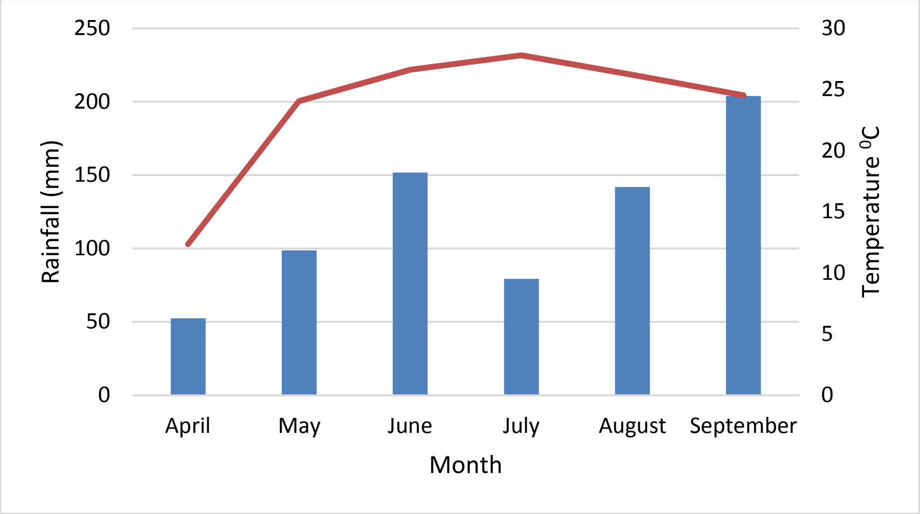

Figure 4: Amount of Rainfall from planting to harvest at Efaw in 2018

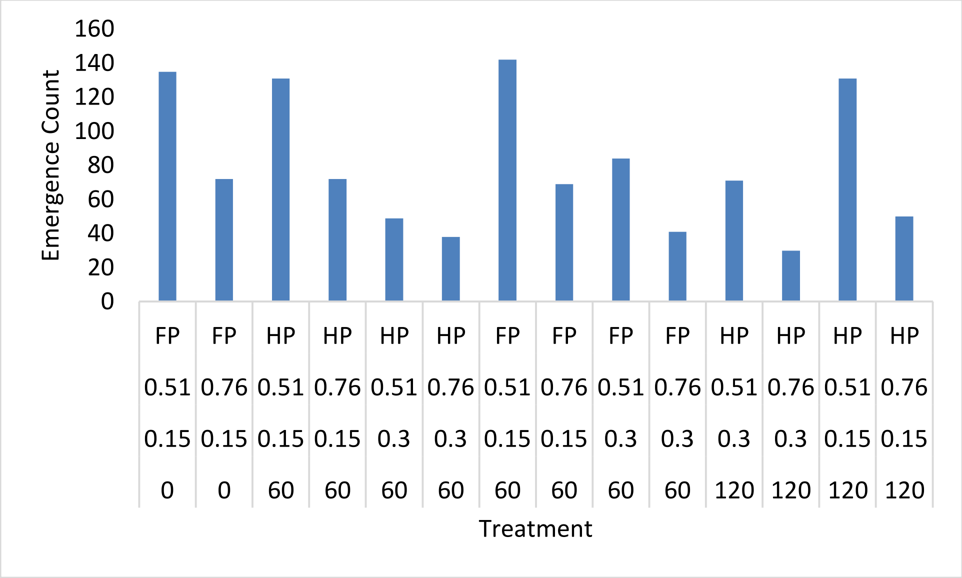

Figure 5: Emergence count as affected by spacing and planter at Perkins 2017

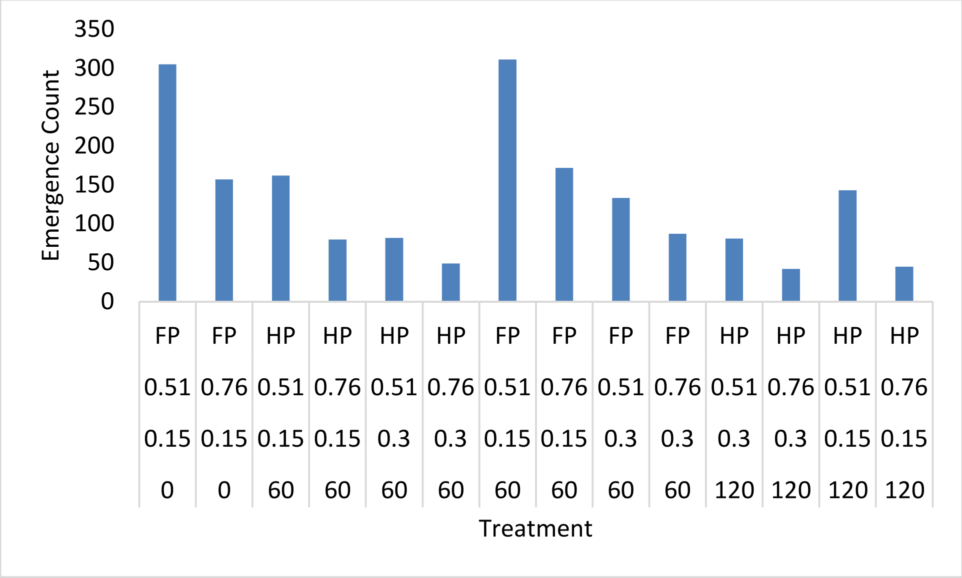

Figure 6: Emergence count as affected by spacing and planter at Lake Carl Blackwell 2017

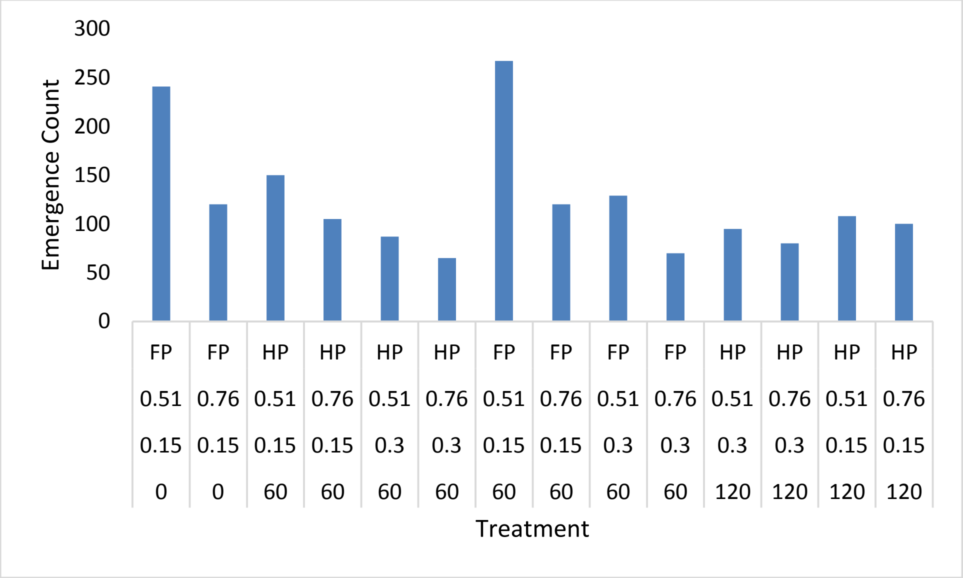

Figure 7: Emergence count as affected by spacing and planter at Lake Carl Blackwell 2018

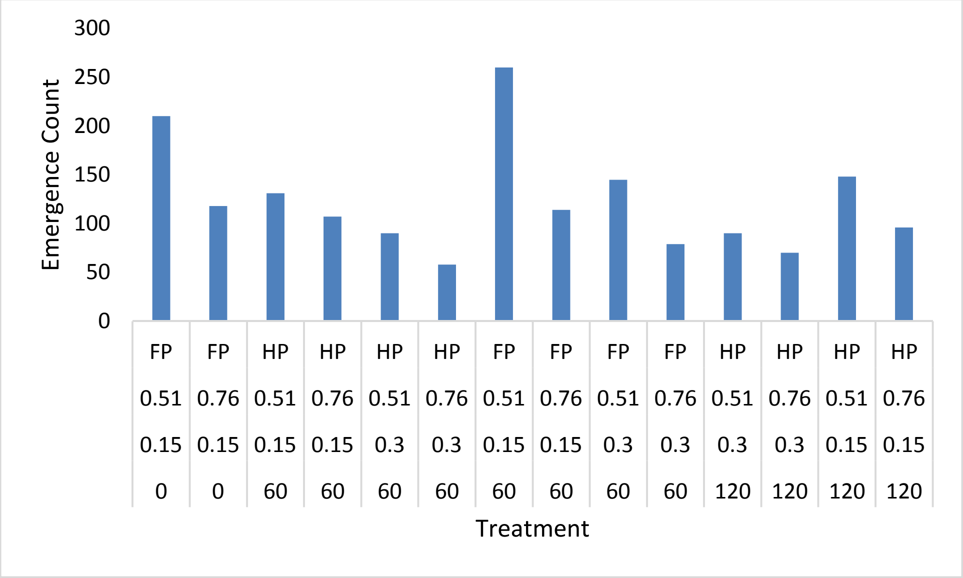

Figure 8: Emergence count as affected by spacing and planter at Efaw 2018

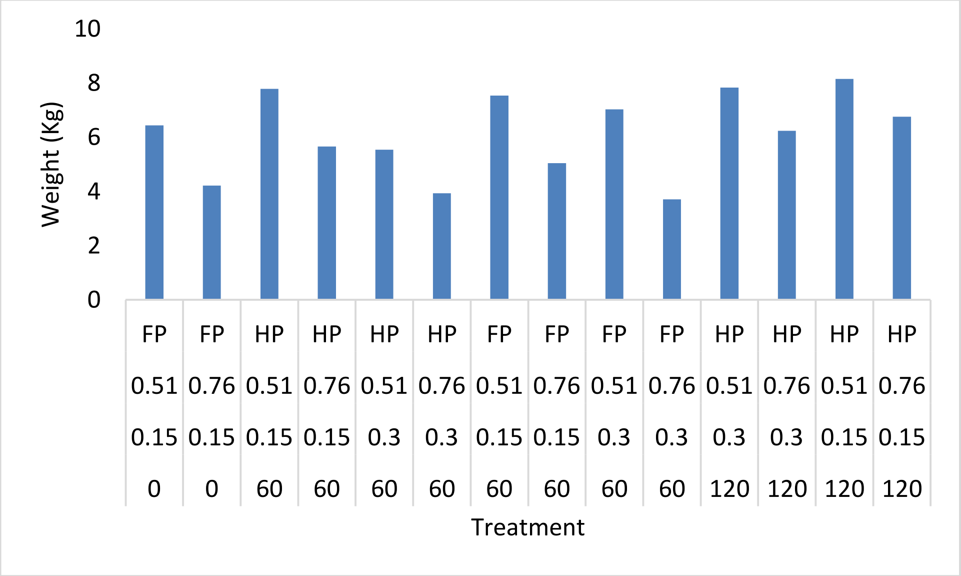

Figure 9: Forage weight as affected by spacing, planter type and N rate at Perkins 2017

Treatment	Side-dress N (kg ha^{-1})	Plant to plant spacing (m)	Row spacing (m)	Planter	Population (Seeds ha^{-1})
1	0	0.15	0.51	FP	130,718
2	0	0.15	0.76	FP	87,719
3	60	0.15	0.51	HP	130,718
4	60	0.15	0.76	HP	87,719
5	60	0.3	0.51	HP	65,359
6	60	0.3	0.76	HP	43,859
7	60	0.15	0.51	FP	130,718
8	60	0.15	0.76	FP	87,719
9	60	0.3	0.51	FP	65,359
10	60	0.3	0.76	FP	43,859
11	120	0.3	0.51	HP	65,359
12	120	0.3	0.76	HP	43,859
13	120	0.15	0.51	HP	130,718
14	120	0.15	0.76	HP	87,719

Figure 10: Treatment structure comprising of N rate, row spacing, plant spacing, planting method and population density.

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CHANGES IN CHECK PLOT YIELDS OVER TIME IN THREE LONG-TERM WINTER WHEAT EXPERIMENTS

Abstract

In long-term experiments, grain yields of the check plot (no N applied) can reveal added information about the environment when studied alone. The objective of this work was to evaluate check plot yields and how they changed over time. Furthermore, changes in check plot yields were expected to provide a better understanding of fertilizer N response and yield potential. Three long-term experiments, were targeted for added analysis, The Magruder Plots, Experiment 222, both near Stillwater, OK, and Experiment 502, just west of Lahoma, OK were included in this analysis. Check plots and nitrogen (N) fertilized plots had similar variability over years, with CV's for both near 30%. Means for check plot (Magruder Plots, Experiment 222, and Experiment 502) were 1072, 1078 and 1674 kg ha^{-1} respectively. The unpredictable variability in grain yields from year to year in both fertilized and unfertilized plots was further documented and that highlights the need for mid-season determination of fertilizer N rates.

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CHAPTER I

CHANGES IN CHECK PLOT YIELDS OVER TIME IN THREE LONG-TERM WINTER WHEAT EXPERIMENTS

INTRODUCTION

Wheat is a cereal grain that originated from the Levant region of the Middle East. It is the third most important cereal crop after rice and maize (Taylor and Koo, 2015). Annual wheat production in the world is approximately 65 billion kilograms, which is grown on approximately 215 million hectares (Taylor and Koo, 2015). The major wheat producers around the world are the European Union, China, India, United States (US) and Russia (Balkovič et al., 2014). The total amount of wheat produced by the US in 2013 was approximately 60 million tons (Balkovič et al., 2014). Wheat is a major source of caloric sustenance to a large part of world population. Next to rice, wheat provides more calories than any other crop and is a good source of high quality protein, vitamins and dietary fiber. With rice, wheat is the world's most favored staple food. Wheat ground into flour is needed for making bread, crackers, biscuits, pancakes, pies, cookies, muffins, rolls, doughnuts, etc. attesting to its culinary versatility.

CHAPTER II

CHANGES IN CHECK PLOT YIELDS OVER TIME IN THREE LONG-TERM WINTER WHEAT EXPERIMENTS

LITERATURE REVIEW

Applied long-term trials conducted by Oklahoma State University continue to convey important information on the changes of yield over time. These changes might be due to different factors such as weather, soil organic matter or available nutrients. According to Davis (2003), understanding the changes in nutrient availability could provide vital information to grasp the understanding of yield changes over time. Long-term trials can be used to evaluate changes in trends that cannot be understood over short periods such as soil organic matter and weather (Girma et al., 2007; Grandstedt and Kjellenberg 1997). In addition, Raun et al. (2017) evaluated long-term trials so as to predict yield goals. They reported that wheat grain averages for 3, 4 or 5 years were not correlated with the ensuing season yields, likely due to the unpredictable nature of environment. Thus, understanding the role environment plays will be very useful.

Kattenberg et al. (1995) reported the current increase in greenhouse gases could result in 2^0 C increment of mean temperature in the next century. Increased atmospheric carbon dioxide (CO_2) could increase yields for temperate crops, however, the negative impacts of higher temperatures in determinate crops will offset the advantages of elevated CO_2 (Batts et al., 1997, 1998).

Temperature has a major role to play in cereal development. Temperature directly determines the duration of grain filling in cereals (Sofield et al., 1977). Wheat exposed to high temperatures before anthesis can result in decreased grain filling (Hunt et al., 1991). Ferris (1998) reported the effect of high temperature stress at anthesis on yield of spring wheat. For this work, wheat was planted under ambient temperature conditions, and 70 days after sowing (DAS), plants were exposed to high temperatures from 16-25^0C until full anthesis was reached. The number of grains per ear decreased with increased maximum temperature recorded during the mid anthesis period. In addition, grain yield and harvest index decreased at the higher temperatures. Grain yield decreased by 350 g m^{-2} when the temperature was increased by 10^0 C at 78 DAS. Also, grain yield showed a negative correlation with thermal time above a base temperature of 31^0 C. Their summary noted that grain set and anther fertilization was sensitive to maximum temperatures during mid anthesis.

Sources of Nitrogen for check plot

Nitrogen is an essential component of amino acids, which form the building blocks of proteins. Nitrogen becomes available to plants through different sources: Mineralization of soil organic matter, animal waste, N fertilizers and lightning. Atmospheric N fixation forms when lightning and thunderstorms occur. This causes elemental oxygen to combine with elemental nitrogen (N_2) to form nitrate (NO_3^-).

Microorganisms also contribute significantly to N availability for the plant. They convert ammonium to nitrate to make it available for plant absorption.

Over 120 years, the average yield from the Magruder check plots was 1254.76 kg/ha and this without any N applied (Davis et al., 2003). Considering the time period and where no N had been applied, other N sources were present that contributed to grain yield.

Rainfall can also contribute small amounts of N to the soil in the form of nitric acid (HNO_3), which breaks down in the soil to form hydrogen and nitrate ions. Nitric acid is formed by the combination of oxygen and hydrogen ions with water because of heat generated by thunderstorms through lightening.

Several studies have analyzed the effect of climatic factors on N contents in the soil. Dean (1938) analyzed how rainfall contributes to N and carbon (C) concentrations in the soil. The study included 30 soils throughout Hawaii with varying rainfall. The results showed an increase in total N content with increased rainfall. In addition, the carbon content increased with an increase in N content and rainfall. The C:N ratio also increased with an increase in rainfall. Also, Sievers and Holtz (1923) and Russell and McRuer (1927) reported that N contents increased with increasing rainfall. In addition, Paauw (1962) reported the effect of winter rainfall on yield and N content. They carried out a three-year study on potatoes, rye and oat. The relationship between total rainfall during the winter (November to February) and yield was negative. Fisher (1924) found a negative correlation between rainfall and yield of wheat at different periods of the year. This negative effect increased in November and reached a maximum in December and January.

Lehr (1961) studied the occurrence of N in different soil layers in relation to winter rainfall. The result showed a negative correlation between yields of rye and the amount of rainfall in the preceding winter. Millington (1961) found that wheat yield and the amount of rainfall in the month following sowing (October) was negatively correlated.

Alternatively, Seif (1978) reported positive effects of rainfall on wheat grain yield of spring wheat. They studied nine different types of cultivars at 11 sites for 5 years in South Wales, Australia. They divided rainfall into four variables (Fall, Autumn, Winter and Spring rainfall) and performed a simple linear correlation between rainfall and yield. This resulted in r-square values of 0.3, 0.6, 0.3, and 0.9 respectively.

Cornish (1950) reported on the influence of rainfall on the yield of wheat from 1896-1941 in South Australia. The experiment was scattered around the entire wheat belt with all climatic conditions represented. He claimed that rainfall has an influence on yield throughout the whole season and not just in a confined month. The results showed a parabolic regression curve between rainfall and yield over time.

Rationale and Objective

Field experiments are often conducted over several years and locations, without focusing on single treatment performance in the combined analysis.

The objectives of this work were to evaluate specific changes in check (no N applied) plot yields over time, as a function of the environment (rainfall and temperature) and to document trends in these yields when analyzed independently. Furthermore, check plot yields by themselves were expected to provide insight into potential N response in ensuing years.

CHAPTER III

CHANGES IN CHECK PLOT YIELDS OVER TIME IN THREE LONG-TERM WINTER WHEAT EXPERIMENTS

METHODOLOGY

Experimental Site

Three long-term experiments from two different locations were used that included the Experiment 222, Magruder plots and Experiment 502. The soil type in Magruder Plots near Stillwater, OK is a native prairie grassland soil, with moderately high soil organic matter. These soils are classified as Kirkland silt loams (fine, mixed, thermic Udertic Paleustolls). Experiment 502, near Lahoma, OK is on a Grant silt loam (fine-silty, mixed, thermic Udic Argiustoll).

Experiment 222

Experiment 222 was started in 1969 to evaluate different rates of N, P and K on the grain yields of winter wheat (figure 3). Winter wheat was grown under conventional tillage, from 1969 to 2010. In 2011 this trial was changed to a zero-tillage management practice to better reflect cultural demands for moisture and soil conservation. For the first 22 years wheat was grown in a 25.4 cm row spacing with a 67 kg/ha seeding rate. From 1992 to present, winter wheat has been planted in 19.05 cm inch rows. Different varieties have been planted over the years. The experimental design is a randomized complete block design with four replications.

Magruder

The Magruder plots are the oldest long-term wheat experiment west of the Mississippi River. They were established in 1892 by Alexander Magruder, with the aim to evaluate wheat production on native prairie soils without fertilization (Davis et al., 2003), and that are now in their 126th year. However, only one plot was used to evaluate the native wheat production without the application of organic or inorganic fertilizer from 1893-1898. From 1899 to 1929, half of the field was fertilized with barnyard manure and the other half was not fertilized as a result of declined wheat performance in the check plot and the other plot receiving organic nitrogen. In 1947 the OSU campus expanded with a new building (Stout Hall) that would displace the Magruder Plots. Horace J. Harper fought to save the Magruder plots by relocating it 1.6 km west of its original location, now known as the Agronomy Research Station. Thus, six of the ten treatments were relocated (surface 0-41 cm) from their original location to the Agronomy Research Station. The six treatments (Figure 1) that have been maintained include: 1. Manure, (applied every four years); 2. Check, no nutrients applied; 3. P, phosphorus applied each year; 4. NP, nitrogen and phosphorus applied each year; 5. NPK, nitrogen, phosphorus, and potassium applied each year; 6. NPK, nitrogen phosphorus, and potassium applied each year with line applied when soil pH <5.5 (Davis et al. 2003). Details of relocation of this experiment in 1947 has been further documented (Chester, 1947; Harper, 1953, 1959).

Wheat row spacing in the Magruder plots was 18.29 cm with 67 kg seed/ha as the seeding rate and where current Oklahoma Agriculture Exp. Station winter wheat varieties have been replaced as needed over the years (Davis et al. 2003).

The Magruder plots are managed under conventional tillage and are not replicated, having been established in 1892, prior to the advent of modern statistics.

Experiment 502

In 1971, Experiment 502 was established to assess the effect of N, Phosphorus (P) and Potassium (K) on winter wheat grain yields (figure 2). This field is under conventional tillage and is on a Grant silt loam (fine-silty, mixed, thermic Udic Argiustoll). The variety Nicoma was planted from 1971-1974, followed by Triumph 64 from 1975-1976 and 1978, Osage in 1977 and 1979, TAM W-101 from 1980-1991, Karl 92 from 1993-1994 and Tonkawa from 1995 to 1999, Custer from 1999 to 2004, Overley, Endurance, Bullet and Ruby Lee from 2004 to 2013 and Iba from 2014 to present. Wheat has been planted in 25.4 cm row spacing at a seeding rate of 67 kg/ha. The experimental design for this experiment was a randomized complete block design with fourteen treatments and four replications.

Analysis

Data was analyzed using SAS version 9.3 (SAS Institute, Cary, NC, USA. PROC GLM) to determine the effects of rainfall and temperature on wheat yield over time. Mean separation was performed using LSD (α = 0.05). Linear plateau models were used to determine trends over time.

CHAPTER IV

CHANGES IN CHECK PLOT YIELDS OVER TIME IN THREE LONG-TERM WINTER WHEAT EXPERIMENTS

RESULTS

Experiment 222

At Stillwater, the influence of rainfall on 46 years of winter wheat yields were evaluated. The check plot (0-0-0) (N, P, K), fertilized (0-30-37) and well fertilized plot (135-30-37) in experiment 222 showed high variability with CV's of 49, 51 and 45 respectively (Table 1). However, due to the extreme variability in the environment, the r^2 for check plot (0-0-0), fertilized (0-60-40) and well fertilized plot (120-60-40) with yield was all near 0.01. Although the linear correlation between rainfall and yield was not significant, similar trends between rainfall versus well fertilized, fertilized and check plot yields were identified (Figure 4). From 1983 to 2017, rainfall and yield at Experiment 222 followed a similar trend. Often, high rainfall resulted in higher yields while low rainfall resulted in lower yields. For years 2014 and 2015, the total rainfall increased from 622 mm to 1064 mm, while yields of well fertilized, fertilized and check plot yields increased from 2029 to 2997 kg ha^{-1}, 868 to 2433 kg ha^{-1} and 2029 to 2148 kg ha^{-1} respectively. On the other hand, for years 2005 and 2006, rainfall dropped from 589 to 422 mm, while yields of well fertilized, fertilized and check plots decreased from 3500 to 1978 kg ha^{-1}, 422 kg ha^{-1} to 146 kg ha^{-1} and 1975 to 140 kg ha^{-1} respectively. Selected data over 15 years showed a trend between rainfall and yields for fertilized, well fertilized and check plots (Figure 5). However, the overall relationship between yield and rainfall was not strong among all treatment (Figure 6, 7 & 8).

The influence of temperature on yields in experiment 222 was highly variable. However, high temperatures often resulted in a yield decrease. From 2006 to 2007, an increase in temperature resulted in a yield decrease from 1139 to 146 kg ha^{-1}, 1978 to 146 kg ha^{-1} and 1135 to 140 kg ha^{-1} for well fertilized, fertilized and check plots respectively (Figure 9). Similarly, from 2010 to 2011 a decrease in average temperature to 7 ^{0}C resulted in yield decreases from 2231 to 1535 kg ha^{-1}, 1880 to 763 kg ha^{-1} and 1879 to 754 kg ha^{-1} for well fertilized, fertilized and check plots respectively.

Magruder Plots

In the Magruder Plots, the influence of rainfall on 48 years of wheat yield were evaluated. The check plot (0-0-0), fertilized (0-60-40) and well fertilized plot (120-60-40) showed high variability with CV's 35, 41 and 40 respectively (Table 1). However, due to the variability in the environment, the r^2 for check plots (0-0-0), fertilized (0-60-40) and well fertilized plots (120-60-40) were all near 0.02. Although the linear correlation between rainfall and yield was not significant, similar trends between rainfall versus well fertilized, fertilized and check plot yields were identified (Figure 10). From 1994 to 2017, rainfall and yield followed a similar trend. Often, high rainfall resulted to higher yields while low rainfall led to lower yields. In 2014-2015, rainfall increased from 622 mm to 1064 mm, while yields of well fertilized, fertilized and check plot yields increased from 2215 to 2638 kg ha^{-1}, 1196 to 1750 kg ha^{-1} and 1194 to 1751 kg ha^{-1} respectively. On the other hand, from 1999 to 2001 rainfall dropped from 942 to 495 mm, while yields of well fertilized, fertilized and check plot decreased from 3501 to 1672 kg ha^{-1}, 1371 to 495 kg ha^{-1}, 1768 to 795 kg ha^{-1}. Specific data selected over 17 years showed a trend between rainfall and yields for fertilized, well fertilized and check plots (Figure 11). However, the overall relationship between yield and rainfall was not strong among all treatment (Figure 12, 13 & 14).

The influence of temperature on yields in the Magruder Plots was highly variable. However, often high temperatures resulted in a yield decrease. From 2006-2007, high temperatures of 14 ^{0}C resulted in a yield decrease from 2959 to 408 kg ha^{-1}, 1546 to 72 kg ha^{-1} and 1540 to 70 kg ha^{-1} for well fertilized, fertilized and check plot respectively (Figure 15). Similarly, in 2010 to 2011 lower annual average temperature of 7 ^{0}C resulted in yield decreases from 2399 to 1556 kg ha^{-1}, 1641 to 568 kg ha^{-1} and 1245 to 568 kg ha^{-1} for well fertilized, fertilized and check plots respectively.

Experiment 502

At Lahoma, the influence of rainfall over 24 years on wheat yield was evaluated. The check plot (0-0-0), fertilized (0-40-60) and well fertilized plot (100-40-60) in Experiment 502 showed high variability with CV's of 31, 31 and 35 respectively (Table 1). However, due to the variability in the environment, the r^2 for the check plot (0-0-0), fertilized (0-60-40) and well fertilized plot (120-60-40) was all near 0.03. Although the linear correlation between rainfall and yield was not significant, similar trends between rainfall versus well fertilized, fertilized and check plot yields were identified (Figure 10). From 1994 to 2017, rainfall and yield at Experiment 502 followed a similar trend. Often, high rainfall resulted in higher yields while low rainfall resulted in lower yields. For the years, 2007 and 2008, total rainfall was basically the same (951 and 972 mm), nonetheless the yields of well fertilized, fertilized and check plot yields increased from 3383 to 5939 kg ha^{-1}, 2604 to 2843 kg ha^{-1} and 2600 to 2840 kg ha^{-1} respectively. These results elucidate the problems associated with correlating total rainfall and average yield levels. Rainfall received soon after planting, securing an adequate stand, and/or during flowering/grain fill may well be much better indicators of what to expect in terms of final grain yield. From 2008 to 2009 rainfall dropped from 972 to 632 mm, while yields of well fertilized, fertilized and check plot decreased from 5939 to 4911 kg ha^{-1}, 2843 to 1556 kg ha^{-1}, 2587 to 1556 kg ha^{-1}. Specific data points selected over 15 years showed a trend between rainfall and yields for fertilized, well fertilized and check plots (Figure 17). However, the overall relationship between yield and rainfall was not strong among all treatment (Figure 18, 19 & 20).

Also, as was expected, the influence of temperature on yields in experiment 502 was highly variable (Figure 21). Yields in the check (no N applied) and an adequately fertilized plot (90-20-55) (N-P_2O_5-K_2O) were plotted for what is now almost 50 years. Evident over this time period is that the check plots have produced near 3 Mg/ha (40 bu/ac) with no N applied. The variability and range in yield levels is striking, and was similar to the variability when adequately fertilized, indicating that prior year yields and N demand were equally influenced by environment (Figure 22).

CHAPTER V

CHANGES IN CHECK PLOT YIELDS OVER TIME IN THREE LONG-TERM WINTER WHEAT EXPERIMENTS

DISCUSSION

Results from this study demonstrated that environmental conditions from year to year were highly variable. The variability over all locations evaluated (well fertilized, fertilized and check) had CV's ranging from 45-51, 35-41 and 31-35, at experiment 222, Magruder and experiment 502 respectively (Table 1). Similarly, rainfall for the locations evaluated showed high variability from year to year with CV's above 20. Rainfall clearly influences yield, but this too was unpredictable as when rainfall was received and what current temperatures were, confounds interpretation. Higher rainfall generally resulted in yield increases while lower rainfall resulted in lower yields. This is in part due to the addition of N to the soil coming in the rainfall. Nitric acid is formed by the combination of oxygen and hydrogen ions with water because of heat generated by thunderstorms through lightening. Porter E (2000) stated that precipitation contributes 3 to 7 kilograms per hectare of inorganic N to the soil. In addition, Raun et al. (2017) evaluated long-term trials to predict yield goals. They reported that wheat grain yield averages for 3, 4 or 5 years were not correlated with ensuing season yields which was due to the unpredictable environment.

Furthermore, the average yearly annual temperature varies from year to year. The CV's for all treatments were above 30. However, the variability in temperature was not as self-evident as rainfall from year to year.

Finally, the variability of the environment impacts final grain yield and that embeds both ambient temperature and rainfall. Unpredictable variability in grain yields from year to year is thus expected and should be internalized at the outset of every planting season. Other random factors including planting date, harvest date, fertilizer application date, weed and insect control further contribute to yield fluctuations from year to year.

TABLES

Table 1. Influence of total rainfall on wheat grain yield coming from three long-term continuous winter wheat experiments.

Location	Treatment, N-P_2O_5-K_20	Linear equation	Years of estimate	r^2	SED	pr>F	CV
Exp 222	0-60-40	y=18.731+0.0215x	45	0.00	7.03	0.92	51.14
Exp 222	120-60-40	y=26.76+0.1175x	45	0.01	9.78	0.62	45.35
Exp 222	0-0-0	y=18.345+0.0002x	46	0.00	6.37	1.00	49.10
Magruder	0-0-0	y=20.19-0.0909x	48	0.01	8.70	0.45	35.79
Magruder	0-30-0	y=26.191-0.218x	48	0.04	11.13	0.16	41.50
Magruder	60-30-0	y=43.115-0.2634x	48	0.02	19.69	0.34	40.48
Exp 502	0-0-0	y=31.195-0.2179x	24	0.04	5.58	0.35	31.68
Exp 502	0-40-60	y=32.002-0.1981x	24	0.03	5.78	0.41	31.13
Exp 502	100-40-60	y=40.677+0.3907x	24	0.02	13.15	0.48	35.79

Table 2. Influence of average temperature on wheat grain yields coming from three long-term continuous winter wheat experiments, Experiment 222, Experiment 502, and the Magruder Plots.

Location	Treatment, N-P-K	Linear equation	Years of estimate	r^2	SED	Pr>F	CV
Exp. 222	0-60-40	y=18.731+0.0215x	45	0.00	7.03	0.92	51.14
Exp. 222	120-60-40	y=26.76+0.1175x	45	0.01	9.78	0.62	45.35
Exp. 222	0-0-0	y=25.187+0.189x	46	0.01	9.57	0.60	43.40
Magruder	0-0-0	y=20.19-0.0909x	48	0.01	8.70	0.45	35.79
Magruder	0-30-0	y=26.191-0.218x	48	0.04	11.13	0.16	41.50
Magruder	60-30-0	y=43.115-0.2634x	48	0.02	19.69	0.34	40.48
Exp. 502	0-0-0	y=31.195-0.2179x	24	0.04	5.58	0.35	31.68
Exp. 502	0-40-60	y=32.002-0.1981x	24	0.03	5.78	0.41	31.13
Exp. 502	100-40-60	y=40.677+0.3907x	24	0.02	13.15	0.48	35.79

Table 3: Winter wheat grain yield statistics for check plot yields from three long term winter wheat experiments, Experiment 502, Experiment 222 and the Magruder Plots.

	Experiment 502 (0-0-0)	Experiment 222 (0-0-0)	Magruder (0-0-0)
	kg/ha	kg/ha	kg/ha
	1970 – 2017	1969-2017	1947-2017
Average	1674	1078	1072
Maximum	2792	2149	1825
Minimum	731	94	116
SD	529	464	426
CV, %	31	47	47

SD, standard deviation

CV, coefficient of variation, %

Table 4: Average winter wheat grain yields in the N fertilized plots (each respective experiment) for three long term trials (Experiment 502, Experiment 222 and the Magruder Plots.)

	Experiment 502 (112-20-56)	Experiment 222 (135-30-37)	Magruder (67-34-0)
	1970 – 2017	1969-2017	1947-2017
Average	3494	2037	2191
Maximum	5940	4424	4101
Minimum	1423	451	176
SD	1238	963	1026
CV, %	31	47	42

SD, standard deviation

CV, coefficient of variation, %

(N, P, K), values in percent, elemental form

Table 5: Average winter wheat grain yields in the check (no fertilizer N applied) for Experiment 502, Experiment 222 and the Magruder Plots.

	Experiment 502 (0-20-56)	Experiment 222 (0-30-37)	Magruder (0-34-0)
	1970 - 2017	1969-2017	1947-2017
Average	1767	1151	1176
Maximum	2844	2434	2557
Minimum	746	79	73
SD	546	538	488
CV, %	32	44	39

SD, standard deviation

CV, coefficient of variation, %

(N, P, K), values in percent, elemental form

Table 6: Average rainfall for Experiment 502, Experiment 222, and the Magruder Plots.

	Experiment 502	Experiment 222	Magruder
	1994 – 2017	1994-2017	1994-2017
Average	733.93	841.49	841.49
Maximum	989	1136.40	1136.40
Minimum	423	422.40	422.40
Stdev	181.84	186.20	186.20

FIGURES

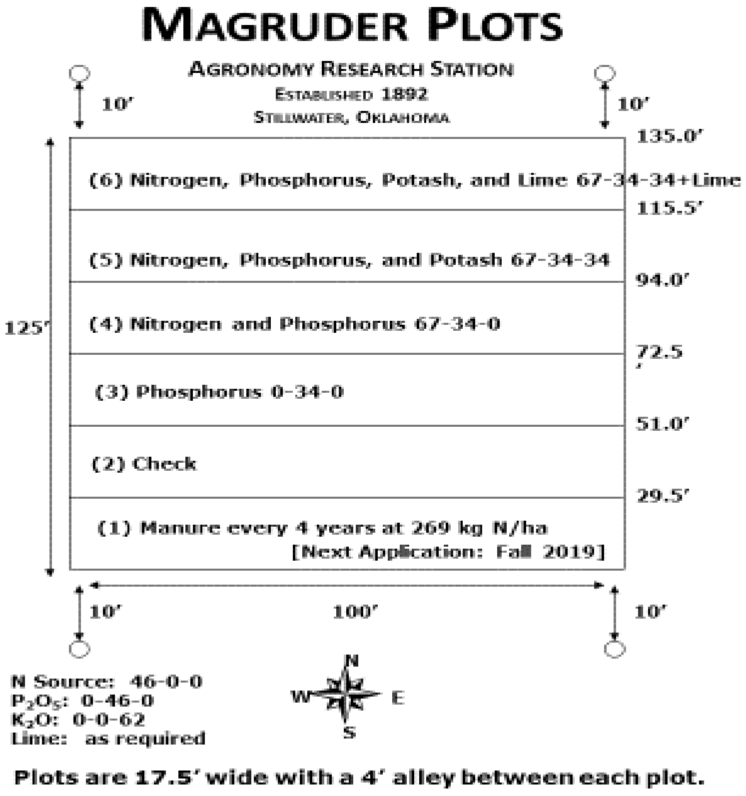
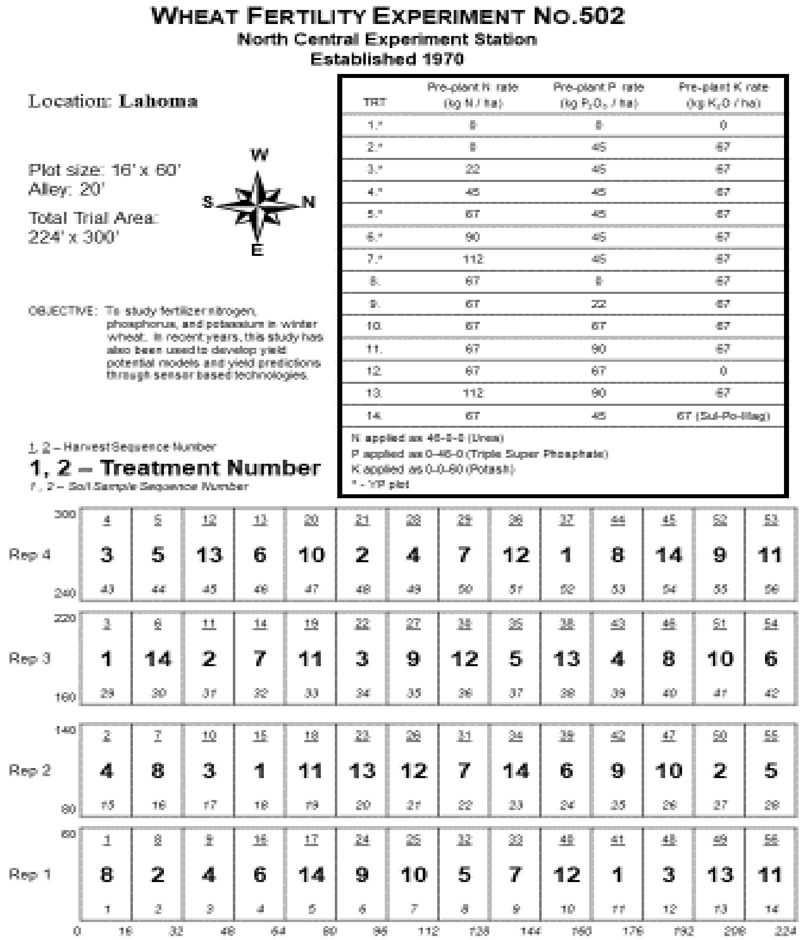


Figure 1. Treatment structure and plot layout, Magruder Plots, Stillwater, OK.



Wheat Fertility Experiment No.502

North Central Experiment Station
Established 1970

Location: **Lahoma**

Plot size: 16' x 60'
Alley: 20'

Total Trial Area:
224' x 300'

OBJECTIVE: To study fertilizer nitrogen, phosphorus, and potassium in winter wheat. In recent years, this study has also been used to develop yield potential models and yield predictions through sensor based technologies.

TRT	Pre-plant N rate (kg N / ha)	Pre-plant P rate (kg P_2O_5 / ha)	Pre-plant K rate (kg K_2O / ha)
1.*	0	0	0
2.*	0	45	67
3.*	22	45	67
4.*	45	45	67
5.*	67	45	67
6.*	90	45	67
7.*	112	45	67
8.	67	0	67
9.	67	22	67
10.	67	67	67
11.	67	90	67
12.	67	67	0
13.	112	90	67
14.	67	45	67 (Sul-Po-Mag)

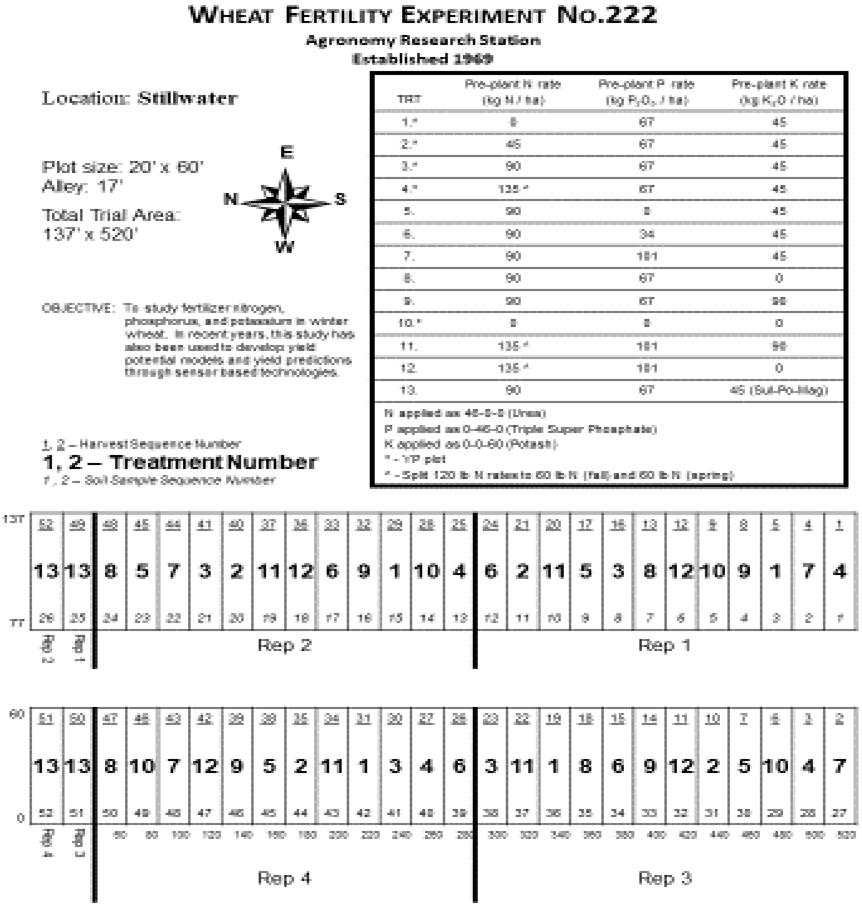
N applied as 46-0-0 (Urea)
P applied as 0-46-0 (Triple Super Phosphate)
K applied as 0-0-60 (Potash)
* - YP plot

<u>1</u>, <u>2</u> – Harvest Sequence Number
1, 2 – Treatment Number
1, 2 – Soil Sample Sequence Number

	300	4	5	12	13	20	21	28	29	36	37	44	45	52	53
Rep 4		**3**	**5**	**13**	**6**	**10**	**2**	**4**	**7**	**12**	**1**	**8**	**14**	**9**	**11**
	240	*43*	*44*	*45*	*46*	*47*	*48*	*49*	*50*	*51*	*52*	*53*	*54*	*55*	*56*
	220	3	6	11	14	19	22	27	30	35	38	43	46	51	54
Rep 3		**1**	**14**	**2**	**7**	**11**	**3**	**9**	**12**	**5**	**13**	**4**	**8**	**10**	**6**
	160	*29*	*30*	*31*	*32*	*33*	*34*	*35*	*36*	*37*	*38*	*39*	*40*	*41*	*42*
	140	2	7	10	15	18	23	26	31	34	39	42	47	50	55
Rep 2		**4**	**8**	**3**	**1**	**11**	**13**	**12**	**7**	**14**	**6**	**9**	**10**	**2**	**5**
	80	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*
	60	1	8	9	16	17	24	25	32	33	40	41	48	49	56
Rep 1		**8**	**2**	**4**	**6**	**14**	**9**	**10**	**5**	**7**	**12**	**1**	**3**	**13**	**11**
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*

0 16 32 48 64 80 96 112 128 144 160 176 192 208 224

Figure 2. Treatment structure and plot layout, Experiment 502, Lahoma, OK.



WHEAT FERTILITY EXPERIMENT NO.222

Agronomy Research Station

Established 1969

Location: Stillwater

Plot size: 20' x 60'
Alley: 17'

Total Trial Area:
137' x 520'

OBJECTIVE: To study fertilizer nitrogen, phosphorus, and potassium in winter wheat. In recent years, this study has also been used to develop yield potential models and yield predictions through sensor based technologies.

TRT	Pre-plant N rate (kg N / ha)	Pre-plant P rate (kg P_2O_5 / ha)	Pre-plant K rate (kg K_2O / ha)
1.*	0	67	45
2.*	45	67	45
3.*	90	67	45
4.*	135 ^	67	45
5.	90	0	45
6.	90	34	45
7.	90	101	45
8.	90	67	0
9.	90	67	90
10.*	0	0	0
11.	135 ^	101	90
12.	135 ^	101	0
13.	90	67	45 (Sul-Po-Mag)

N applied as 46-0-0 (Urea)
P applied as 0-46-0 (Triple Super Phosphate)
K applied as 0-0-60 (Potash)
* - YP plot
^ - Split 120 lb N rates to 60 lb N (fall) and 60 lb N (spring)

1, 2 – Harvest Sequence Number
1, 2 – Treatment Number
1, 2 – Soil Sample Sequence Number

52	49	48	45	44	41	40	37	36	33	32	29	28	25	24	21	20	17	16	13	12	9	8	5	4	1
13	**13**	**8**	**5**	**7**	**3**	**2**	**11**	**12**	**6**	**9**	**1**	**10**	**4**	**6**	**2**	**11**	**5**	**3**	**8**	**12**	**10**	**9**	**1**	**7**	**4**
26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Rep 2	Rep 1	Rep 2												Rep 1											

51	50	47	46	43	42	39	38	35	34	31	30	27	26	23	22	19	18	15	14	11	10	7	6	3	2
13	**13**	**8**	**10**	**7**	**12**	**9**	**5**	**2**	**11**	**1**	**3**	**4**	**6**	**3**	**11**	**1**	**8**	**6**	**9**	**12**	**2**	**5**	**10**	**4**	**7**
52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27
		60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520
Rep 4	Rep 3	Rep 4												Rep 3											

Figure 3. Treatment structure for Experiment 222, Stillwater, OK.

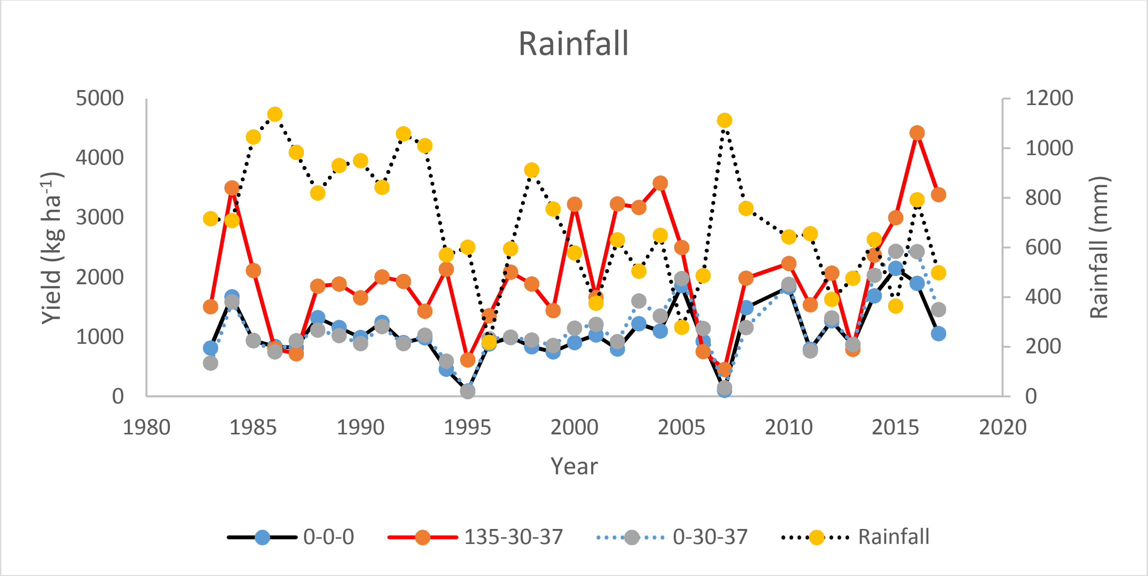


Figure 4. Wheat grain yield versus rainfall, 1983 to 2017, Experiment 222, Stillwater, OK.

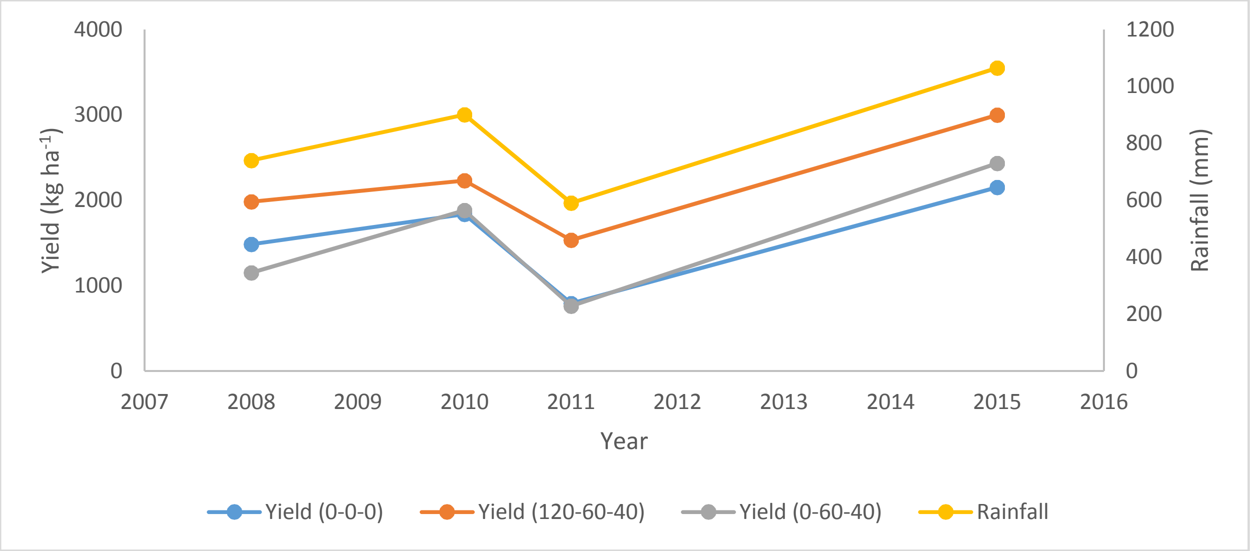


Figure 5. Trends between wheat yields (fertilized and unfertilized) and rainfall over selected years from 1994-2009, Experiment 222, Stillwater, OK.

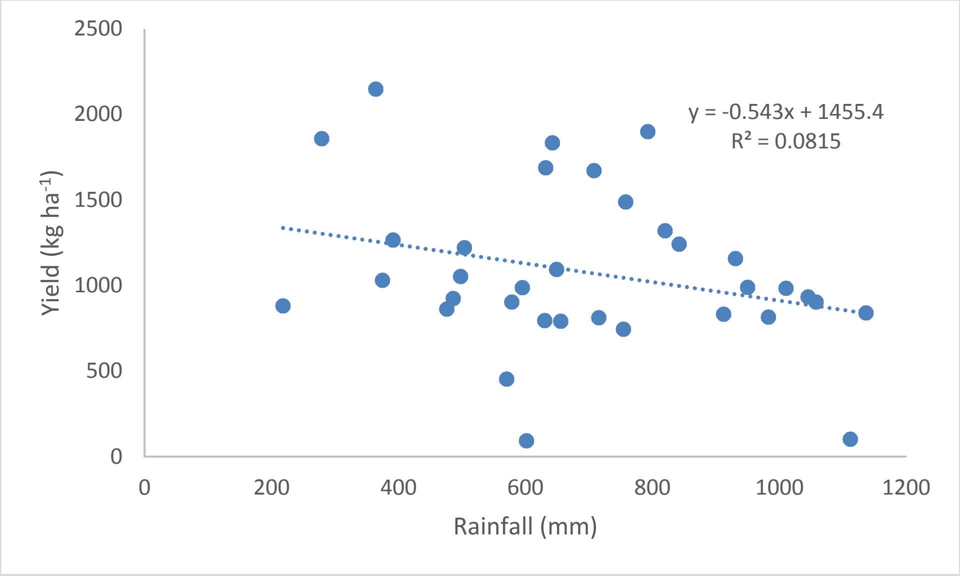


Figure 6. Average rainfall versus wheat grain yields from Experiment 222, in the check plot (no N applied), Stillwater, OK, 1983 to 2018.

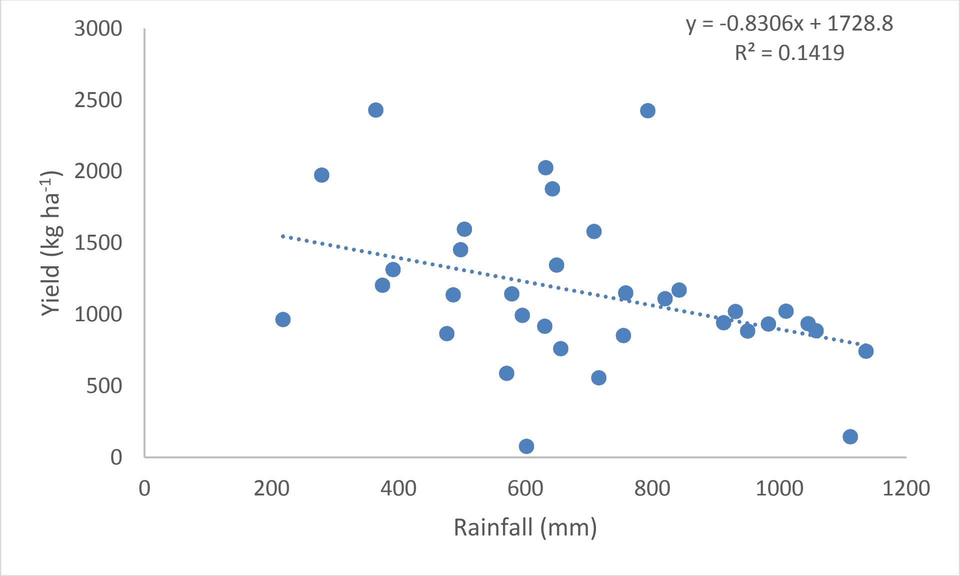


Figure 7. Average rainfall versus wheat grain yields from Experiment 222, in the fertilized (0-30-37), Stillwater, OK, 1983 to 2018.

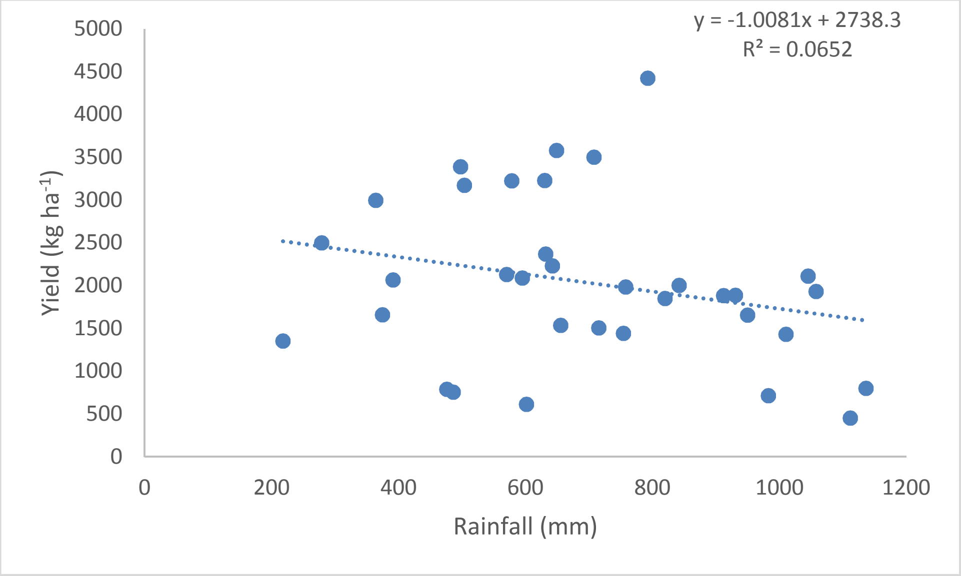


Figure 8. Average rainfall versus wheat grain yields from Experiment 222, in the fertilized plot (135-30-37), Stillwater, OK, 1983 to 2018.

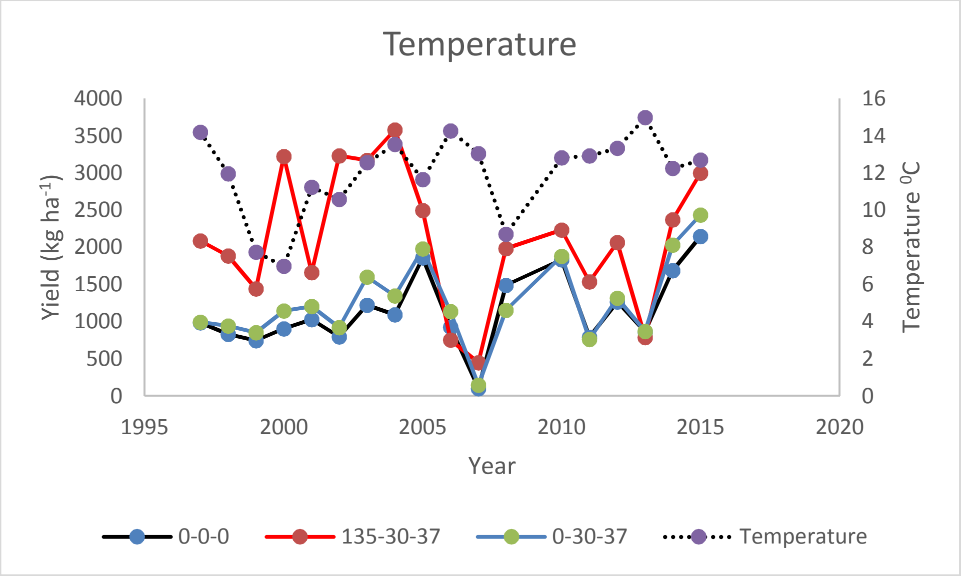


Figure 9. Wheat grain yield versus temperature, 1997 to 2015, Experiment 222, Stillwater, OK

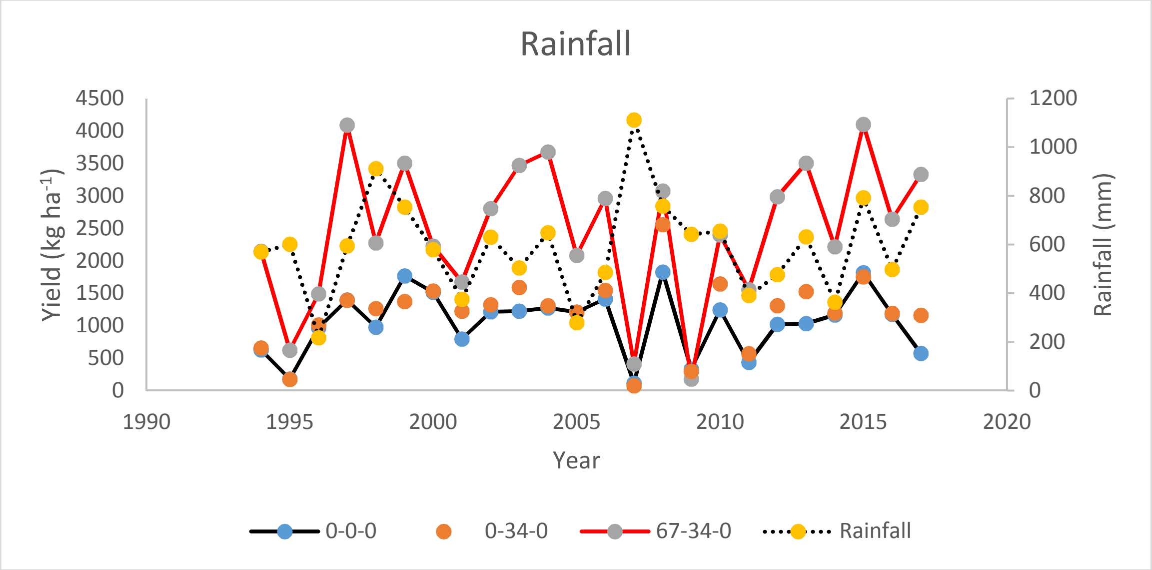


Figure 10. Wheat grain yield versus rainfall from 1994 to 2017, Magruder Plots, Stillwater, OK.

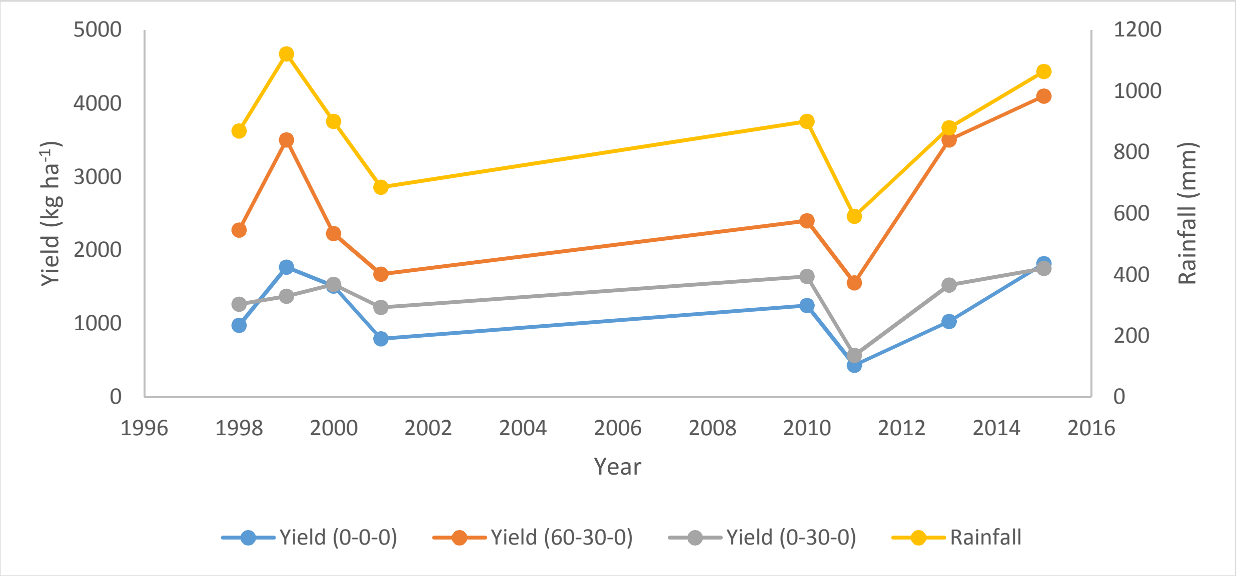


Figure 11. Trends between wheat yields (fertilized and unfertilized) and rainfall over selected years from 1998 to 2015, Magruder Plots, Stillwater, OK.

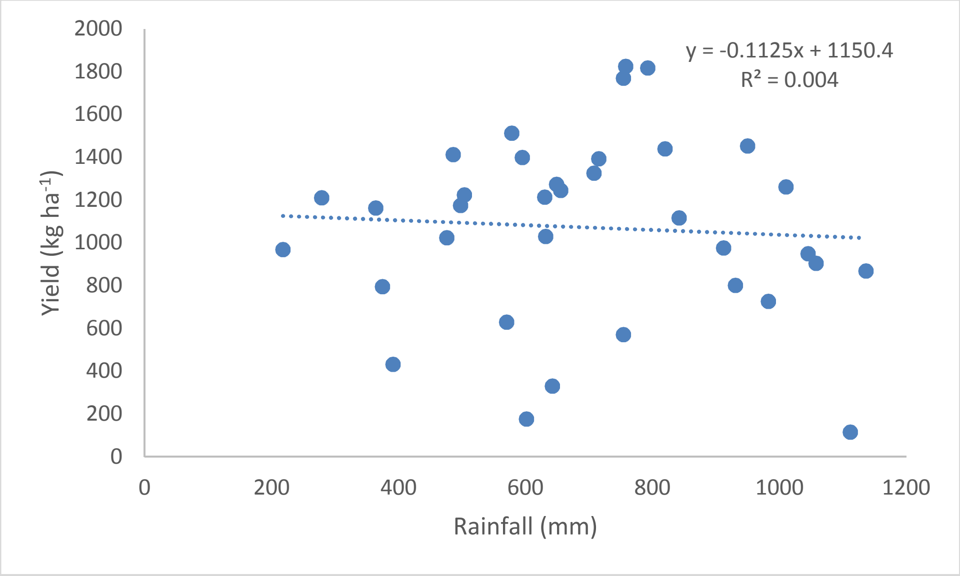


Figure 12. Average rainfall versus wheat grain yields from Magruder, in the check plot (no N applied), Stillwater, OK, 1983 to 2018.

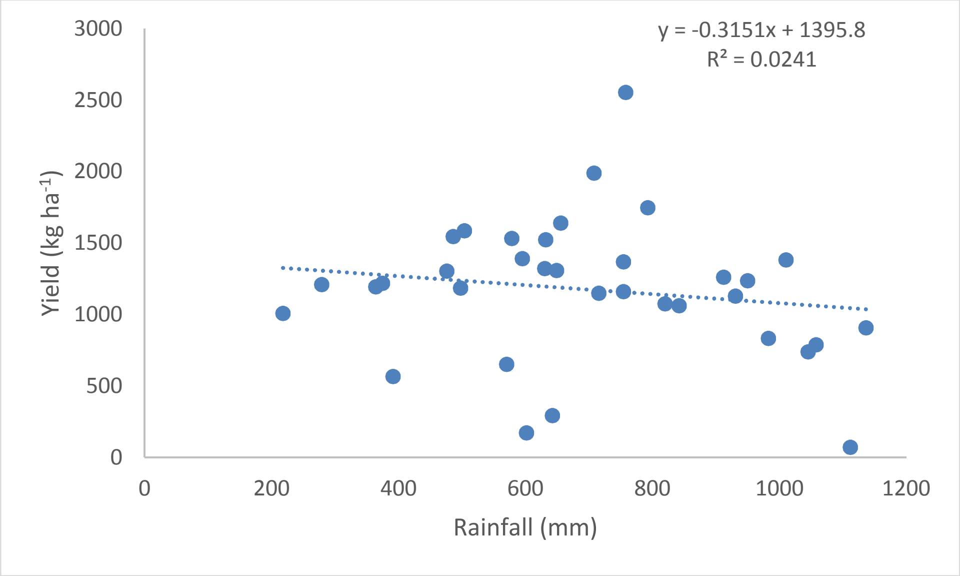


Figure 13. Average rainfall versus wheat grain yields from Magruder, in the fertilized plot (0-34-0), Stillwater, OK, 1983 to 2018.

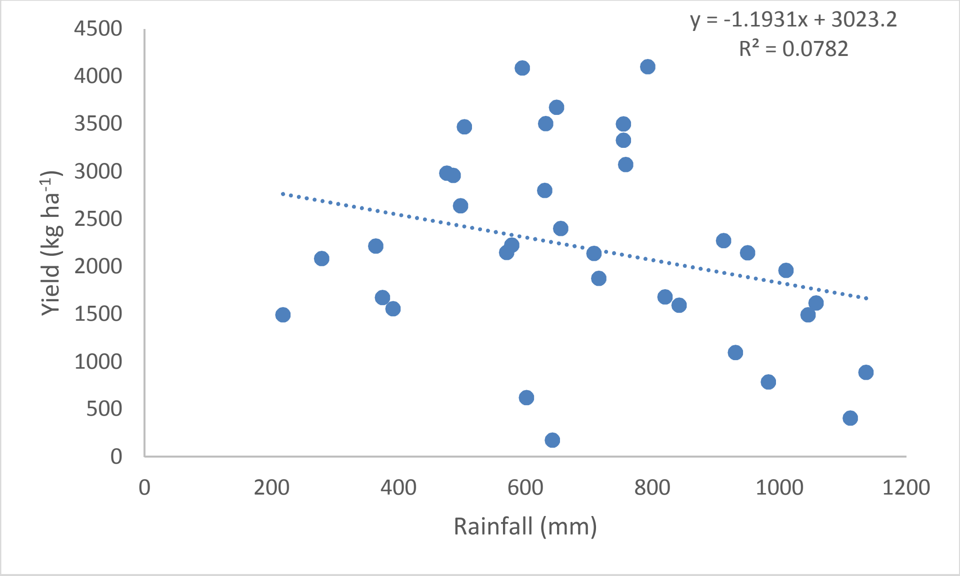


Figure 14. Average rainfall versus wheat grain yields from Magruder, in the well fertilized plot (no N applied), Stillwater, OK, 1983 to 2018.

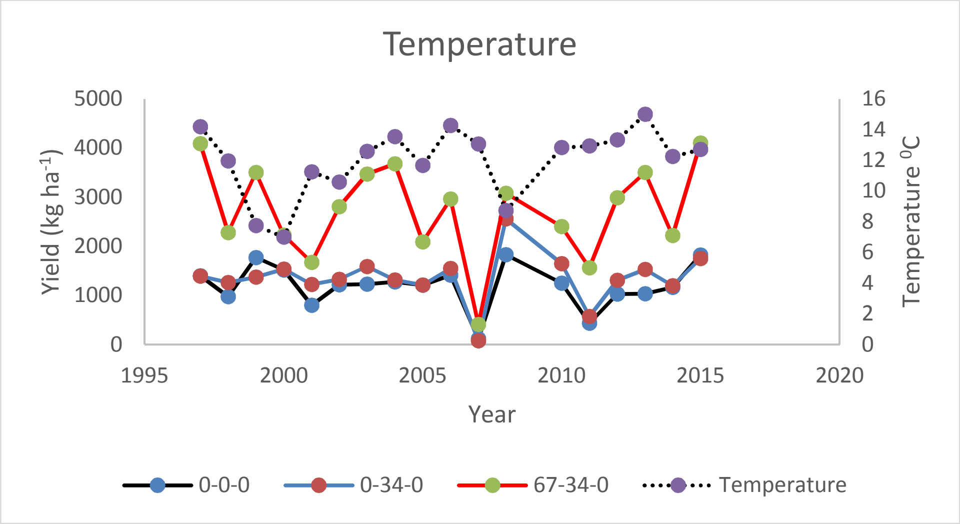


Figure 15. Wheat grain yield versus temperature , 1997 to 2015, Magruder Plots, Stillwater, OK

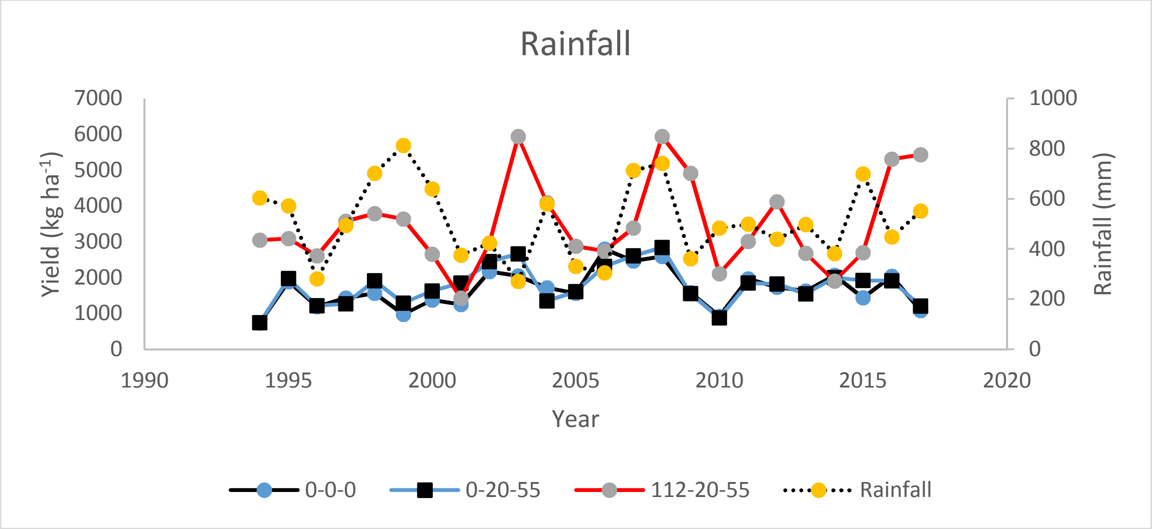


Figure 16. Wheat grain yield versus rainfall, 1994 to 2017 in Experiment 502, Lahoma, OK.

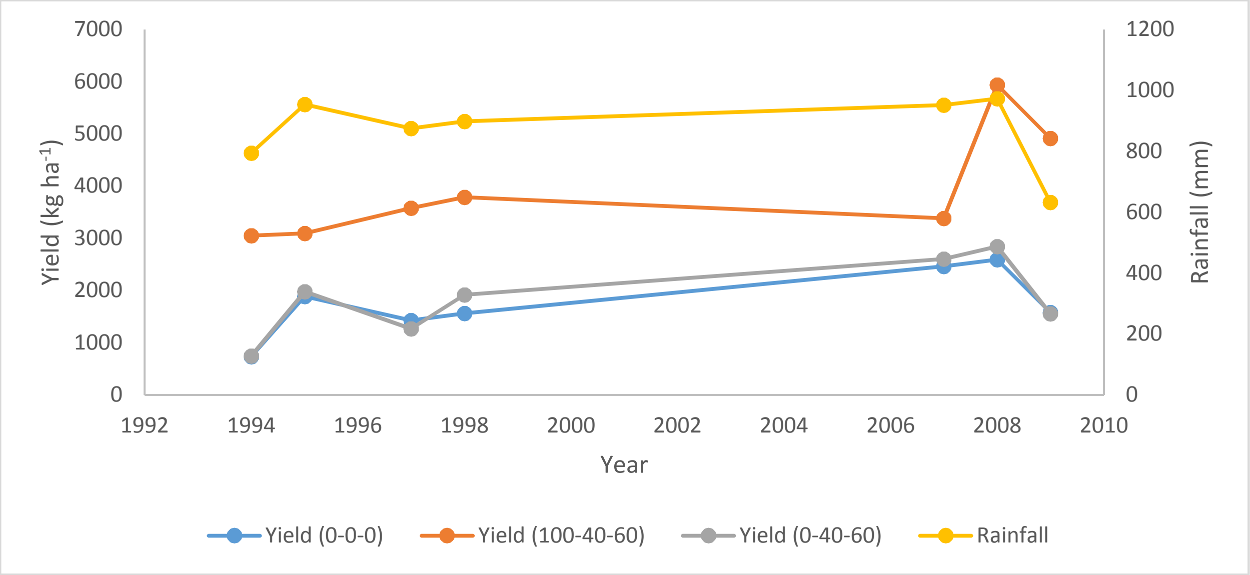


Figure 17. Trends in wheat grain yields (fertilized and unfertilized) and rainfall over selected years from 1994-2009, Experiment 502, Lahoma, OK.

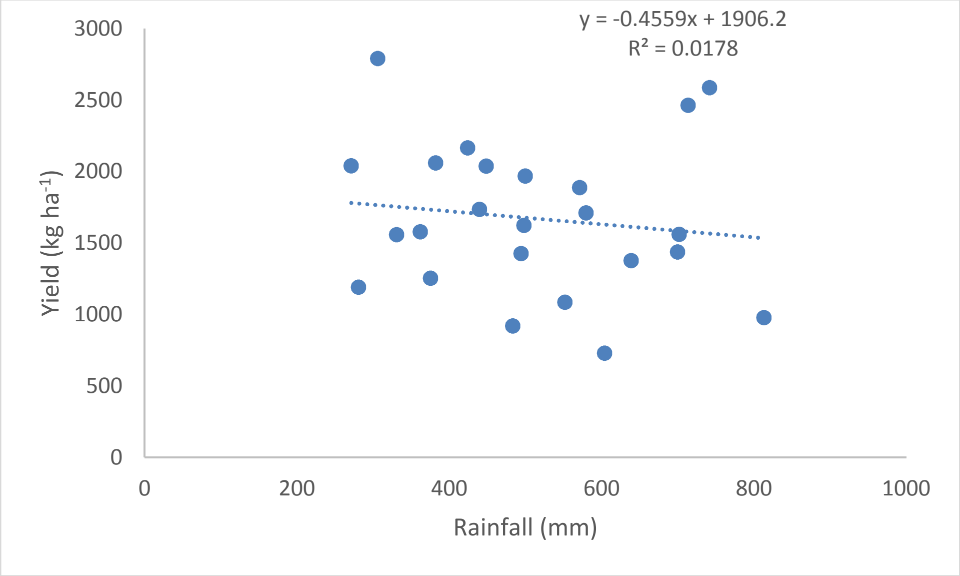


Figure 18. Average rainfall versus wheat grain yields from Experiment 502, in the check plot (no N applied), Stillwater, OK, 1994 to 2018.

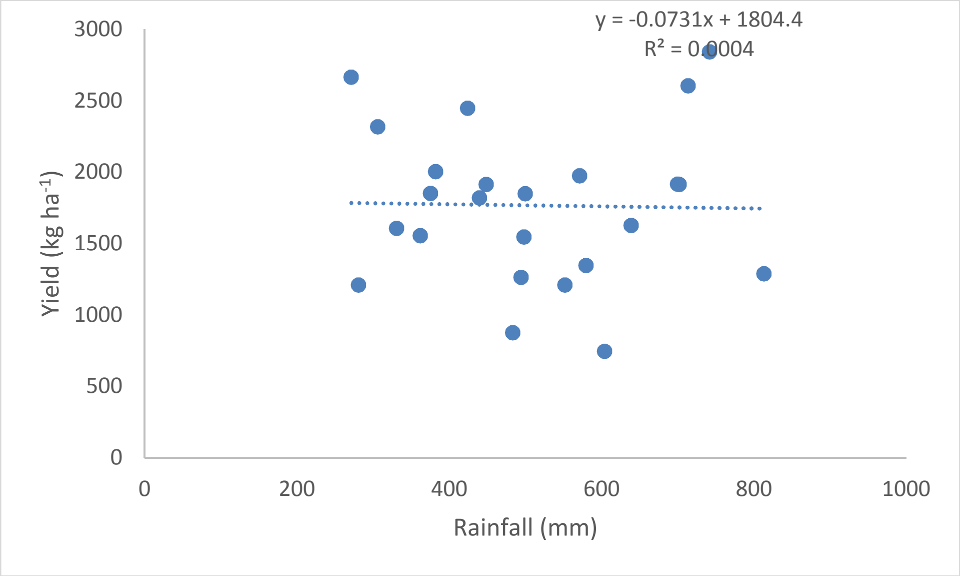


Figure 19. Average rainfall versus wheat grain yields from Experiment 502, in the fertilize plot (0-20-55), Lahoma, OK, 1994 to 2018.

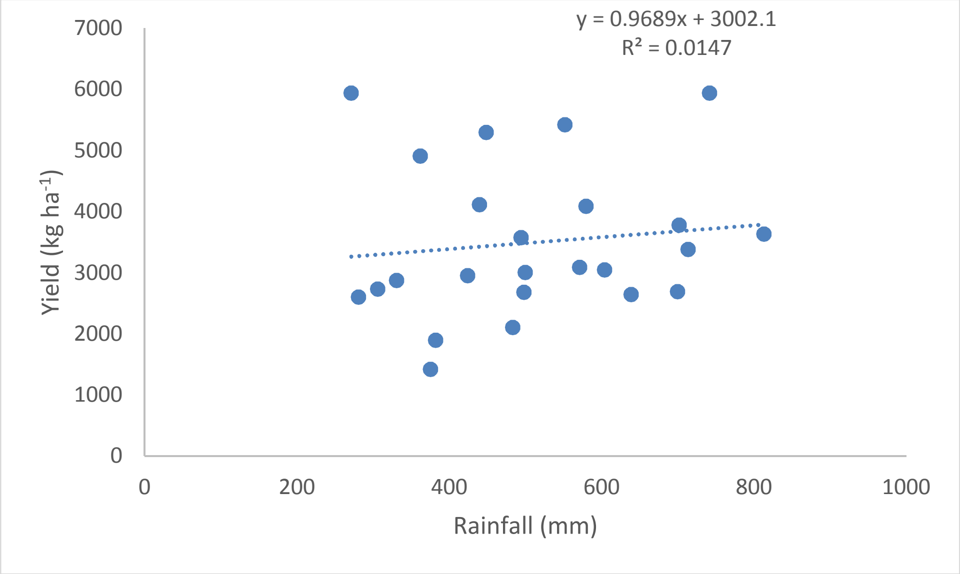


Figure 20. Average rainfall versus wheat grain yields from Experiment 502, in the well fertilize plot (112-20-55), Lahoma, OK, 1994 to 2018.

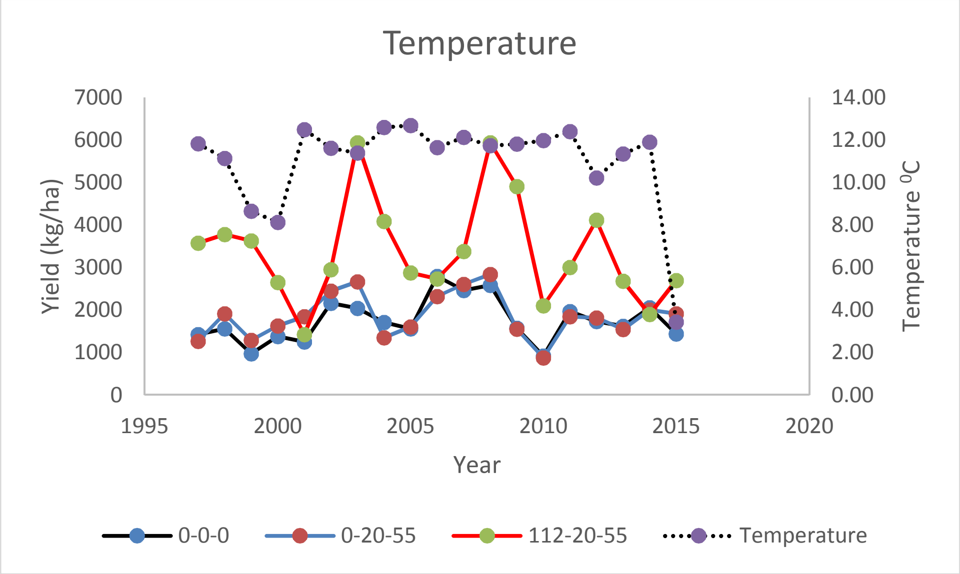


Figure 21. Average wheat grain yields and ambient temperature, 1997 to 2015, Experiment 502, Lahoma, OK.

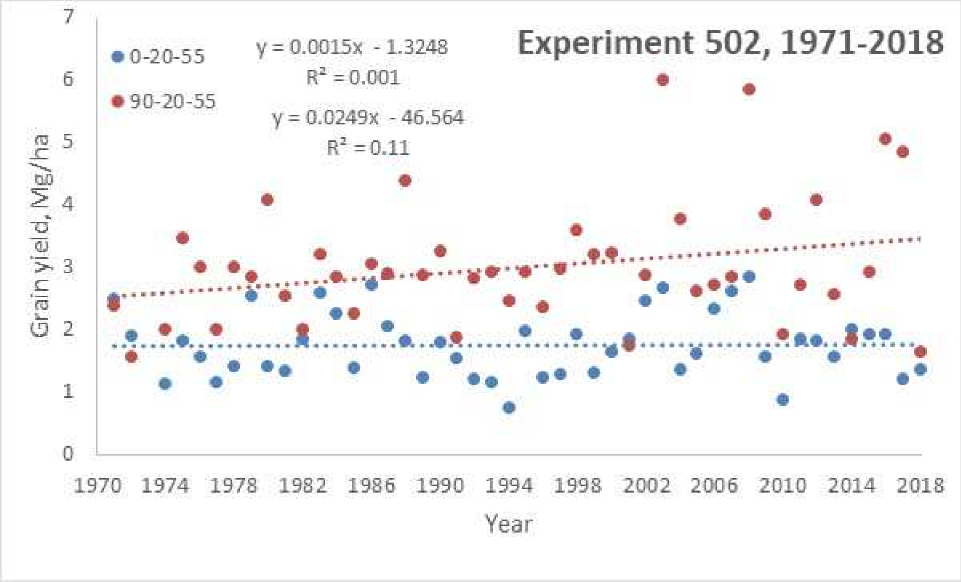


Figure 22. Wheat grain yields from Experiment 502, in the check plot (no N applied) and an adequately fertilized plot, Lahoma, OK, 1971 to 2018.

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