ON-FARM EVALUATION OF DOUBLE CROP

FETIILTY MANAGEMENT

IN OKLAHOMA

By

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Abstract:

Many producers in Oklahoma choose to plant summer crops following the harvest of winter crops to increase farm revenue. Often this practice is done while limiting costly inputs to reduce economic risk. This study aims to determine whether there is potential for producers to increase yields of double crops with the addition of fertilizer. Also, the study will evaluate soil test as a way to predict nutrient response. Nutrient rich strips of nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) were applied at 61 sites across Oklahoma in 2016 and 2017, on three different double crops (soybean, grain sorghum, sunflower), with varying environmental conditions. Nutrient rich strips were applied at a rate of 257.6 kg ha^{-1} of product to a 1.8 by 45.7 meter strip each. Urea (46-0-0), triple super phosphate (0-45-0), potash (0-0-60), and gypsum (0-0-0-19) were used for sources N, P, K, and S, respectively. Composite surface (0-15 cm) and subsurface (15-45cm) soil samples were taken prior to application of the strips for soil nutrient analysis. At maturity, four- one m^2 subplots were hand harvested from each strip, as well as four one m^2 subplots from the producer practice outside of the plot. Of 61 locations and 244 comparisons, 20 positive responses were recorded on 14 sites. Of these responses, one was a response to N, five were a response to P, ten were responses to K, and there were four responses to S. Seventeen responses were on soybean sites (0 N, 5 P, 9 K, 3 S), three were on grain sorghum sites (1 N, 0 P, 1 K, 1 S), and zero sunflower sites that were responsive. This study documented that the produces nutrient management strategies maximized yields in 77% of the fields evaluated. This high value indicates that Oklahoma double crop producers are adequately managing the nutrient inputs. Yet as there were 23% of the fields that responded to addition fertility there is still room to be gained. This project suggests that further work is needed to provide producers with a more reliable measure of when fertilizer is needed.

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CHAPTER I

INTRODUCTION

Annual application of fertilizer and lime to fields across the state of Oklahoma is estimated to cost producers approximately $340 million, (USDA-NASS, 2017). With such a large cost, producers must find a balance between fertilizing at an economically optimal rate or not fertilizing at all. For many producers, this decision comes with what crop is being grown and the soil conditions at planting.

Winter wheat (*Triticum aestivum* L.) is the primary field crop produced in Oklahoma, with 2,145,000 hectares planted in 2015 as either a forage or grain crop (USDA-NASS, 2016). In a typical year, with adequate moisture and temperature, winter wheat is planted by October and harvested in early June, leaving a four month period where the field can either lay fallow or be planted with a warm season crop, such as soybean or sorghum.

Soybean (*Glycine max* L.), is primarily grown in Oklahoma for grain production. It is either grown as a double crop after the harvest of winter wheat, or as a full season crop following a fallow winter growing season. In 2015, 152,000 hectares were harvested in soybeans, with an average yield of approximately 2,200 kg ha^{-1} (USDA-NASS, 2016). The majority of this crop is on dry land; without irrigation.

Grain sorghum, or *Sorghum bicolor* (L.) due to its high protein content and drought tolerance, is primarily grown in Oklahoma for grain production. In 2015, 166,000 hectares of grain sorghum was harvested, and yielded approximately 3,500 kg ha^{-1} (USDA-NASS, 2016). As with soybeans, a majority of this crop is grown on dry land.

Sunflower, or *Helianthus annuus* (L.) has increased popularity in recent years due to a growing oil seed industry in Oklahoma. In 2015, approximately 2,300 hectares of sunflower was harvested, and yielded approximately 1,600 kg ha^{-1} (USDA-NASS, 2016).

When growing soybeans, grain sorghum, and sunflowers in Oklahoma as a double crop, some producers will minimize fertilization, as to not add increased inputs, and therefore, decrease the costs to their crop. Low input nutrient management practices lend to decreased yields, and therefore, decreased productivity in low fertility soils.

Much of the limiting factors from these yields come from the fertilization, or the lack thereof. Nutrient availability in the soils generally lack in some, if not all, of the essential macronutrients: Nitrogen, Phosphorus, and Potassium, as well as the some micronutrients, such as Sulfur. In order to learn how many nutrients in the soil, generally a soil test is taken.

CHAPTER II

LITERATURE REVIEW

All crops need certain nutrients in order grow, reproduce, and complete their life-cycle. These nutrients fall into 3 different subsections of nutrients: primary, secondary, and micro nutrients. Primary nutrients include nitrogen (N), Phosphorus (P), and potassium (K). Secondary nutrients include sulfur (S), magnesium (mg), and calcium (Ca). Micronutrients include manganese (Mn), chlorine (Cl), copper (Cu), molybdenum (Mo), boron (B), iron (Fe), and zinc (Zn).

Nitrogen

Nitrogen is the nutrient applied in the greatest quantity in the United States, with approximately 12 million tons of product in 2014, or approximately 57% of all fertilizer spread (USDA, 2018). Nitrogen, while needed in the highest amount compared to the other primary nutrients, is one of the least available nutrients to the plant found in the soil, due to other factors such as leaching, volatization, and microorganisms (Brady, 1984).

Nitrogen is an essential compound of many processes within plants (Novoa, 1981), including amino acids. These amino acids can bind to form proteins, which are known to be the building blocks of cell tissue. Some arrangements of proteins will aid or facilitate reactions between and within cells, called enzymes. Enzymes allow processes such as root growth, photosynthesis, carbohydrate utilization, cell movement, cell mitosis, and the synthesis of many different compounds to occur within the plant. While N, as N_2, is the most abundant gas in our atmosphere, the availability of N to plants is relatively low in most living systems (Vance, 2001; Vituosek, 1997). Nitrogen in the soil is found in 3 different forms: organic N, ammonium N (NH_4^+), and soluble inorganic N compounds such as nitrate (NO_3^-) (Brady, 1984).

The majority of N within soils is found in the organic form (Brady, 1984). This is the form that immediately subsequent decaying plant material. This form of N is not available to the plant, due to its immediate consumption by microorganisms in the soil. Any organic N not consumed by microorganism will undergo mineralization, thus forming ammonia (NH_3). Mineralization, conducted by the microorganisms found within the soil, allows the many different types of organic forms of nitrogen to mineralize NH_3 gas. The chemical equation of mineralization is as follows.

$$R - N \rightarrow NH_3 \text{ (g)} \tag{1}$$

$$NH_3\ (g) + H_2O \leftrightarrow NH_4^+\ + OH^- \tag{2}$$

After mineralization occurs, N, found in NH_4 form, can then be utilized by plants, as well as converted to other inorganic forms. As evident by the formula above, the reaction is in a constant flux between mineralization, which makes NH_4+, and immobilization, which consumes NH_4+ to make NH_3.

Ammonium N can also be broken on down into its nitrite (NO_2) and nitrate (NO_3) forms (Brady, 1984). The nitrification reaction is as follows.

$$NH_4^+ \rightarrow HONH_2 \rightarrow HONNOH \rightarrow NO_2^- + \ H^+ + energy \tag{3}$$

$$NO_2^- \rightarrow \ NO_2^- + energy \tag{4}$$

Nitrate can then be separated into 4 pools. It can be utilized by microorganisms, taken in by plants, lost by leaching, or volatilized. These pools account for the N that is in the soil for plants/organisms to use. However, much of this N will not be consumed by the crops, due to it being outside the root zone, or in an unavailable form.

There are other ways that N can be added to the soil. One way utilizes lightning to form ammonia and nitrates out of N_2 gas. These then fall to earth and enter our soils via rainfall.

Nitrogen fixation is one of the most important reactions that occurs in soil, and one way that atmospheric nitrogen is made available for crops. Nitrogen fixation occurs by utilizing a biologic organism to convert N_2 into NH_3 (Brady, 1984). This reaction can be both a symbiotic and a non-symbiotic relationship with a host. The reaction that occurs in all legume crops is a symbiotic relationship between the legume and a bacterium called Rhizobia. Rhizobia form nodules at the root of legumes, such as soybean, which become reaction sites for N fixation. The microorganisms will take in N_2 gas, and utilizing energy and protons absorbed from the host plant, will form NH_4^+. The reaction equation is as follows.

$$N_2 + 6H^+ + \ 6e^- \xrightarrow{(nitrogenase)} 2NH_3 \tag{4}$$

The N manufactured in this biological reaction then follows four different pathways (Brady, 1984). A part of the N will be absorbed by the plant for immediate use. The rest of it is added to the soil, either part of a solution, or excreted by the microorganisms through the node. This portion will then follow the process of mineralization mentioned and explained earlier. Some of the nitrogen will be tied up in the root system. The rest will be held by the microorganisms that run the reaction. For both the root system and the microorganisms, when the organism dies, the nitrogen will return to the soil, and follow the path of mineralization.

N_2 can also be formed into a usable form of N in the soil via industrial fixation. Named by the creators of the process, Fritz Haber and Carl Bosch, the Haber-Bosch process utilizes N_2 and H gas to create ammonia gas. This gas can then go through other chemical reactions to make fertilizers.

The concentration of both NH_4^+ and NO_3^- in the soil differs depending on the soil type and its structure. In aerated soils, nitrate is generally found in higher concentrations (Novoa, 1981).

Nitrogen, found in soils as NH_4^+ and NO_3^- , can be transported into cells through both transport cycles. Since N is majorly mobile in the soil, it can be absorbed in the root system sorption zone (Bray, 1954). Once in the plant, ammonium and nitrate undergo more chemical reactions to become directly usable for the plant (Smil, 2000). Ammonium will be used to form amino acids which the plant then uses. Nitrate is reduced into ammonium, and follows the same reaction as above.

The amount of N in the soil that is usable by plants depend on both temperature and pH (Bassioni, 1970). On a study conducted on barley roots, it was discovered that the nitrate (NO_3^-) uptake was increased as the temperature increases. This is also true on other crops such as maize, soybeans, and some trees (Bose, 2001). . Nitrate uptake is generally favored by an acidic pH (Bose, 2001).

Nitrogen, as an essential mobile nutrient, is required in large amounts by the plant. The demand of N can be determined by the rate of growth, and the N composition of tissues being grown (Novoa, 1981). When soil N is not found in high enough quantities, the plant can become deficient. At different stages of the plant growth, deficiencies can occur different levels. Research conducted at the University of Arizona on wheat shows that the biomass of plants is composed of approximately 1.6 mg g^{-1} N, while the grain is composed of 2.3 mg g^{-1}. Therefore, the requirement for nitrogen is higher while producing grain than when producing biomass. (Thompson, 1975).

In most plants, N deficiencies arise in older growth. Nitrogen deficiencies are expressed through diminished protein concentration in the leaves (Novoa, 1981). When N is adequate, the only leaves where a protein loss is found in the oldest leaves where diminished productivity is present. . When N becomes less than adequate, the protein losses in older leaves may happen faster, due to the remobilization of N from older growth into newer growth. However, when N is very inadequate, newer growth can be seen to be losing proteins. In most crops, this can be seen through chlorosis in the veins. If inadequacy persists, then loss of yield will follow. When N supplied naturally by the environment does not meet crop requirements, producers can supplement levels in the soil, increase the N soil concentration, and therefore, increasing the yield potential.

Phosphorus

Phosphorus is another primary essential plant nutrient that is fertilized in large quantities each year. In the United States in 2014, approximately 4,300,000 metric tonnes of P fertilizer was applied, making up about 20% of nutrients applied (USDA, 2018). Phosphorus, unlike N, is an immobile nutrient in the soil.

Phosphorus is utilized as the main component of the energy storing and releasing compounds adenosine diphosphate ((NADP)) and adenosine triphosphate (ATP), as well as a major component of the nucleic acids, deoxyribonucleic acid (DNA), and ribonucleic acid (RNA) (Brady, 1984). It also takes an important role in other functions of plants, including cell division, maturation of crops, root and stem development, and formation of flowers and fruits.

Phosphorus in the soil can be in either organic or inorganic forms. Organic P comes from the decomposition of organic material, such as plant and animal residue. Inorganic phosphorus comes from the minerals and chemicals within the soil itself. When looking at soil P, it is found as one of three different forms: labile, non-labile, and solution.

Solution-P is the most readily available form and can immediately be absorbed by the plant by diffusion. Solution P comes in the forms of phosphates, primarily $H_2PO_4^-$ and HPO_4^{2-}. However, these fast absorbing molecules also make up the smallest amount of soil phosphorus, about 1% (Brady, 1984).

The second form of soil phosphorus is that of labile phosphates. Phosphates in this form are combined with metals and minerals in the soil; the metals available are based on the soil pH. In acidic soils, phosphates will be formed with metals such as iron- (Fe), aluminum- (Al), manganese- (Mn) phosphates are formed (Arnall, 2017). In basic soils, and calcium- (Ca) and magnesium- (mg) phosphates are formed. These phosphates are generally found on the surface of particles in the soil. Labile phosphates are not readily absorbed by the plants, because of their bond to soil particles. However, these phosphates have the ability to move into soil solution. Labile phosphates make up small portion of the total soil P in most soils, about 8-9%(Brady, 1984).

The remaining 90% of P in the soil is found in the third form, as non-labile P. This is P that is tightly bonded to particles, such as clay, in the soil. They are generally held tightly to the surface via multiple bonds. This does not allow the phosphate to move around and be available for use until the bonds are broken.

Temperature can affect how P is used in the soil. Warmer temperatures increase the solubility of phosphate compounds. As the soil temperature increases as the year progresses, solubility increases, and therefore more readily available P. Double crops are planted in later, warmer months, therefore, during times of high P solubility.

With many soils being deficient in P, fertilization must occur. However, one of the challenges with fertilizing for P is that the fertilizer that is applied is only utilized up to about 15% (Selles et al., 2011). This is due to the reactions that will occur after the fertilizer is applied. However, depending on the amount of P applied, P from the applied fertilizer could be available and utilized by subsequent crops (Selles et al., 2011; Spratt)

Phosphorus deficiencies in the plant can cause some issues with a growing plant. In the plant, phosphorus is mobile, unlike in the soil. Therefore, if there is a deficiency, its symptoms will appear as spots in older growth in the plant first. Phosphorus is vital to the duplication of cells, and therefore the growth of the plant. When deficiencies occur, the plant will become stunted, and in some crops, will become purple due to the accumulation of sugars (Mosaic, 2017)

Potassium

The last primary macronutrient that is essential for plant growth is potassium. Fertilizer use of K in the United States falls very closely to that of P usage, approximately 4,800,000 metric tonnes, making up 23% of all the nutrients spread (USDA, 2018). Potassium is a relatively immobile nutrient in the soil, however, mobile within the plant.

Potassium is involved in many different roles that are essential to a plants life. However, it rarely ever becomes part of a larger chemical structure, but works mainly on regulation within the plant. Potassium becomes very important in the activation of enzymes, in cellular transport, and in photosynthesis.

Enzymes are utilized throughout many cells in order to catalyze a reaction. Potassium's role in enzyme activation allows the reaction to begin. Potassium, when bonded to the enzyme, will change the shape and orientation of the enzyme, and expose the reaction sites for the molecules to bond to and begin the reaction.

Active diffusion utilizes energy from ATP in order to move nutrients up the concentration gradient, from a lower concentration to a higher concentration. Potassium, or more specifically, K^+, is used in many cases to transport the sugars. Potassium can move across cell membranes very easily, making transporting sugars much easier.

Soil-K content exceeds crop demand in most soils. K deficiencies are most likely in sandy soils and areas of extremely high rainfall; up to about 35,000-55,000 kg per hectare-furrow slice (Brady, 1984). However, not all the potassium found within the soil is usable. Potassium, similar to phosphorus, can be found in 3 different forms within the soil.

Most K within the soil is still in its mineral-rock state. Only about 1-2% of soil K is actually readily available for plant use (Arnall, 2017). The readily available potassium is called exchangeable, or solution, potassium.

The next form of soil K is slowly available potassium. This form of K is generally non-exchangeable immediately, and can sometimes be fixed to other particles within the soil. This form of K makes up about 1-10% of the total soil K level.

The majority of soil K is found in the final form of potassium, relatively unavailable potassium. Feldspars, micas, and other rocks and minerals within the soil are made up of potassium.

Once the parent materials are broken down (e.g. K-feldspar, mica), the two other pools of potassium are in equilibrium. As one is removed, the equilibrium shifts to replenish. This demonstrates the ability of a soil to recover some of the potassium used while cropping without the use of fertilizer. This also works with the addition of K fertilizer as well. When a K fertilizer is added to the soil, a portion of the fertilizer will go the readily available form, able to be immediately used by the plant, and the rest will become "fixed" within the colloids in the soil and become slowly available (Brady, 1984). Even though the slowly available K is not immediately usable, it can be resistant to leaching, unlike the ready available nutrients.

Like phosphorus, pH has an influence on potassium's availability. At low pH (4-5), the soil solution potassium is very high, around 18 cmol kg^{-1} (Brady, 1984). As the soil pH increases, H^+ enters solution, and as a result, K^+ can be sorbed more easily. This can lead to the amount of soil solution potassium to decrease approximately 2 cmol kg^{-1}, as it becomes fixed to colloids within the soil.

Potassium also affects drought resistance of plants. Low K levels during periods of very dry weather can be very problematic, and can make it much more difficult for crops to survive. During times of dry weather, root growth, as well as the diffusion and uptake of K+, is restricted (Wang et al., 2013). During these drought-stress conditions, applied potassium has been reported to improve root growth, vegetative growth, growth rate, and improve water use efficiency (Andersen, 2009). When K is more accessible, plants speed up the delivery of the nutrient to the roots.

Deficiencies can occur in agriculture intensive areas that crops are intensively managed for many years, depleting much of the available and slowly available supply, and removal of much of crop residues. Furthermore, when producers are looking to decrease input costs, many will choose to reduce the amount of fertilizer used. However, this can lead to deficiencies. Potassium deficiencies can lead to stunted root development in young plants (Ashley et al., 2006). In mature plants, older leaves of plants turn brown on the edges as the potassium is transported to newer growth.

Sulfur

For the past two centuries, sulfate (SO_4) dissolved from the atmosphere in rainfall has supplied all necessary S for the plants. However, the Clean Air Acts has resulted in better management of pollutant emissions over the past 30 years, the S deposition that rainfall supplies has decreased greatly ((NADP), 2013). This resulted in only a small amount of additional S needed to sustain yields.. Recently there has been an increase in the amount of crops presenting with S deficiencies and needing additional S for sustained yields (Chibber, 2007), which has resulted in increased number of producers and researchers finding significant yield responses from the addition of S. .

Sulfur is characterized as a secondary nutrient, because it is needed in less quantities than that of the primary nutrients: N, P, and K. Sulfur is a pivotal component of four amino acids, methionine, cysteine, taurine, and homocysteine (Brady, 1984). This makes S crucial when it comes to the creation and manufacturing of proteins.

Similar to nitrogen, S, or its ion for SO_4^{2-}, is a mobile nutrient, and therefore, the plant requirements of S is yield driven, not sufficiency driven as phosphorus and potassium (Zhang, 2013b). However, a much smaller amount is needed. Anywhere from 1/10 to 1/20 of the amount of nitrogen applied is needed by sulfur (Brady, 1984; Zhang, 2013a).

Sulfur is found in the soil naturally via soil minerals, S gases from the atmosphere, and organic material (Brady, 1984). Parent materials containing nickel- and iron- sulfides are the source of S formed within the soil. The minerals are then broken down by natural weathering, the sulfides are oxidized to sulfate, which can then be utilized by plants. Other sulfur containing minerals, such as sulfate minerals, are common in soils with very low amounts of rainfall.

The last pathway that S can enter the soil naturally is through organic matter. This sulfur is generally found in the form of proteins from living tissue (Brady, 1984). These proteins are subject to microbial utilization and breakdown first. As the proteins are broken down, the sulfur containing molecules are oxidized and released to the soil.

Sulfur can be found in the soil in three major forms: sulfides, sulfates, and organic (Brady, 1984). If the sulfur enters the soil naturally as organic matter, it will be broken down as stated above, and decayed into a sulfide. When being oxidized further, other sources of sulfur, such as elemental sulfur, thiosulfates, and polythionates will also decay into a sulfide. Oxidation will then occur of all sulfides down into a sulfate. The chemical transitions of sulfides and elemental sulfur into sulfates is as follows.

$$H_2S + 2O_2 \rightarrow H_2SO_4 \rightarrow 2H^+ + SO_4^{2-} \tag{5}$$

$$2S + 3O_2 + 2H_2O \rightarrow 2H_2SO_4 \rightarrow 4H^+ + 2SO_4^{2-} \tag{6}$$

Deficiencies in the United States, though rare, have been found. Fawcett et al (Fawcett et al., 2018) observed sulfur deficiencies in Iowa alfalfa and corn fields. Another study conducted in Ohio presents that sulfur deficiency can even be predicted by looking at soil pH, soil organic matter, and rainfall (Kost et al., 2008). Research conducted in Oklahoma has shown that deep sandy soils where exceeding amounts of leaching occurs are more likely to be deficient in sulfur than other texture types (Zhang, 2013a).

When plants become deficient, the amino acids cysteine and methionine manufacturing slows down. With amino acid creating ceased, the synthesis of proteins is inhibited (Marschner, 2012). Unlike the other nutrients that have been discussed, within the plant, sulfur is not mobile. Therefore, the symptoms of deficiency will not show up in the older growth, but in new growth. The physical symptoms of sulfur deficiency will be interveinal chlorosis in the newer leaves. This is from the lack of proteins being manufactured.

Over fertilization and Nutrient Use Efficiency

With soil testing being a singular instance look at the soil nutrient availability at one point in time, it is harder to understand how it fluctuates over time. Producers and consultants will apply more nitrogen fertilizer than a soil test will recommend, to make up for perceive error associated with soil test. This, along with low soil infiltration, and high amounts of erosion, can lead to a loss of fertilizer that will never be used in the soil. Even with high soil infiltration, if there is a surplus of usable N in the soil, and the crop cannot utilize all of it, leaching can still occur.

This can result in an economic loss of the producer and can cause harm to the environment. For the environment, over fertilization in the field where it is applied, in addition to large rainfall events, high soil infiltration, and poor soil structure can lead to nutrient runoff.

Nutrient runoff has been a large problem for many producers, especially those who are near large bodies of water. Some states have even enacted laws to help circumvent the issues with nutrient runoff, such as Maryland’s Chesapeake Bay runoff laws (Maryland Department of Agriculture, 2016). Nutrient runoff can lead to the growth of algal blooms in bodies of water. Algal blooms are large masses of algae that has grown in a body of water with high nutrient availability, due to runoff and leaching of the nutrients.

Producers utilizing nutrient use efficiency can help alleviate issues with over- and under-fertilization of crops. Nutrient use efficiency is defined as yield compared to input of the nutrient (Hawkesford, 2014). In recent years, many researchers are pushing to learn more about using nutrients more efficiently.

According to Cui et al., achieving a balance between the N supply and demand of the crop, without excess or deficiency is the key to optimizing profits, yield, and environmental protection (Cui et al., 2010a). Leaching can be a problem two-fold. The foremost problem for the producer is the financial portion. If rates of any nutrient fertilizer are applied at the most efficient amount, the producer can spend the most efficient amount of fertilizer, and not any more than is needed. This will save the producer money.

The study conducted in the North China Plain was to learn more about the in-season fertilization of winter wheat (Cui et al., 2010b). This study focused on learning more about the optimal nitrogen fertilization rate for winter wheat. Upon completion, it was concluded that the optimal rate of fertilizer for the crop also was similar to the economically optimal rate.

Double Crop Fertilization

A double crop, to most producers, is considered a second crop grown in the same calendar or fiscal year, after the harvest of the primary crop. For much of the double crop production region, double crop fertilization occurs before the crop is even planted or during the fertilization of the previous crop (generally wheat). That is to say, producers will fertilize additional during their fall/spring applications of their primary crop, so that there will be leftover for the double crop (Godsey, 2008). This practice is recommended by many of the universities in the Southeast and Midwest (Godsey, 2008; Holshouser, 2015; Minor, 1998; Slaton, 2012; Thomas, 1982).

The recommendations for phosphorus and potassium tend to be based around fertilizing from the previous crops. Following soil test recommendations for the previous crop should provide adequate nutrients. The amount of these nutrients needed by the double crop is no different than that same crop as a full season variety (Slaton, 2012).

For soybeans, nitrogen requirements are generally lower than for other crops, as it is a legume. Oklahoma State University recommends 11-22 kg ha^{-1} of N for soybean crops(Arnall, 2017). Also, an application of 11-22 kg ha^{-1} N in double crop soybeans applied after flowering has been shown to increase yield (Godsey, 2008). Phosphorus and Potassium levels for soybeans is recommended to be 32.5 mg kg^{-1} and 175 mg kg^{-1}, respectively. Sulfur fertilization is based on a yield model, and varies depending on crop (Zhang).

Because of the limited production range of grain sorghum, more limited research has been conducted on sorghum in a double-crop setting. However, many recommend the same amount of nutrients supplied for double crop as they do with full season varieties.

Nitrogen levels for grain sorghum, as with other crops, is yield driven. This sometimes leads to inadequate fertilization of sorghum based on inaccurate yield goals. Publications from Alabama, Illinois, Kentucky, and Tennessee recommend 67-140 kg of N ha^{-1}.(Mask; McLure, 2009).

For areas in the Mid-South, anywhere from 44-90 kg ha^{-1} of P_2O_5 should be applied for the crop needs. This is to keep levels within the soil to be around 20-25 mg kg^{-1}, or 56-67 kg ha^{-1} (Program, 2010).

Potassium for grain sorghum levels are sufficiency based. OSU recommends a critical soil test value of 125 mg kg^{-1} in Oklahoma(Oklahoma Cooperative Extension Service, 2016), however, others recommend anything greater than 130 mg kg^{-1} (McLure, 2009).

In the past 20 years, the oilseed industry in Oklahoma has led to the increase in land planted in sunflower. Recommendations of this crop are similar to that of canola, another oil seed crop. Phosphorus levels for sunflowers are recommended to be 32.5 mg kg^{-1}. Potassium levels for sunflower's, like sorghum, needs to be more than 125 mg kg^{-1}. Nitrogen rates are based around yield goal. For the yearly average of 600 kg in Oklahoma in 2014, the nitrogen needed to be fertilized would be about 93 kg ha^{-1} (Oklahoma Cooperative Extension Service, 2016; Oklahoma Department of Agriculture, 2015). Sulfur recommendations for oil seed crops is approximately 1.12 kg ha^{-1} sulfur application for every 11.2 kg ha^{-1} nitrogen applied.

Some research has shown that, especially in sandy soils, small grain crops can be responsive to an addition of chloride. Due to this, Oklahoma State University's current recommendation is 39.2 kg ha^{-1}, or approximately 17.5 mg kg^{-1}, in the top 40.64 cm (Zhang, 2006; Zhang, 2013c).

CHAPTER III

OBJECTIVE

- To determine whether the addition of nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) fertilizer to the soil above current production practices will increase the grain yield of the double crops in Oklahoma
- To determine whether pre-plant soil test could predict the influence of additional N, P, K and S applications have on in grain yield.

CHAPTER IV

METHODOLOGY

This study was conducted in 2016 and 2017 at 29 and 32 on-farm locations in Oklahoma, respectively. Some locations were lost due to missed harvest/stand loss/extreme variability of data. Figure 1 displays the arrangement of the 61 location-years across the state of Oklahoma, as well as their climatic divisions (Figure 1).

At each location, 15 soil samples were taken using a 2.54 cm diameter soil probe from each site at depths of 0-15 and 15-30 cm. Samples were mixed from each depth allowing two composite samples from each site. The samples were then sent to Oklahoma State University Soil, Water, and Forage Analytical Laboratory (SWFAL) to be analyzed for pH, NO_3-N, extractable P, K, S, Ca, Mg, Fe, Zn, B, Cu, Cl, and organic matter. Samples were dried at 65°C overnight and ground to pass a 2 mm sieve prior to extraction and analysis. The pH was measured by using a combination electrode within a 1:1 ratio of soil to water suspension. Nitrate-N was determined using a 1M KCl extraction solution with 2 g of soil to 20 mL of solution with 15 minutes of shaking time. Nitrate-N was then determined by automated colorimetric flow-injection analysis (Lachat Quickchem 8000, Loveland, CO). Mehlic-3 (M-3) was used to find extractable P, K, Ca, and Mg, by extracting 2 g of soil with 20 mL of M-3 solution and shaking for 5 minutes. Exchangeable S was found by mixing 10 g of soil with 25 mL of 0.008M calcium phosphate solution and shaking for 30 minutes. Concentration of P, K, Ca, Mg, and S in the extracts were determined with an inductively coupled plasma atomic emission spectrometer (ICP-AES).

A plot consisted of four parallel strips 1.8 x 45.7 M wide by length. A tractor with a custom built NPKS applicator(Figure 2) was transported to every site. The applicator applies a dry fertilizer for each of the four treatments. The treatments consisted of urea (46-0-0), triple super phosphate (0-46-0), muriate of potash (0-0-62) and gypsum (22% Ca and 17% S). The NPKS applicator is comprised of four dry fertilizer boxes, in this case each holding a unique fertilizer. Each fertilizer box has three polyurethane tubes connected to a 12 m boom where it dispersed its fertilizer evenly throughout a 1.8 m strip, parallel to one another. The agitator in the fertilizer boxes are attached, by a chain, to a drive shaft. The drive shaft is rotated by two, ground-contact driven wheels. The dry fertilizer is then forced through polyurethane tubing pneumatically by a PTO controlled fan. Each treatment was applied at approximately 224 kg of product ha-1 post crop emergence. For each nutrient, this equates to 92 kg N ac-1, 92 kg P2O5 ac-1

120 kg K_2O ac^{-1}, and 44 kg SO_4 ac^{-1}. At maturity three 1 m^2 sections were harvested from each strip at every site-year by hand cutting the total biomass 2.54 cm above the soil surface for soybeans, and cutting the heads for sorghum and sunflowers. Each sample was placed into its own individual labeled paper seed sack and sealed. Samples were dried into a dry room, which sits at approximately 45℃. Samples upon drying were threshed. For soybeans, threshing occurred via Kincaid 18” bundle thresher (Kincaid Equipment, Haven, KS). For sorghum, threshing occurred by feeding sorghum heads through a Wintersteiger Delta plot combine equipped with a HM-1000 GrainGage made by HarvestMaster™ (Wintersteiger Inc., Salt Lake City, UT). Sunflower yield was estimated utilizing the a calculation developed by North Dakota State University (Kandel, 2012). Each sample had its weight recorded, and the yield per area was

calculated. Statistical analysis performed using SAS 9.4. Individual locations were analyzed separately using Proc GLM and Dunnett's Test identifying significant variables using alpha=0.05.

CHAPTER V

RESULTS

In 61 site years, 244 comparisons were made towards Oklahoma producer's double crop fertility practices. Of these 244 comparisons, only 20 comparisons yielded significantly different from the producer practice. Of the 20 comparisons, 4 fields had multiple nutrient rich strips with significant responses. Responses were distributed equally between the 2016 and 2017 growing seasons. 1.7% (1), 8.3% (5), 16.7% (10), and 6.7% (4) sites responded to the N, P, K, and S rich strips, respectively.

Of the 20 responses, there were 17 soybean sites with nutrient responses, three grain sorghum sites with nutrient response, and there were zero sunflower sites that were responsive. The distribution of the 17 soybean responses was zero, five, nine, and three of N, P, K, and S, respectively. Of the three grain sorghum sites responses, one was responsive site for N, K, and S.

The average LSD for double crop soybean site locations was approximately 600 kg ha^{-1}, or 30% of the farmer practice strips grain yield of 2031 kg ha^{-1}. The average LSD for DC grain sorghum sites was approximately 1100 kg ha^{-1}, or 30% of the farmer practice grain yield of 3575 kg ha^{-1}. Due to the lack of sunflower locations, and lack of sunflower location responses, average LSD was not calculated for sunflower sites. Based on these LSD values, a change of 30% in yield above or below farmer practice would be required to observe a statistically significant response.

Due to the magnitude of change required to yield a statistically significant response, a yield response would not be expected due to the deficiency of required nutrients (from those based on sufficiency model: i.e. P and K) unless those nutrients were greater than 30% deficient. Of the 38 soybean sites that were below 100% sufficiency of P, zero of those were below 70% sufficiency, or 7.5 mg kg-1. Of the 7 soybean sites below 100% sufficiency of K, zero of those were below 70% sufficiency, or 104 mg kg-1. Of the three grain sorghum sites that were below 100% sufficiency of P, zero of those were below 70% sufficiency, or 7.5 mg kg-1. Due to the lack of locations with soil test values below the 70% sufficiency value, it was hypothesized that it would be unlikely to see a large number of locations with significantly positive response to added P and K.

Weather Conditions

Weather conditions and soil moisture are the primary decision construct in determining to move into a double-crop system. Many producers will make their decision on planting double-crop if adequate moisture is at or near planting. Figures 3 through 6 display the weather conditions for each climatic zone in Oklahoma where sites are located, as established by Abit et al. (Abit et al., 2017).

Soil moisture in the top 10 cm of soil for the northeast and central climatic divisions for both double crop planting seasons in 2016 and 2017 were drier than average, while in the southwest, soil moisture had a higher moisture content than average for both years. In the west central climatic division, both years had average soil moisture in the top 10 cm. In the north central climatic division, 2016 had above average soil moisture, while it was drier in 2017.

Double Crop Yield and Soil test by Location by Crop

The following will discuss each of the comparisons with resulted in a significant difference from the check. This discussion will be organized by crop then nutrient.

Soybean

Nitrogen

As discussed prior, soybean crops, as a legume, have little to no requirements of nitrogen. However, Oklahoma State University recommends 11-22 kg ha^{-1} of N for soybean crops (Arnall, 2017). Also, an application of 11-22 kg ha^{-1} N in double crop soybeans applied after flowering has been shown to increase yield (Godsey, 2008). Therefore, this amount of nitrogen was used in analysis of nitrogen responses.

In the two years of this study, only two of the 50 soybean sites were found to be below 11 kg ha^{-1} NO_3^- from 0-45 cm. There was no responsive soybean sites from the additional nitrogen inputs. From these results, it can be assumed that either there was enough residual N and/or proper nodulation.

Phosphorus

Unlike nitrogen, phosphorus nutrient requirements are not based upon yield goals, but on soil concentrations and a sufficiency scale. For all three crops involved in this study, grain sorghum, soybeans, and sunflowers, OSU recommendations are based on 32.5 mg kg^{-1} of Mehlich-3 extractable P being 100% sufficient (Arnall, 2017)).

For soybean sites, 38 out of the 50 sites were found to have soil test P values be below the critical threshold of 32.5 mg kg^{-1} in the 0-15 cm soil sample. Of these 38 locations, zero locations had a STP value below 7.5 mg kg^{-1}, or 70% sufficiency. As mentioned earlier based upon the average yield and LSD, it would not be expected to statistically differentiate a yield response to added fertilizer when soil test values exceeded 7.5 mg kg^{-1}. No locations had soil test values below this threshold. However in the two years of this study, 5 out of 50 sites soybean locations were found to be responsive to additional phosphorus fertilizer when compared to the farmer practice strip.

Locations 5 and 38 in 2016 were responsive to the P rich strip (Table 7). Locations 5 and 38 had STP in the surface below 100% sufficiency values; 10 mg kg^{-1} and 14 mg kg^{-1}, however neither fell below the 70% sufficiency value. Both locations had pH within values where P is most available. Producer applied 55 kg ha^{-1} at location 5 for the primary crop, while OSU recommendations would have included 45 kg ha^{-1}. Producer applied 11 kg ha^{-1} at location 38 for the primary crop, while OSU recommendations would have included 36 kg ha^{-1}. The farmer practice reduced the maximum yield for both locations by not applying additional P. These responses are hypothesized to be due to low STP values.

Location 31 in 2017 was also responsive to the P rich strip (Table 7). In the surface, the STP was 54 mg kg^{-1}, above 100% sufficiency value. This location also had a pH of 4.8. For the primary crop, OSU recommendations would not have included any additional P fertilizer. The producer applied 35 kg ha^{-1} of P_2O_5 for the primary crop, winter wheat. The farmer practice maximum yield was reduced by not applying additional phosphorus. While STP was above the minimum sufficiency values recommended by OSU, due to the low pH, it is hypothesized that not all phosphorus was available in the soil due to phosphorus reactions with metals such as aluminum (Al), iron (Fe), and manganese (Mn) to become insoluble compounds (Arnall, 2017).

Potassium

Similar to phosphorus, potassium fertilizer recommendations are based on a sufficiency model, therefore not yield driven. According to Oklahoma State University's recommendations, for 100% sufficiency in soybeans, this value is 139 mg kg^{-1} STK (Arnall, 2017). For 70% sufficiency, this value is 104 mg kg^{-1}.

Out of the 50 soybean site-years, only seven sites were found to be below sufficiency according to the pre-plant soil test, however, only 9 out of 50 site-years were found to be responsive to additional potassium fertilizer when compared to the farmer practice strip.

Locations 3, 5, and 29 in 2016 were responsive to the K rich strip (Table 8). These locations had STK below 100% sufficiency, 81 mg kg^{-1}, 62 mg kg^{-1}, and 22 mg kg^{-1}, respectively; however, none of these were below 70% sufficiency. The producer's applied K_2O at rates recommended by OSU at locations 3 and 5. Location 29 did not have any K applied, even though OSU recommendations would have included a K application. The farmer practice reduced the maximum yield for these three locations by not applying additional K. These responses are hypothesized to be due to low STK values.

Of the seven sites that were below 100% sufficiency of K, zero of these sites were below 70% sufficiency, or 53 mg kg^{-1}. Utilizing this value, we would not have predicted a statistically significant response to yield to any site-year.

Sulfur

Similar to nitrogen, sulfur fertilizer recommendation are based on yield goal models, however, no yield goal was recorded for this study. Therefore, yield goal was assumed using soil test results, producer inputs, and utilizing OSU recommendations.

Location 33 in 2017 had sulfate levels in the surface of 7.5 kg ha^{-1}, while the subsurface had 1.2 kg ha^{-1} (Table 9). The producer did not apply sulfur fertilizer for either the previous crop, winter wheat, or the double crop, soybeans. The farmer practice strip reduced maximum yield by not underestimating yield potential. This response was expected to occur due to its sulfate levels being below requirements for maximum potential yield.

Location 46 in 2017 had sulfate levels in the surface of 39.6 kg ha^{-1}, while the subsurface had 48.8 kg ha^{-1} (Table 8). The producer applied 6 kg ha^{-1} for the primary crop. OSU recommendation for this site would not have included additional S fertilizer application based on the soil test. Above average rainfall in the northeast climate zone in the growing season is suspected to have leached out sulfate, leading to sulfur response of the double crop.

Grain Sorghum

Nitrogen

For grain sorghum, nitrogen requirements are based on yield goals, however, no yield goal was recorded for this study. Therefore, yield goal was assumed using soil test results, as well as producer inputs, and utilizing OSU recommendations.

Location 7 in 2016 had residual NO_3-N levels of 16 kg ha^{-1} in the surface, and 25 kg ha^{-1} from subsurface (Table 6). The producer applied 67 kg ha^{-1} NO_3-N for the wheat, as their primary crop, and applied an additional 40 kg ha^{-1} for the double crop, grain sorghum. It is hypothesized that producer application of nitrogen fertilizer did not receive any rainfall after application, as the north central climate division had below average moisture in June, leading to less nitrogen being available for uptake (Figure 4). A larger amount of N in the soil profile in the N strip was available, leading to more uptake by the crop.

Phosphorus

Unlike nitrogen, phosphorus nutrient requirements are not based on yield goals, but on a sufficiency scale. For grain sorghum, OSU recommendations are based on 32.5 mg kg^{-1} of STP being 100% sufficient (Arnall, 2017).

Of the 7 grain sorghum site-years, only three sites were below 32.5 mg kg^{-1} soil test P, with zero sites below 7.5 mg kg^{-1}. There were no grain sorghum sites that responded to the addition of P fertilizer. Due to zero fields falling below the 70% sufficiency value, 7.5 mg kg^{-1}, there were also no grain sorghum fields expected to respond to the addition of P fertilizer.

Potassium

Similar to phosphorus, potassium fertilizer recommendations are based on a sufficiency model, therefore not yield driven. According to Oklahoma State University's recommendations, for grain sorghum, 100% sufficiency levels are based on 125 mg kg^{-1} of STK (Arnall, 2017). There were no grain sorghum sites that were below 125 mg kg^{-1} in either 2016 or 2017.

Location 19 in 2017 had STK in the surface of 249 mg kg^{-1} (Table 8). The surface chloride level was 12.4 mg kg^{-1}, while the subsurface was 2.3 mg kg^{-1}. For the primary crop, OSU recommendations would not have included any additional K fertilizer. The producer did not apply potassium for either the primary crop, winter canola, or the double crop, grain sorghum. The farmer practice yield was reduced without the addition of K. Due to low chloride levels, it is hypothesized that this site was responsive with the addition of Cl via KCl fertilizer application. Though not common, chloride deficiencies are possible, and recommendations for small grain crops are 35 mg kg^{-1}(Zhang, 2006).

Of the three sites that were below 100% sufficiency of K, zero of these sites were below 70% sufficiency, or 53 mg kg^{-1}. Utilizing this value, we would not have predicted a statistically significant response to yield to any site-year.

Sulfur

Similar to nitrogen, sulfur fertilizer recommendation for grain sorghum are based on yield goal models, however, no yield goal was recorded for this study. Therefore, yield goal was assumed using soil test results, producer inputs, and utilizing OSU recommendations.

Location 22 in 2017 had sulfate levels in the surface of 15.8 kg ha^{-1}, while the subsurface had 30.6 kg ha^{-1} (Table 9). The producer did not apply sulfur fertilizer for either the previous crop, winter wheat, or the double crop, grain sorghum. Based on yield of sulfur rich strip, the sulfur requirements of this site would be 6 kg ha^{-1}. Located in the same climate zone as location

11, this site experienced above average rainfall in August, and has been hypothesized that this could lead to leaching, even though soil test sulfate levels were above necessary levels.

Sunflower

Nutrient requirements

For sunflower crops, nitrogen and sulfur requirements are based on yield goals, however, no yield goal was recorded for this study. Therefore, yield goal was assumed using soil test results, as well as producer inputs, and utilizing OSU recommendations.

Phosphorus and potassium requirements for sunflowers is based on the sufficiency model, similarly to both soybean and grain sorghum. The sufficiency values for sunflowers is 32.5 mg kg^{-1} and 125 mg kg^{-1} for phosphorus and potassium, respectively.

Of the four sunflower site years, two sites were below 32.5 mg kg^{-1} soil test P, with one being below 20 mg kg^{-1}. None of the four sunflower sites were below 125.5 mg kg^{-1} soil test K.

In the 4 site-years planted in sunflowers, there were no responses to any nutrient rich strip (Table 4).

Discussion

Only 1 site yielded a response to nitrogen, and is hypothesized to be due to leaching from high rainfall events post fertilizer application. Non-legumous sites were those that were expected to return some yield response, and of those, none of which that had lower levels of nitrate responded to the additional N fertilizer. Thirteen sites across both years were predicted to provide a yield response, and the one that did yield a response was not predicted.

Of 61 locations, 29 locations applied higher than OSU recommended rates of P_2O_5 for the primary crop, and six for the double crop. The 12 locations that applied K_2O for the primary crop applied higher than OSU recommended rates, and four of the six locations that had K_2O applied,

applied higher than OSU recommended rates for the double crop. Higher than recommended rates for the primary crop is could be either due the producers standard practice, the pre-plant soil test values were lower for the field composite, or the producer was preparing for DC by over fertilizing the primary. Eight sites that applied higher rates of P_2O_5 for the primary crop applied P_2O_5 again for the DC. Six locations which received K_2O for the DC only four locations that had PC fertilizer application data. Of these, one site applied K_2O to the DC while applying higher than recommended rates for the PC.

Out of 38 sites predicted to yield a response from the addition of P, only 5 did. One site was predicted to have a phosphorus response due to low pH, while the other four were predicted due to soil test P values being below 100% sufficiency. Two of these four had P_2O_5 applied at higher than OSU recommended rates for the PC. Four out of the five responses also occurred in the same sites that K responses were found.

Out of the 7 sites that were expected to respond due to low STK, only 2 sites responded. 8 sites responded that were not predicted to respond from the soil test. 10 sites total responded to potassium fertilizer, 2 of which are hypothesized to be due to drought conditions, one was hypothesized to be due to under fertilization of potassium fertilizer, 3 were hypothesized to have responded to the chloride addition from KCl input, and 3 were hypothesized to be due from a combination of the three.

Even though there were no sites expected to yield a response from the sulfur rich strips, 4 sites responded to the addition of sulfur. These are hypothesized to have occurred due to leaching from an above average moisture growing season in 2017.

Based on the LSD calculation discussed prior, there were no sites that would be expected to yield a significant response, for both soybean and grain sorghum, due to a deficiency of required nutrients P and K unless those nutrients were greater than 30% deficient. Across 61 site-years, of which, 38 site-years were below 100% sufficiency of phosphorus, and 7 site-years were below 100% sufficiency of potassium, there were no sites that were below 70% sufficiency for either phosphorus and potassium. Based on this, no response to either additional phosphorus or potassium would have been expected.

There were no responses found from the nutrient rich strips in site-years containing sunflowers. Site-years that were planted with sunflowers were sites that contained the highest additional fertilizer inputs during the double crop growing season. This is assumed to be due to the idea of sunflowers not being a “catch-all” crop, or a crop that is planted due to the low risk, moderate reward nature as soybeans and grain sorghum are seen. Producers who planted sunflowers in this study tended to increase their fertilizer inputs. Therefore, a lack of response to any additional nutrient inputs above the producer practice would be expected. These producers are not missing out on yield, because they are increasing inputs.

CHAPTER VI

CONCLUSIONS

This project was initiated as an extension tool, and therefore, the ability to differentiate between treatments was sacrificed in order to increase locations to provide a true geographic range. This testing method allows for the collection of enough statewide sites to compile meaningful dataset which can be used to improve understanding of how current variables, such as management practices, weather, and soil variability can affect yield (Association, 2017).

In 61 site years, 244 comparisons were made towards Oklahoma producer's double crop fertility practices. Of these 244 comparisons, only 20 comparisons yielded significantly different from the producer practice. Of the 20 comparisons, 4 fields had multiple nutrient rich strips with significant responses. 1.7% (1), 8.3% (5), 16.7% (10), and 6.7% (4) sites responded to the N, P, K, and S rich strips, respectively. The majority of producer's current double crop fertility practices maximize yield, as 46 out of the 61 locations, or 75%, did not yield a response to any additional nutrient inputs. Soil test results and critical values were able to correctly identify the locations that would not respond to additional nutrient inputs, as only 12 out of 186 (6.5%) non-predicted responses yielded a significant response. Of the 122 comparisons for P and K, based upon soil test values, producer fertilizer application and the limitations of the variance in harvested plots, it was hypothesized that there would be no response to added P and K. However, there were 15 significant comparisons made. While that is just 12% of the comparisons made, it does highlight the challenges in predicting the response to immobile nutrients based solely on a soil test. This suggests that further work is required to provide producers with a more reliable measure of when fertilizer is needed.

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TABLES

Table 1 Summary of soil test from 2016 and 2017

	Depth	**pH**	**NO_4-N (kg ha^{-1})**	**STP (mg kg^{-1})**	**STK (mg kg^{-1})**	**SO_4-S (kg ha^{-1})**	**Cl (mg kg^{-1})**
				2016			
AVERAGE	0-15 cm	5.6	24	34	189	28.0	13.4
	15-45 cm	6.2	12	12	156	33.5	13.8
MAX	0-15 cm	7.9	49	12	378	323.6	45.2
	15-45 cm	8.1	37	33	296	523.1	49.0
AVERAGE	0-15 cm	4.5	7	10	62	6.8	3.6
	15-45 cm	5.2	4		50	6.3	3.5
				2017			
AVERAGE	0-15 cm	5.5	25	28	182	10.0	20.2
	15-45 cm	6.0	14	12	172	11.8	13.2
MAX	0-15 cm	7.5	57	96	336	81.4	184.8
	15-45 cm	7.8	30	75	424	101.2	75.1
AVERAGE	0-15 cm	4.7	4	2	56	3.4	4.2
	15-45 cm	5.3	3	1	44	2.2	3.3

Table 2 Year, site, soil test results, OSU recommendations, and fertilizer application of all soybeans sites.

Year	Site	pH		NO3		STP		STK		SO4		Cl		OSU Recommendations		Producer Fertilizer Application							
	2017	0-15 cm	15-45 cm	0-15 cm	15-45 cm	0-15 cm	15-45 cm	0-15 cm	15-45 cm	0-15 cm	15-45 cm	0-15 cm	15-45 cm	P_2O_5	K_2O	Primary Crop				Double Crop			
																N	P_2O_5	K_2O	S	N	P_2O_5	K_2O	S
														kg ha^{-1}		kg ha^{-1}							
2016	1	6.6	6.6	7	20	16	3	67	31	16.7	26.4	16.5	5.7	38	61	168	49	74	22	0	0	0	0
2016	3	6.4	6.5	29	16	19	5	81	33	20.6	9.2	50.4	5.2	32	50	146	35	73	0	0	0	0	0
2016	4	7.4	7.5	29	24	28	6	80	31	8.6	16	4.1	2.4	16	51	168	26	58	22	0	0	0	0
2016	5	7	7.1	31	24	10	1	62	25	11.3	15.2	9.9	3.4	48	65	168	55	63	22	0	0	0	0
2016	8	7.8	8.1	32	32	36	8	241	97	14	27.2	6.3	1.8	0	0	214	87	0	0	0	0	0	0
2016	9	5.5	5.7	16	32	18	6	135	72	13.3	18.4	5.7	2.1	35	0	164	29	0	0	0	0	0	0
2016	21	6.6	-	41	-	25	-	152	-	15.2	-	22.3	-	22	0	168	0	0	54	0	0	0	0
2016	22	5.6	6.4	10	12	39	8	189	88	14.9	30.4	14.2	5.4	0	0	68	29	0	0	0	0	0	0
2016	23	7.4	-	9	-	28	-	193	-	15.8	23.2	15.8	6	17	0	68	29	0	0	0	0	0	0
2016	24	6	6.4	12	12	32	3	154	55	46.6	38.4	9.7	23.4	9	0	68	29	0	0	0	0	0	0
2016	25	4.9	5.8	18	16	31	4	104	55	15.4	26.8	5.7	4.5	11	32	68	29	0	0	0	0	0	0
2016	26	5.4	5.9	16	28	19	5	188	83	14	27.2	8.7	5.4	32	0	17	40	0	0	3	18	13	0
2016	27	5.2	5.7	19	24	34	5	170	68	15.6	29.2	7.8	4.1	0	0	17	40	0	0	3	18	13	0
2016	29	6.1	6.9	25	20	22	2	173	87	9.4	13.6	5.8	3.2	28	0	17	40	0	0	3	18	13	0
2016	30	5.5	5.9	24	24	58	7	161	63	17.3	16	7	7.3	0	0	17	40	0	0	0	0	0	0
2016	31	6.4	7.1	11	16	30	7	259	110	12.1	22.8	9	2.5	12	0	11	38	0	0	0	0	0	0
2016	32	4.5	5.2	31	32	84	15	159	63	13.6	31.2	8.9	4.7	0	0	11	38	0	0	0	0	0	0
2016	33	5.9	7.1	21	24	16	4	166	71	14.6	18.8	13.1	3.4	38	0	78	0	0	0	0	0	0	0
2016	34	7.1	7.9	15	8	96	17	374	148	6.8	34.8	7.1	1.9	0	0	78	0	0	0	0	0	0	0
2016	36	5.5	6.5	20	16	21	6	222	95	11.6	17.2	8.4	3.4	29	0	134	34	0	0	0	0	0	0
2016	38	5.4	6.2	18	24	14	5	157	59	10.8	17.2	7.3	5.1	42	0	29	11	0	0	0	0	0	0
2016	39	6.7	7	18	8	25	3	170	94	16.7	26.4	16.5	5.7	21	0	109	35	0	0	0	0	0	0
2016	40	7	6.9	20	12	19	3	183	81	20.6	9.2	50.4	5.2	32	0	109	35	0	0	0	0	0	0
2017	3	7.5	7.7	22	32	8	3	188	93	12.9	28.4	5.1	2.3	52	0	-	-	-	-	-	-	-	-
2017	7	5.6	-	16	-	23	-	240	-	16.8	-	20.3	-	25	0	101	0	84	0	0	0	0	0
2017	8	6.5	-	15	-	15	-	235	-	14.9	-	15.3	-	40	0	101	0	84	0	0	0	0	0
2017	9	6.1	-	19	-	24	-	214	-	34.6	-	66.6	-	23	0	101	0	84	0	0	0	0	0
2017	10	6.3	6.5	4	24	3	10	173	84	19.9	28	5.7	2.8	61	0	87	44	0	0	0	0	0	0
2017	11	5.7	6.1	13	12	69	12	336	212	15.3	28	6	2.2	0	0	87	44	0	0	0	0	0	0
2017	12	6.3	6.4	8	8	19	4	177	89	19.8	34.4	6.7	2.8	32	0	87	44	0	0	0	0	0	0
2017	13	6	6.5	27	28	17	4	141	82	12.3	25.6	7.1	2.4	37	0	87	44	0	0	0	0	0	0
2017	14	5.6	5.6	13	8	17	4	198	71	13.8	20.4	4.2	1.6	37	0	87	44	0	0	0	0	0	0
2017	15	6.4	7.2	9	8	18	3	202	103	8.7	19.6	9.5	3.8	35	0	81	29	0	0	0	0	0	0
2017	16	5.5	5.7	19	32	23	7	209	95	19.3	34.4	7.2	1.9	26	0	81	29	0	0	0	0	0	0
2017	25	6.5	6.9	25	20	32	6	216	99	10.6	14.8	15	4	10	0	151	29	0	0	0	0	0	0
2017	26	5.4	5.6	25	28	39	11	300	127	15.8	22	39.8	4.3	0	0	151	29	0	0	0	0	0	0
2017	27	5.9	6.6	26	60	25	7	193	107	20.2	22	24.5	13.9	21	0	144	34	0	9	0	0	0	0
2017	28	6.9	7.6	18	28	30	7	193	106	16.7	42	23.8	26	12	0	144	34	0	9	0	0	0	0
2017	29	6.1	6.2	37	36	96	38	314	158	9.5	16.4	5.9	2.1	0	0	8	35	0	6	0	0	0	0
2017	30	5.8	6.5	32	28	23	3	155	88	16.6	24	9.3	3.2	26	0	8	35	0	6	0	0	0	0
2017	31	4.8	6	26	40	54	5	131	111	13.3	24.4	8.3	4.6	0	0	8	35	0	6	0	0	0	0
2017	33	7.4	7.8	36	20	9	1	183	106	7.5	9.6	10.5	3.1	50	0	111	35	0	0	0	0	0	0
2017	37	6.5	7.3	24	20	18	1	143	70	11.8	13.6	8	3.2	35	0	15	38	0	0	0	0	0	0
2017	38	5.5	6.4	22	28	14	2	148	69	16.1	22	10.2	2.9	42	0	15	38	0	0	0	0	0	0
2017	42	4.9	7.4	49	44	85	2	101	71	27.5	27.6	17.3	4.5	0	35	15	38	0	0	3	15	15	3
2017	43	6.7	7.1	7	60	2	8	62	27	18	23.6	6	8	63	65	289	205	168	6	0	0	0	0
2017	44	6.3	6	20	16	22	3	76	34	182.2	-	33.3	37.5	28	54	112	39	71	0	0	0	0	0
2017	45	5.3	5.5	40	24	12	1	84	82	18	126.4	36	12.1	45	48	140	38	67	6	0	0	0	0
2017	46	6	5.6	26	8	9	2	118	21	39.6	48.8	184.8	5.9	50	22	140	43	55	6	0	0	0	0
2017	49	6.4	7.3	26	20	16	2	56	38	37.8	-	43	28.9	38	69	177	205	168	6	0	0	0	0

Table 3 Year, site, soil test results, OSU recommendations, and fertilizer application of all grain sorghum sites

Year	***Site***	**Crop**	**pH**		**NO3**		**STP**		**STK**		**SO4**		**Cl**		**OSU Recommendations**		**Producer Fertilizer Application**							
			0-15 cm	15-45 cm	0-15 cm	15-45 cm	0-15 cm	15-45 cm	0-15 cm	15-45 cm	0-15 cm	15-45 cm	0-15 cm	15-45 cm	P_2O_5	K_2O	Primary Crop				Double Crop			
																	N	P_2O_5	K_2O	S	N	P_2O_5	K_2O	S
															kg ha^{-1}		kg ha^{-1}							
2016	*7*	Grain Sorghum	7.2	7.7	16	24	21	4	293	106	23.2	33.6	45.2	19.1	28	0	40	43	0	0	67	0	0	0
2016	*17*	Grain Sorghum	7.9	8.0	49	72	30	6	378	144	12.7	-	3.6	-	13	0	-	-	-	-	69	8	2	0
2016	*18*	Grain Sorghum	7.1	-	43	-	123	-	288	-	16.9	32.4	15.8	7.7	0	0	-	-	-	-	69	8	2	0
2016	*35*	Grain Sorghum	6.0	6.2	38	32	63	11	354	121	11.4	12.4	4.6	38.3	0	0	146	22	0	0	0	0	0	0
2017	*19*	Grain Sorghum	5.4	6.4	43	52	21	4	249	115	28.9	38	12.4	5	28	0	43	44	0	0	40	35	0	0
2017	*20*	Grain Sorghum	6.5	6.1	34	40	37	12	266	90	20.9	24	11.6	3.4	0	0	43	44	0	0	40	35	0	0
2017	*22*	Grain Sorghum	5.5	5.3	49	32	31	8	312	94	15.8	30.4	13	3.4	11	0	43	44	0	0	40	35	0	0

Table 4 Year, site, soil test results, OSU recommendations, and fertilizer application of all sunflower sites

Year	*Site*	Crop	pH		NO3		STP		STK		SO4		Cl		OSU Recommendations		Producer Fertilizer Application							
			0-15 cm	15-45 cm	0-15 cm	15-45 cm	0-15 cm	15-45 cm	0-15 cm	15-45 cm	0-15 cm	15-45 cm	0-15 cm	15-45 cm	P_2O_5	K_2O	Primary Crop				Double Crop			
																	N	P_2O_5	K_2O	S	N	P_2O_5	K_2O	S
															kg ha^{-1}		kg ha^{-1}							
2016	*12*	Sunflower	6.0	6.5	37	8	21	6	153	77	13.9	27.2	45.1	24.5	28	0	113	26	0	11	46	18	0	0
2016	*13*	Sunflower	6.4	6.7	38	6	23	7	236	99	13.3	18.3	39.7	-	25	0	113	26	0	11	46	18	0	0
2017	*5*	Sunflower	5.7	6.4	9	2	18	3	287	90	9.3	18.2	5.4	1.8	35	0	87	26	0	0	50	0	0	0
2017	*6*	Sunflower	5.8	6.3	57	11	26	6	146	58	13.2	21.3	7.3	2.7	19	0	86	26	0	0	50	0	0	0

Table 5 Year, crop, Farmer practice strip yield, nutrient strip yield and delta (Δ) between nutrient strip and FPS.

Year	**Crop**	**Farmer Practice Strip**	**N-Strip**		**P-Strip**		**K-Strip**		**S-Strip**	
		kg ha^{-1}								
			Yield	Δ	Yield	Δ	Yield	Δ	Yield	Δ
2016	Soy	2050	1868	-182	2006	-44	2137	87	1825	-225
2016	Sorghum	5100	5492	392	5440	340	5912	812	5273	173
2016	Sunflower	2647	3543	896	3128	481	3195	548	2978	331
2017	Soy	2012	1940	-72	1937	-75	2051	39	1961	-51
2017	Sorghum	2050	2113	63	2448	398	3013	963	3055	1005
2017	Sunflower	4004	3942	-62	4112	108	3852	-152	3525	-479

Table 6 Site number, year, double crop, soil test results, fertilizer application, and grain yield for the sites responsive to N.

N Response Sites

Location	**Year**	**Crop**	**Soil test NO_3-N**		**Total Applied N**		**Grain Yield (kg ha^{-1})**	
			0-15 cm	**15-45 cm**	**Primary Crop**	**Double Crop**	**FPS**	**N-rich strip**
			kg ha^{-1}		kg ha^{-1}		kg ha^{-1}	
7	2016	Grain Sorghum	16	6	67	40	2762	4206

Table 7 Site number, year, double crop, soil test results, fertilizer application, and grain yield for the sites responsive to P.

P Response Sites

Location			pH		STP		Producer Applied P_2O_5		OSU Recommendations		Grain Yield	
	Year	**Crop**	**0-15 cm**	**15-45 cm**	**0-15 cm**	**15-45 cm**	**Primary crop**	**Double crop**	**Primary Crop**	**Double Crop**	**FPS**	**P- rich strip**
					mg kg^{-1}		kg ha^{-1}		kg ha^{-1}		kg ha^{-1}	
5	2016	Soy	7.0	7.1	10	1	55	0	45	45	2446	3073
29	2016	Soy	6.1	6.9	22	2	40	0	28	28	1192	1568
38	2016	Soy	5.4	6.2	14	5	11	0	36	36	1568	2760
31	2017	Soy	4.8	6.0	54	5	35	0	0	0	941	1756
33	2017	Soy	7.4	7.8	9	1	35	0	50	50	1505	2070

Table 8 Site number, year, crop, soil test results, fertilizer application, and grain yield for the sites responsive to K

K Response Sites

Location	**Year**	**Crop**	**Cl**		**STK**		**Total Applied K_2O**		**OSU Recommendations**		**Grain Yield**	
			0-15 cm	**15-45**	**0-15 cm**	**15-45 cm**	**Primary Crop**	**Double crop**	**Primary Crop**	**Double Crop**	**FPS**	**K- rich strip**
			mg kg^{-1}		mg kg^{-1}		kg ha^{-1}		kg ha^{-1}		kg ha^{-1}	
3	2016	Soy	20.6	9.8	81	33	73	0	50	50	2215	2685
5	2016	Soy	20.4	2.6	62	25	63	0	65	65	2617	3423
29	2016	Soy	8.7	2.7	22	2	0	0	96	96	1275	1678
38	2016	Soy	4.6	1.9	157	58	0	0	175	175	1678	3758
39	2016	Soy	8.4	1.7	170	94	0	0	0	0	1879	2752
40	2016	Soy	7.3	2.6	183	81	0	0	0	0	2215	3624
19	2017	Grain Sorghum	12.4	2.3	249	115	0	0	0	0	1761	3019
27	2017	Soy	24.5	7.0	193	107	0	0	0	0	1275	2416
28	2017	Soy	23.8	13.0	193	106	0	0	0	0	1074	2215
33	2017	Soy	10.5	1.6	183	105	0	0	0	0	1611	2215

Table 9 Site number, year, double crop, soil test results, fertilizer application, and grain yield for the sites responsive to S.

S Response Sites

Location	**Year**	**Double Crop**	**Soil Test SO_4**		**Total Applied S**		**Grain Yield**	
			0-15 cm	**15-45 cm**	**Primary Crop**	**Double crop**	**FPS**	**S-rich strip**
			kg ha^{-1}		kg ha^{-1}		kg ha^{-1}	
11	2017	Soy	15.3	28.1	0	0	902	2105
22	2017	Grain Sorghum	15.8	30.6	0	0	1902	3592
33	2017	Soy	7.5	9.7	0	0	1804	2405
46	2017	Soy	39.6	48.8	6	0	3082	3683

FIGURES

Figure 1Map of all sites in 2016 and 2017 and their climatic zone. Purple points depict sites in 2016. Red points depict sites in 2017.

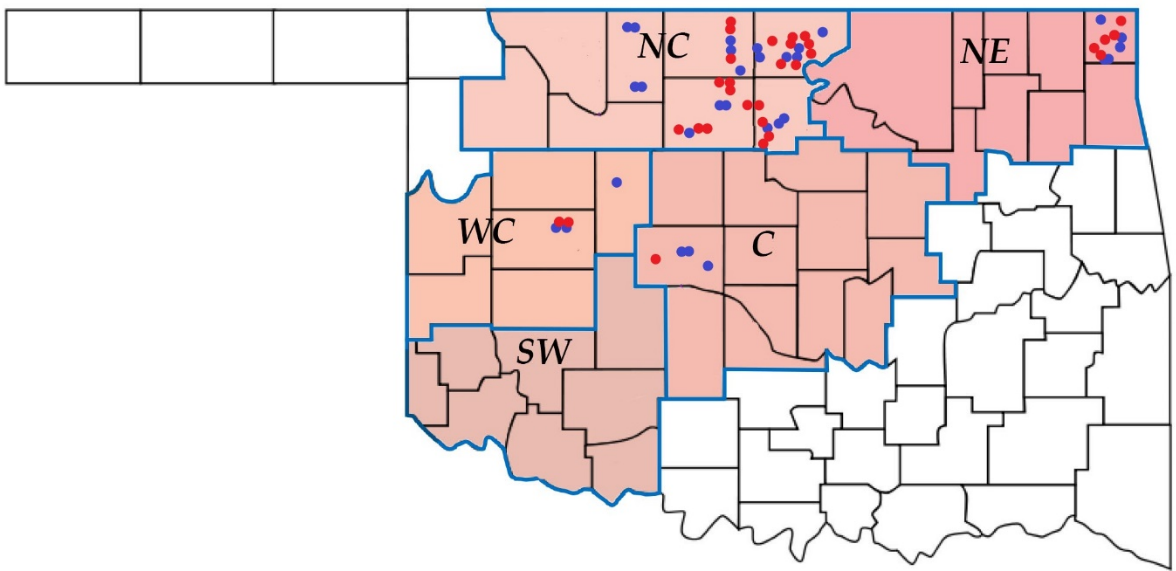


Figure 2 NPKS applicator

Figure 3 North East Climate Zone 15 year average rainfall and temperature compared with 2016 and 2017 values

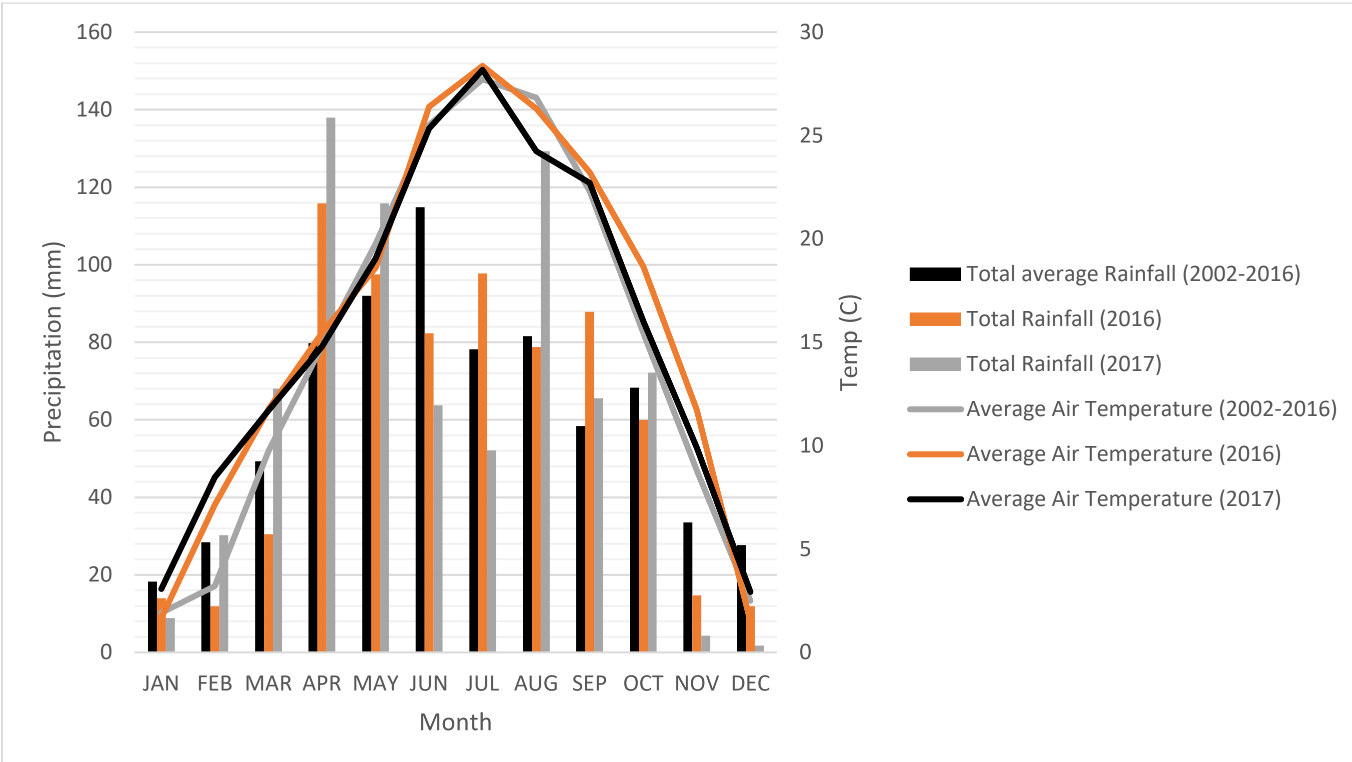


Figure 4 North Central Climate Zone 15 year average rainfall and temperature compared with 2016 and 2017 values

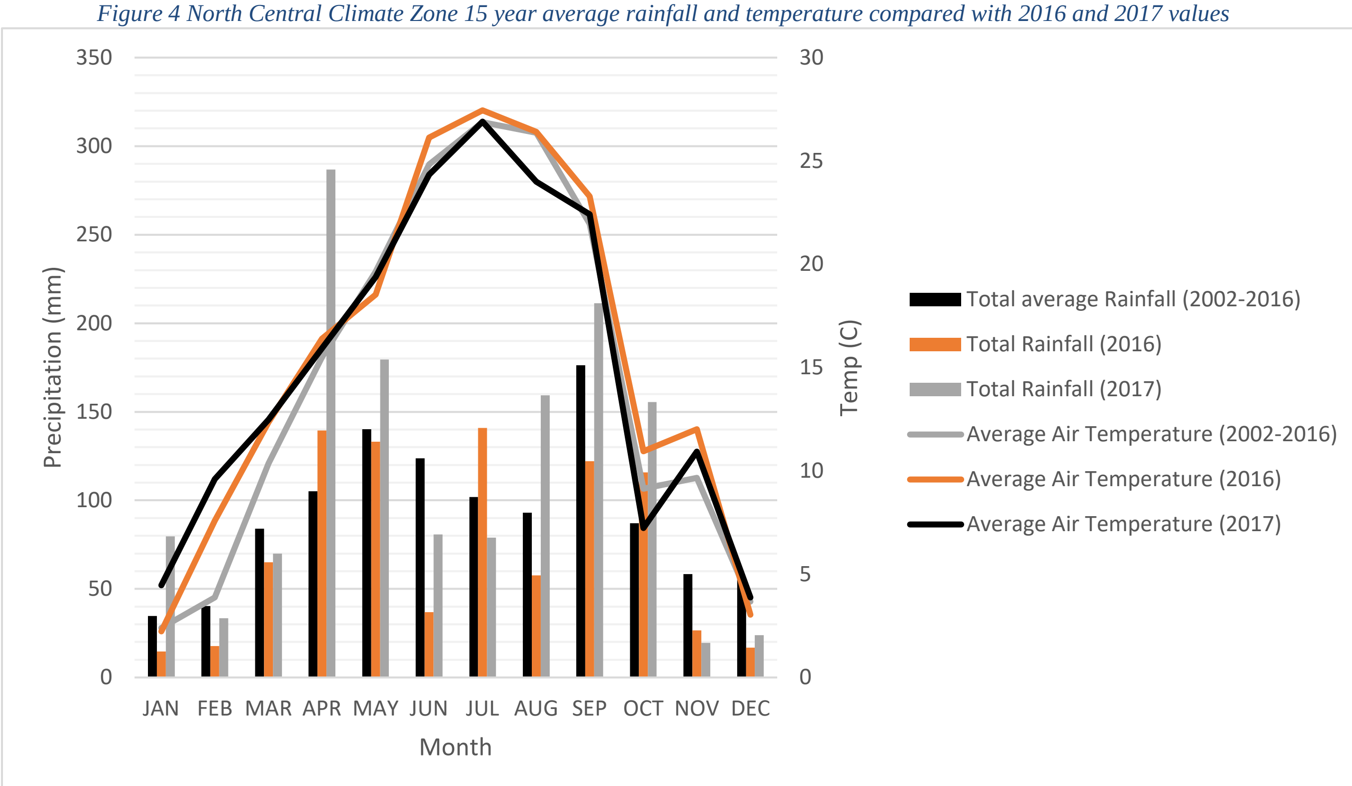


Figure 5 West Central Climate Zone 15 year average rainfall and temperature compared with 2016 and 2017 values

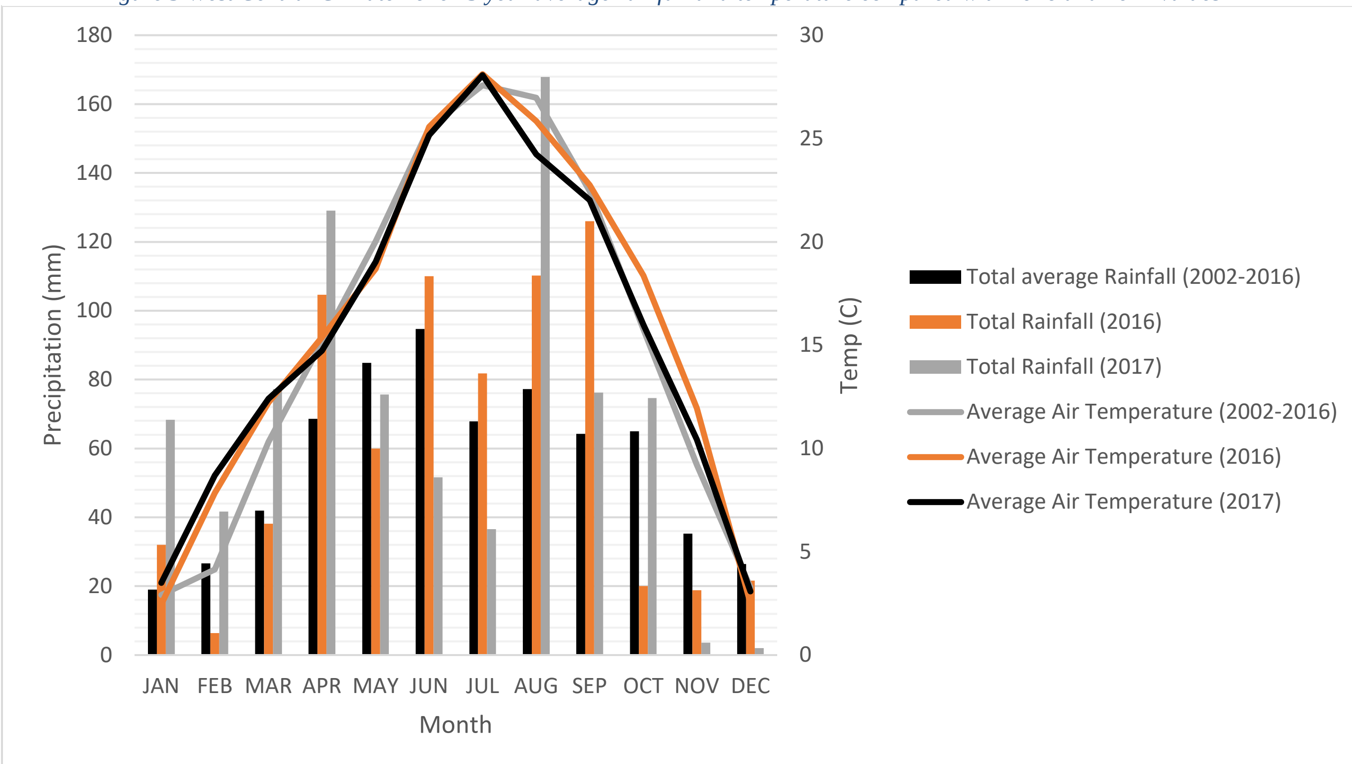
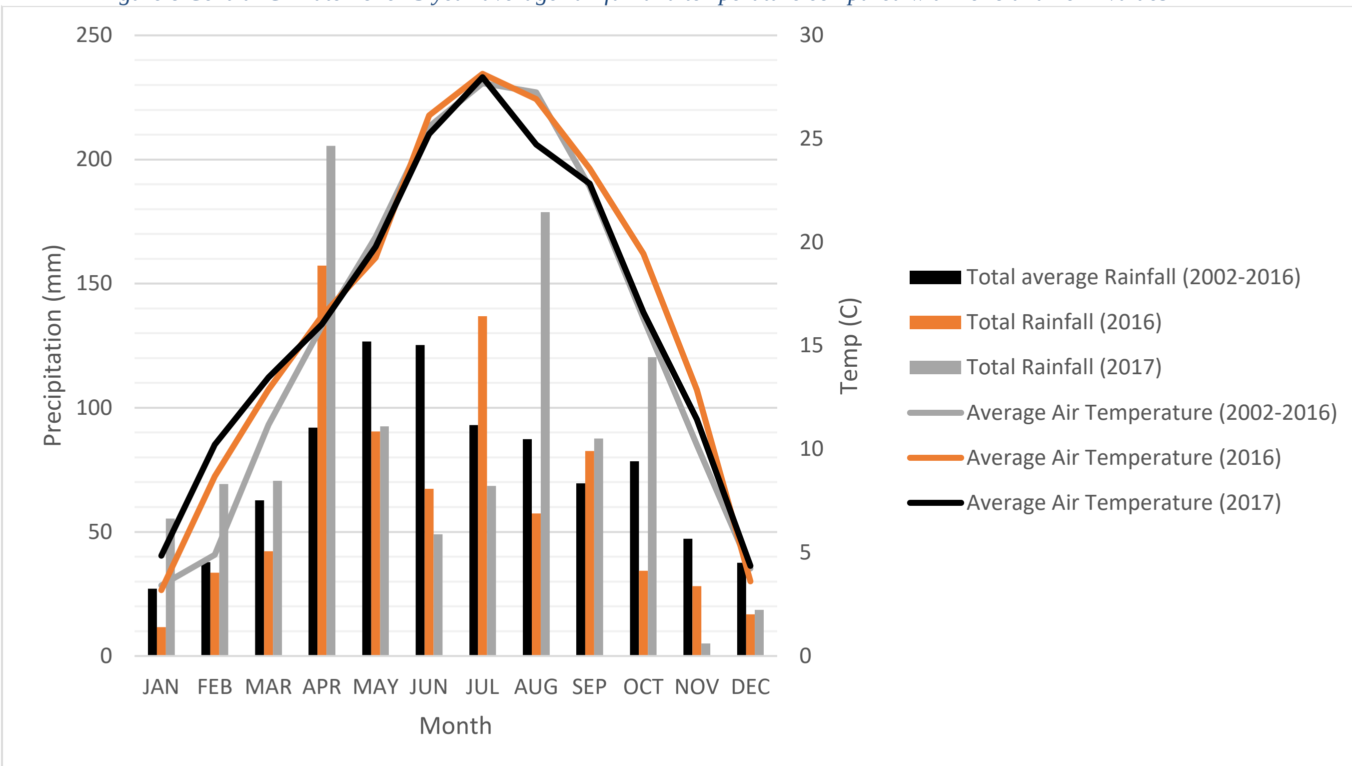


Figure 6 Central Climate Zone 15 year average rainfall and temperature compared with 2016 and 2017 values



APPENDICES

Year, county, soil series, soil description, climate division, tillage practice, and nutrient responses of the 61 NPKS-strip locations in 2016-2017

Year	**County**	**Soil Series**	**Soil Description**	**Climate Division**	**Tillage Practice**	**N**	**P**	**K**	**S**
2016	Ottawa	Parsons silt loam	FINE, MIXED, ACTIVE, THERMIC MOLLIC ALBAQUALFS	NE	No till				
2016	Ottawa	Taloka silt loam	FINE, MIXED, ACTIVE, THERMIC MOLLIC ALBAQUALFS	NE	No till			*	
2016	Ottawa	Dennis silt loam	FINE, MIXED, ACTIVE, THERMIC AQUIC ARGIUDOLLS	NE	No till				
2016	Ottawa	Dennis silt loam	FINE, MIXED, ACTIVE, THERMIC AQUIC ARGIUDOLLS	NE	No till		*	*	
2016	Garfield	Kirkland silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till	*			
2016	Garfield	Kirkland silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2016	Garfield	Tabler silt loam	FINE, MIXED, ACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2016	Custer	St. Paul silt loam	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC PACHIC ARGIUSTOLLS	WC	No till				
2016	Custer	St. Paul silt loam	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC PACHIC ARGIUSTOLLS	WC	No till				
2016	Canadian	Watonga silty clay	FINE, SMECTITIC, THERMIC UDIC HAPLUSTERTS	C	Conventional				
2016	Canadian	Lovedale fine sandy loam	FINE-LOAMY, MIXED, SUPERACTIVE, THERMIC UDIC ARGIUSTOLLS	C	Conventional				
2016	Canadian	Dale silt loam	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC PACHIC HAPLUSTOLLS	C	Conventional				
2016	Noble	Port silt loam	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC CUMULIC HAPLUSTOLLS	NC	No till				
2016	Noble	Renfrow and Grainola soils	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2016	Noble	Renfrow and Grainola soils	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2016	Noble	Renfrow and Grainola soils	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2016	Kay	Agra silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2016	Kay	Agra silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2016	Kay	Agra-Foraker complex	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till		*	*	
2016	Kay	Milan loam	FINE-LOAMY, MIXED, SUPERACTIVE, THERMIC UDIC ARGIUSTOLLS	NC	No till				
2016	Kay	Ashport silt loam	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC FLUVENTIC HAPLUSTOLLS	NC	No till				
2016	Kay	Ashport silt loam	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC FLUVENTIC HAPLUSTOLLS	NC	No till				
2016	Alfalfa	Reinach very fine sandy loam	COARSE-SILTY, MIXED, SUPERACTIVE, THERMIC PACHIC HAPLUSTOLLS	NC	No till				
2016	Alfalfa	McLain silt loam	FINE, MIXED, SUPERACTIVE, THERMIC PACHIC ARGIUSTOLLS	NC	No till				
2016	Alfalfa	Pond Creek silt loam	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC PACHIC ARGIUSTOLLS	NC	No till				
2016	Alfalfa	Grant silt loam	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC UDIC ARGIUSTOLLS	NC	No till				
2016	Grant	Bethany silt loam	FINE, MIXED, SUPERACTIVE, THERMIC PACHIC PALEUSTOLLS	NC	No till		*	*	
2016	Grant	Kirkland silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till			*	
2016	Grant	Kirkland silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till			*	
2017	Canadian	Bethany silt loam	FINE, MIXED, SUPERACTIVE, THERMIC PACHIC PALEUSTOLLS	C	No till				
2017	Custer	Woodward silt loam	COARSE-SILTY, MIXED, SUPERACTIVE, THERMIC TYPIC HAPLUSTEPTS	WC	No till				
2017	Custer	St. Paul silt loam	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC PACHIC ARGIUSTOLLS	WC	No till				
2017	Garfield	Kirkland silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Garfield	Kirkland silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Garfield	Kirkland Renfrow complex	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Kay	Kirkland silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Kay	Agra silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				*

2017	Kay	Agra-Foraker complex	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Kay	Agra-Foraker complex	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Kay	Agra silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Kay	Kirkland silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Kay	Agra-Foraker complex	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Garfield	Port silt loam	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC CUMULIC HAPLUSTOLLS	NC	No till			*	
2017	Garfield	Kirkland silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Garfield	Pond Creek silt loam	FINE-SILTY, MIXED, SUPERACTIVE, THERMIC PACHIC ARGIUSTOLLS	NC	No till				*
2017	Garfield	Kirkland silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Garfield	Tabler silt loam	FINE, MIXED, ACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Garfield	Kirkland silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till			*	
2017	Garfield	Kirkland silt loam	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till			*	
2017	Grant	Tabler silt loam	FINE, MIXED, ACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Grant	Tabler silt loam	FINE, MIXED, ACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Grant	Tabler silt loam	FINE, MIXED, ACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till		*		
2017	Kay	Kirkland-Renfrow complex	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till		*	*	*
2017	Noble	Norge silt loam	FINE-SILTY, MIXED, ACTIVE, THERMIC UDIC PALEUSTOLLS	NC	No till				
2017	Noble	Renfrow and Grainola soils	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Noble	Renfrow, Grainola, and Pawhuska soils	FINE, MIXED, SUPERACTIVE, THERMIC UDERTIC PALEUSTOLLS	NC	No till				
2017	Ottawa	Dennis silt loam	FINE, MIXED, ACTIVE, THERMIC AQUIC ARGIUDOLLS	NE	No till				
2017	Ottawa	Taloka silt loam	FINE, MIXED, ACTIVE, THERMIC MOLLIC ALBAQUALFS	NE	No till				
2017	Ottawa	Taloka silt loam	FINE, MIXED, ACTIVE, THERMIC MOLLIC ALBAQUALFS	NE	No till				
2017	Ottawa	Dennis silt loam	FINE, MIXED, ACTIVE, THERMIC AQUIC ARGIUDOLLS	NE	No till				*
2017	Ottawa	Parsons silt loam	FINE, MIXED, ACTIVE, THERMIC MOLLIC ALBAQUALFS	NE	No till				

Latitude and Longitude for each location in each year

Year	Site	Lat/Long	**Year**	Site	Lat/Long
2016	1	36.941672, -94.818232	**2017**	3	35.479677°, -98.032162°
2016	3	36.932462, -94.788098	**2017**	5	35.695243°, -98.811797°
2016	4	36.913986, -94.806314	**2017**	6	35.697124°, -98.786284°
2016	5	36.914764, -94.806307	**2017**	7	36.583571°, -97.710313°
2016	7	36.303455, -97.836361	**2017**	8	36.581939°, -97.656200°
2016	8	36.419013, -97.585387	**2017**	9	36.534562, -97.644738
2016	9	36.422979, -97.621301	**2017**	10	36.767858°, -97.082328°
2016	10	35.880727, -98.469738	**2017**	11	36.800911°, -97.012471°
2016	12	35.705261, -98.809627	**2017**	12	36.797025°, -97.043594°
2016	13	35.693609, -98.844416	**2017**	13	36.780810°, -96.996710°
2016	17	35.587635, -97.954508	**2017**	14	36.764108°, -97.014669°
2016	18	35.586406, -97.946739	**2017**	15	36.795882°, -97.050229°
2016	21	35.537142, -97.780104	**2017**	16	36.810055°, -97.024860°
2016	22	36.273599, -97.337044	**2017**	19	36.301809°, -97.865659°
2016	23	36.261359, -97.353942	**2017**	20	36.299449°, -97.855898°
2016	24	36.261394, -97.354629	**2017**	22	36.298192°, -97.890616°
2016	25	36.243112, -97.390302	**2017**	25	36.422124°, -97.622920°
2016	26	36.762848, -97.013547	**2017**	26	36.417723°, -97.621226°
2016	27	36.767738, -97.013478	**2017**	27	36.434082°, -97.464787°
2016	29	36.811201, -96.976637	**2017**	28	36.434442°, -97.450933°
2016	30	36.761980, -97.084892	**2017**	29	36.812418°, -97.603656°
2016	31	36.767831, -97.456878	**2017**	30	36.849058°, -97.605538°
2016	32	36.767668, -97.459786	**2017**	31	36.862872°, -97.605631°
2016	33	36.899130, -98.280575	**2017**	33	36.781865°, -97.299203°
2016	34	36.899078, -98.286296	**2017**	37	36.248247°, -97.354864°
2016	35	36.492810, -98.273658	**2017**	38	36.277275°, -97.424439°
2016	36	36.492318, -98.250713	**2017**	42	36.171060°, -97.393827°
2016	38	36.708754, -97.570218	**2017**	43	36.914300°, -94.814400°
2016	39	36.815205, -97.606770	**2017**	44	36.911300°, -94.824600°
2016	40	36.813877, -97.606836	**2017**	45	36.907029°, -94.833102°
			2017	46	36.899408°, -94.824210°
			2017	49	36.942416°, -94.806469°

VITA

Vaughn Thomas Seymour Reed

Candidate for the Degree of

Master of Science

Thesis: ON FARM EVALUATION OF DOUBLE CROP FERTILITY MANAGEMENT IN OKLAHOMA

Major Field: Plant and Soil Science

Biographical:

Education:

Completed the requirements for the Master of Science in Plant and Soil Science at Oklahoma State University, Stillwater, Oklahoma in May, 2018.

Completed the requirements for the Bachelor of Science in Agriculture at Murray State University, Murray, Kentucky in May, 2016

Experience:

Employed by Oklahoma State University, Department of Plant and Soil Sciences, as a Precision Nutrient Management Graduate Research Assistant (2016-2018).

Professional Memberships:

American Society of Agronomy
Crop Science Society of Agronomy
Soil Science Society of America
Alpha Sigma Phi