STARTER FERTILIZER MANAGEMENT FOR CORN AND SOYBEAN IN THE SOUTHERN PLAINS

By

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Abstract: Early plant growth and grain yield may be depressed in no-till cropping systems compared to conventional tillage because of the poor nutrient availability early in the growing season. Oklahoma no-till corn (Zea mays L.) and soybean (Glycine max L.) may benefit from starter fertilizer because it places a band of available nutrients near the root-zone. The objectives of this study were to evaluate the effects of various starter fertilizer placements and rates on full-season corn and soybean in the Southern Plains. Placement methods consisted of in-furrow, 2x2 (5 cm to the side and 5 cm below the seed), and 2x4 (5 cm to the side and 10 cm below the seed). The corn in-furrow treatments received N rates from 11 to 45 kg ha^{-1}. Three additional corn in-furrow treatments were N + Zn, N + S, and N + Zn + S. The N was balanced to 168 kg ha^{-1} on all in-furrow corn treatments. The corn 2x2 treatments received N rates from 101 to 168 kg ha^{-1}. The corn 2x4 treatments received N rates of 134 and 168 kg ha^{-1}. The soybean in-furrow treatment received an N rate of 6 kg ha^{-1}. The soybean 2x2 treatments received N rates from 11 to 34 kg ha^{-1}. An additional soybean 2x2 treatment was N + Zn + S. Corn in-furrow placement at 11 kg N ha^{-1} increased early growth without decreasing stand emergence. No differences, for any corn locations, in initial stand counts were observed for 2x2 and 2x4 treatments at rates of 168 kg N ha^{-1}. Corn NDVI decreased as rates increased from 101 to 168 kg N ha^{-1} in the 2x2 treatments. Corn grain yield was not affected by placement or rate of starter fertilizer. Soybean in-furrow placement at 6 kg N ha^{-1} significantly reduced stand, but not yield. Soybean stand, early growth, and grain yield was not affected by any of the 2x2 treatments. Our results showed that starter fertilizer placement and rate increased early growth in corn but had a minimal effect on yield when yield potential was low.

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INTRODUCTION

Introduction

Corn [*Zea mays*] and soybean [*Glycine max*] make up 48.5% of harvested cropland acres in the United States (NASS, 2011). Corn is planted on more acres of land than any other crop in the United States. Soybean is the next most abundant crop planted, after corn. According to the 2007 Census, corn and soybean rank 2nd and 4th for the largest harvested acres for grain and beans in Oklahoma, wheat being 1st and grain sorghum 3rd (NASS, 2011).

No-till is a farming practice becoming more common in Oklahoma. Producers' have started looking to no-till for a number of reasons: moisture conservation, high fuel prices, and government programs to name a few. The increasing number of acres planted to corn and soybean in Oklahoma, along with the increased acres of no-till, has raised questions about the need for starter fertilizers in these systems. Early plant growth and grain yield may be depressed in no-till cropping systems compared to conventional tillage, due to the speed at which soil temperatures warm up thus affecting mineralization activity. The rate of mineralization is dependent on a number of factors, a major one being soil temperature. Cold soils depress the mineralization process which affects the availability of plant nutrients. Early planted corn and soybean may benefit from starter fertilizer because it places a band of available nutrients near the root-zone.

A concern that must be addressed prior to applying a starter fertilizer near the seed is the maximum amount of certain nutrients allowable without seedling injury. Factors to consider when applying fertilizer near the seed are soil texture, soil moisture, type of crop, distance from the seed, and salt index of the fertilizer. These factors determine the allowable amount of fertilizer that can be placed near the seed. Placing fertilizer with the seed at planting is the most sensitive starter fertilizer placement because too high of a concentration will prevent the seed or seedling from taking in moisture, which is due to water potential. A study conducted in Kansas, by Niehues et al. (2004) found, that starter fertilizer placed with the seed at planting at rates above 22 kg N ha^{-1} reduced corn stand. Fertilizer placed near but not in direct contact to the seed can still cause injury (Rehm and Lamb, 2009).

The purpose of this study is to evaluate various starter fertilizer placements and nitrogen (N) rates for corn and soybean in Oklahoma to determine if it is an effective way to maximize early plant vigor, grain yield, and economic return. Similar studies have been done throughout the US and the world but none have been conducted in Oklahoma.

CHAPTER II

LITERATURE REVIEW

Mineralization

When planting full-season summer crops, such as corn or soybean it is typical to plant early so the plant has a longer period to establish, photosynthesize, and flower before the hottest part of the summer. When the chance of frost is minimal it is recommended that the seed be planted as soon as a critical soil temperature is reached, but it doesn't mean nutrients are readily available to the plant. Some key nutrients may not be available because mineralization must occur in order for organic compounds to be converted into inorganic compounds (Zhang and Raun, 2006). Most inorganic compounds that are released during the mineralization process are readily available to plants (NH_4^+, H_2PO_4, SO_4^{2-}, and Zn^{2+}). Mineralization rate increases when the following occur: soil temperatures reaching 25-30^{o}C, close to neutral pH, adequate soil moisture, and good aeration (Brady and Weil, 2008). Perhaps the main nutrient made available by mineralization is nitrogen. Nitrogen mineralization occurs by the decomposition of organic material, releasing ammonia (NH_3). Ammonia may then bind to water, forming ammonium (NH_4^+).

$$NH_3 + H_2O \leftarrow \rightarrow NH_4^+ + OH^-$$

The rate at which organic material decomposes in the soil is partly dependent of the Carbon/Nitrogen (C/N) ratio (Brady and Weil, 2008). A higher C/N ratio slows the soil microbes' decomposition of plant residues. Soil microbes need approximately 1 part N for every 24 parts C (Brady and Weil, 2008).

Another factor to consider is the effect of soil temperature on soil microbial activity and root growth. Warmer soils have more active microbes than colder soils. Soil temperature has been shown to be affected by producers' farming methods. Methods such as conventional tillage and conservation tillage differ because the soil temperature increases sooner in conventional tillage than in conservation tillage. Conservation tillage will generally have 28% lower temperature near the surface than conventional tillage (Johnson and Lowery, 1985). Mackay and Barber (1984) found, in Indiana, that cool soils around 10^{o}C cause slow root growth which can be countered by using starter fertilizer. They found that root growth of corn will increase 5 fold when the temperature increases from 18 to 25^{o}C. A soil with a temperature of 18^{o}C and a P concentration of 5 $_{u}$M had a similar P uptake as a soil with a temperature of 25^{o}C. They summarized that root growth increases the root surface area which increases nutrient uptake. Furthermore, a high soil test P may compensate for low soil temperature and slow root growth (Mackay and Barber, 1984).

Typically full-season summer crops are planted before rapid mineralization takes place, therefore methods such as starter fertilizer or strip tillage may need to be used to provide the plant with essential nutrients. Starter fertilizer containing N and P has been found to speed up the early growth of corn in no-till soils (Bermudez and Mallarino 2002). In Iowa, they found that starter fertilizer placed in-furrow at planting at low rates

(3.9-8.6 kg N ha^{-1}) increased yield in seven of eight fields and increased early growth in nine of nine fields. The response with later planted summer crops may not be similar since mineralization has likely taken place.

Nutrient

There are 16 essential nutrients needed by plants in order for the plant to be able to complete its life cycle. The three primary non-mineral nutrients are Carbon (C), Hydrogen (H), and Oxygen (O). The three primary mineral nutrients are Nitrogen (N), Phosphorus (P), and Potassium (K). The three secondary mineral elements are Calcium (Ca), Magnesium (Mg), and Sulfur (S). The micro-nutrients needed by the plant are Manganese (Mn), Chlorine (Cl), Copper (Cu), Molybdenum (Mo), Boron (B), Iron (Fe), and Zinc (Zn). The availability of micro-nutrients is largely dependent on the pH of the soil.

Nitrogen is the most abundant mineral nutrient found in the plant. Ammonium (NH_4^+) and nitrate (NO_3^-) are the two forms of nitrogen that can be taken up by the plant (Tisdale et al. 1993). Nitrogen is a constituent of several cell components which include: proteins, amino acids, and nucleic acids. (Taiz and Zeiger, 2010) Nitrogen aids in proper plant growth and development. In Oklahoma, N is generally the second most limiting factor found in non-legume crops besides water. The main reason is due to the large amounts required and lost by the plant and the large amounts lost via volatilization, leaching, and denitrification. Corn grain harvested at 15% moisture, yielding 9,408 kg ha^{-1} will remove about 131 kg N ha^{-1} (USDA, 2012). Soybean harvested at 13% moisture, yielding 2,688 kg ha^{-1} will remove about 153 kg N ha^{-1} (USDA, 2012).

Phosphorus is a primary mineral nutrient that is essential to the plant in large quantities. Orthophosphates, $H_2PO_4^-$ and HPO_4^{2-} are two forms phosphorus can be taken up by the plant (Tisdale et al. 1993). Phosphorus is immobile in the soil so for plants to take up this nutrient the roots must come in direct contact with P compounds. In addition to phosphorus being immobile, up to 99% of the P in the soil can be unavailable to the plant due to the formation of compounds that typically have low solubility (Zhang and Raun, 2006). The pH of the soil can be a factor that determines the solubility of P (Figure 1). Acidic soils cause inorganic P to react with Fe and Al forming Fe-P and Al-P precipitates and/or be absorbed by Fe and Al oxides and clay minerals (Tisdale et al. 1993). Basic soils cause inorganic P to react with Ca forming Ca-P precipitates and/or be absorbed by $CaCO_3$ and clay minerals (Tisdale et al. 1993). Banding P at a high concentration has been found to slow the fixation of phosphorus because the soil to fertilizer contact is minimized (Tisdale et al. 1993).

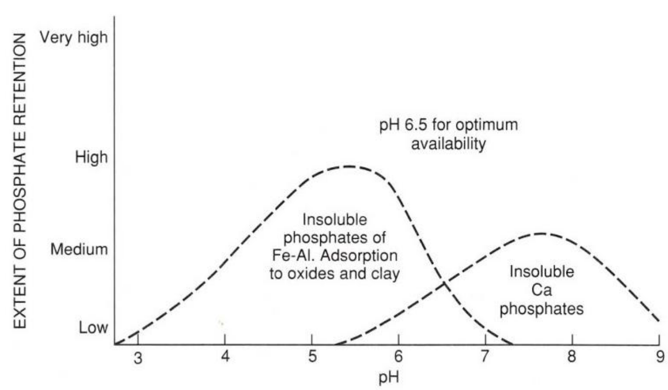

Figure 1. Absorption and precipitation of P as affected by pH.
Source: Stevenson, Cycles of Soil, p.250, John Wiley, 1986

Years of soil testing proved that P is one of the elements most deficient in Oklahoma (Zhang and Raun, 2006). Common P deficiency symptoms are stunted growth in young plants, purple coloration on the outside margins of the lower leaves, and necrotic spots (Taiz and Zeiger, 2010). In Kansas, Schwab et al. (2006) conducted a study to evaluate the effect of subsurface banded ammonium poly phosphate in stratified soils that had twice the soil test P in the surface 7.5 cm compared to the 7.5 to 15 cm depth. They found that subsurface banded starter fertilizer at a rate of 20 kg P ha^{-1} generally increased corn yield, but not soybean yield compared to surface broadcast (applied before plowing and disking) of 20 kg P ha^{-1}. Mallarino et al. (1999) found, in Iowa, that P starter fertilizer placed 2x2 at planting at the rate of 14 and 28 kg P ha^{-1} increased early growth of no-till corn over the control (no starter fertilizer), broadcast, and deep band placements at 14 of 15 fields. The authors did not find grain yield increase due to P and K unless the soils were deficient in these nutrients.

Oklahoma soils, predominantly in the western part of the state have adequate available K (Zhang and Raun, 2006). Potassium is relatively immobile in the soil because it's positively charged and soil is negatively charged. The potassium ion (K^+) is the readily available form taken up by the plant (Tisdale et al. 1993). Potassium's main functions in the plants are aiding in sugar transport and photosynthesis (Taiz and Zeiger, 2010). Mallarino et al. (2011) found that starter fertilizer only containing K did not affect early growth or grain yield unless K was deficient in the soil. They found in-furrow starter fertilizer at a rate of 5 to 7 kg P ha^{-1} and 10 to 14 kg K ha^{-1} in combination with a broadcast application at a rate of 49 to 66 kg P ha^{-1} and 112 to 140 kg K ha^{-1} increased growth and P and K uptake at two of six trials but did not increase yield compared to only broadcast P-K in Iowa (Mallarino et. al. 2011).

The pH in Oklahoma soils vary from calcareous to acidic from the northwest corner to the southeast corner of the state (Zhang and Raun, 2006). The pH is largely dependent of the parent material. Soils derived from alkaline parent material will typically have a higher pH than soils derived from acidic parent material. A factor largely responsible for lowering the soil pH is the application of commercial fertilizer, more specifically the N fertilizer that produces H^+ during nitrification. Other factors that affect soil pH are crop production, annual rainfall, and organic matter. The areas with intensive crop production, high annual rainfall and low buffer indexes will typically have low pH levels. Intensive crop production lowers the pH because more basic material is removed from the field than acidic material (Zhang and Raun, 2006). The pH level has a significant effect on the availability and reaction of essential nutrients (Figure 2). For example, the availability of P will be highest within pH ranges of 6.5 to 7.5. Nitrogen will react differently at different pH levels. Levels of pH greater than 7 and soil temperatures greater than 10^oC will increase ammonia volatilization when N fertilizer (urea) is applied to the soil surface.

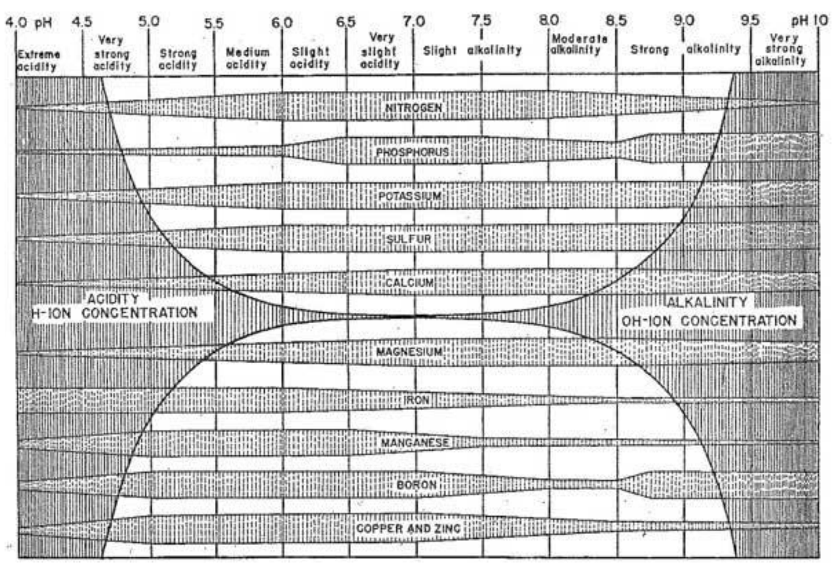

Figure 2. Truog's (1946) interpretation of the elemental availability as affected by pH.

Calcium, Mg, and S are secondary nutrients, which are typically not deficient in Oklahoma soils. Calcium and Mg deficiencies have been found in eastern Oklahoma where there are deep acidic sandy soils and high amounts of forages removed annually. These deficiencies can be fixed by liming because lime contains both Ca and Mg.

Sulfur has some of the same characteristics as N in that it is found in soil organic matter; negatively charged sulfate ions are prone to leaching and constituents of protein (Zhang and Raun, 2006). Sulfur is taken up in two ways, through the roots and leaves in the forms of SO_4^{2-} and SO_2 (Tisdale et al. 1993). Sulfur dioxide is absorbed through the leaves in very small quantities (Tisdale et al. 1993). Non-legume plants require a 1:20 S to N ratio in order for the plant to properly function (Zhang and Raun, 2006). Legume plants are based off of yield goal. For example, if the soybean yield goal is 3360 kg ha^{-1} then the S required would be 16.8 kg S ha^{-1} (Zhang and Raun, 2006). Sulfur is another element that when the soil temperatures are cool it can become unavailable and contained in the soil organic matter. Sulfur may not become adequately available to the plant until mineralization rates increase or plant roots attain the leached S in the B horizon. Deficiencies in S are similar to N deficiencies in that they cause the plant to be stunted, light green, and accumulation of anthocyanin (red pigment). Deficiency symptoms in sulfur will first appear in younger leaves.

Micro-nutrients are needed in the smallest amount of all the essential nutrients. Rarely documented micro-nutrient deficiencies in Oklahoma include: Mn, Cl, Cu, and Mo. Boron deficiencies have been documented in peanuts primarily due to the deep sandy soils their grown on. Iron deficiencies in Oklahoma are generally limited to the western part of the state because the high pH makes it unavailable.

Zinc is typically found deficient in soils that have low amounts of soil organic matter or do not have a thick layer of topsoil. Zinc is taken up by the plant in the form of Zn^{2+} (Tisdale et al. 1993). Corn and soybean have a higher affinity for Zn than most other crops because Zn may be required for chlorophyll biosynthesis (Taiz and Zeiger, 2010). Deficiencies can easily be corrected by applying Zn fertilizer. Common Zn deficiency symptoms are rosette growth habits in young plants, interveinal chlorosis, curled leaf margins, and decreased internodal growth (Taiz and Zeiger, 2010).

Fertilizer Placement

The use of starter fertilizers can provide the nutrients that are unavailable during early growth stage. Crop production demands fertilizer to be placed near the seed at planting so the plant roots come in contact with the fertilizer immediately or early in the vegetative growth stage, depending on placement. Fertilizer placed near the seed may promote plant and root vigor as well as higher yields. Fertilizer placement below the soil surface places immobile nutrients like P and K near the roots which reduces soil fixation. Lauzon and Miller (1997) conducted a study, in Ontario, to evaluate the effect of corn and soybean on P placed with the seed versus P placed to the side and below the seed. The rate of P applied (liquid source: 10-14.8-0) (N-P-K) with the seed was 7 kg ha^{-1} regardless of STP and the rate of P applied to the side and below the seed was 39 and 9 kg ha^{-1} for low and medium STP. They found that corn grain yield increased when fertilizer was placed with the seed regardless of STP. The 39 kg P ha^{-1} placed to the side and below the seed in a low P testing soil increased corn grain yield more than 7 kg P ha^{-1} with the seed. They also found soybean yield and emergence was not affected by fertilizer placed with the seed, but that yield was affected by STP level. The STP level caused a linear increase in yield (510 kg ha^{-1}) from 3 to 35 STP in one of the two sites (Lauzon and Miller, 1997). The various methods that are used today are still being researched to decide which is the most effective and this study focuses on in-furrow placement, 2x2 placement (5 cm by 5 cm), and 2x4 placement (5 cm by 10 cm).

In-furrow placement, also known as "pop-up" is fertilizer placed in contact with the seed, which may provide immediate nutrient availability to the seedling (Figure 3). The in-furrow method must be done carefully because seedling damage may occur if the fertilizer is applied at too high of a rate.

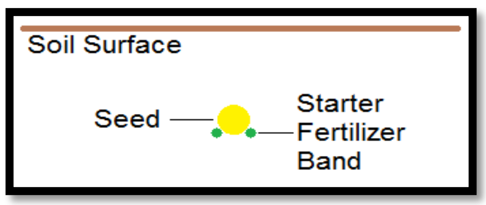

Figure 3. In-furrow placement method.

An alternative to in-furrow placement is the placement of a fertilizer band 5 cm (2 inches) beside and 5 cm (2 inches) below the seed (Figure 4). The common name for this method in the USA is *2x2 placement.* Two by two is perhaps the most common of the starter fertilizer subsurface banding methods because it is placed in the root zone and far enough away to prevent salt and ammonia injury to the seed.

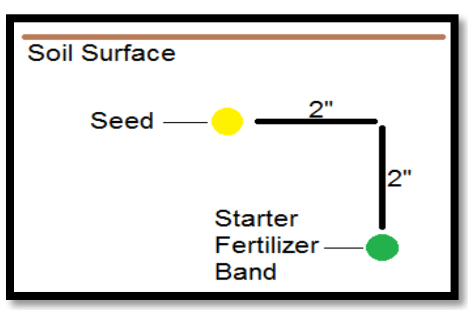

Figure 4. Five cm by five cm (2x2) placement method.

Another method similar to 2x2 placement but not as common is a band of fertilizer 5 cm (2 inches) beside and 10 cm (4 inches) below the seed (Figure 5). The name for this method in the USA is *2x4 placement*. This method is farther from the seed than 2x2 placement so theoretically more fertilizer may be applied without injuring the seed. Another consideration with this method may allow the total nutrient plan to be applied at planting. If seed injury is a concern, 2x4 may be a safer method than 2x2. Two by four placement may not be as practical as 2x2 because in no-till it may disturb too much soil due to the depth of the coulters and/or cause more drag thus increasing fuel usage.

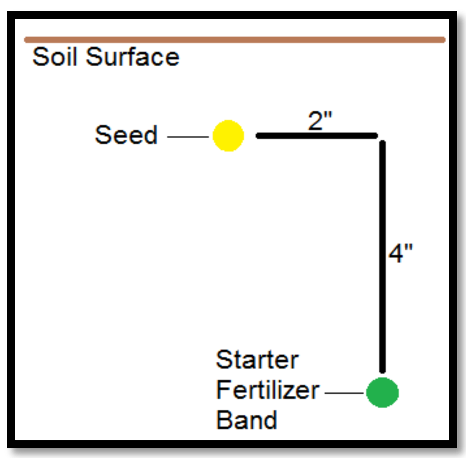

Figure 5. Five cm by ten cm (2x4) placement method.

Two by two and 2x4 placements are typically applied with a shank and coulter that has a tube down the back side of the shank. The tube places the fertilizer at the bottom of the furrow made by the coulter and shank. Two by two and 2x4 placement methods are commonly used when planning to apply a starter fertilizer, total nutrient program or when concerns of seedling damage, volatilization, or runoff may occur.

Starter fertilizer banded near the seed using the 2x2 or 2x4 placement method does not eliminate the risk of injury to the seedling. The rate of N+K_2O, soil texture, and soil moisture are all factors that must be considered when applying starter fertilizer.

Salt and Ammonia

Perhaps the most important aspect to consider when placing fertilizer near the seed is the concentration of salt or ammonia being applied. A high rate of starter fertilizer containing a high salt concentration may lead to the seedlings inability to take up soil moisture. The salts in the soil solution may cause a more negative water potential than the seedling, which prevents the seedling from taking in moisture. Some factors to consider when applying fertilizer near the seed are soil texture, soil moisture, type of crop, distance from the seed, salt index of the fertilizer, and row spacing.

The soil texture has a major effect on the sensitivity the seed or seedling has on the starter fertilizer. Crops with starter fertilizer placed near the seed in sandy soils are more likely to have seedling injury than clayey soils because sandy soils dry out quicker. Having high soil moisture will reduce the risk of salt injury because it dilutes the salt concentration around the seed. Corn is less affected by salt injury than soybean because corn does not have to take in as much moisture for germination to occur. Having distance between the seed and keeping the starter fertilizer salt concentration away from the seed, reduces the risk of salt injury. The farther the fertilizer is placed from the seed the higher the salt index can be without plant injury. Rehm and Lamb (2009) found, in Minnesota, in loamy fine sand, that starter fertilizer placed approximately 2 cm below the seed at planting at the rate of 13-20-0 kg ha^{-1} significantly reduced stand emergence. The same placement in the same soil texture at the rate of 5-5-10 kg ha^{-1} and 2-5-10 kg ha^{-1} had no effect on stand emergence. They also found all three starter rates to have no effect on emergence when applied to a silty clay loam soil. They concluded that the rate of N had a larger salt effect than K.

The salt index is a measurement of the salt concentration in the soil solution caused by the fertilizer applied (Follett et al. 1981). Salt index is measured by determining the change of the soil solutions osmotic pressure (Follett et al. 1981). Salt index is expressed as the ratio of the soil solutions osmotic pressure of the fertilizer source and sodium nitrate (Follett et al., 1981). Typically higher-analysis fertilizers have lower salt indices when applying equal amounts of elemental nutrients (Follett et al. 1981). For example, the salt index for ammonium sulfate is lower than ammonium nitrate, but when applying the same rate of N the salt index is higher because ammonium nitrate has a higher-analysis (Follett et al. 1981). A common method used to account for salt index is by adding up the amount of N and K_2O applied. For example, a fertilizer mixture of 7-21-7 applied at a rate of 100 kg ha^{-1} will have a total of 14 kg ha^{-1} of N+K_2O (100*0.07+100*0.07). Oklahoma State Universities, current recommendation for banding fertilizer near the corn seed is 8 kg ha^{-1} of N+K_2O (Zhang and Raun, 2006).

Row spacing is another aspect to consider when applying fertilizer in-furrow. As the row spacing decreases the fertilizer rate can increase because the concentration decreases per unit row (Tisdale et al. 1993). For example, if the same rate of fertilizer was applied, the fertilizer concentration per unit row would be half in a 38 cm row spacing than in a 76 cm row spacing. Niehues et al. (2004) found, in Kansas, that corn starter fertilizer in-furrow at planting (76 cm row spacing) at rates above 22 kg N ha^{-1}

reduced stand and did not increase yield in two of three years. Raun et al. (1986) concluded, in Nebraska, that 8 kg ha^{-1} of $N+K_2O$ starter fertilizer in-furrow (76 cm row spacing) was a safe rate for corn in a silty clay loam soil. Mengel et al. (1988) found, in Indiana, in a silt loam soil, that 7 kg N ha^{-1} in-furrow (76 cm row spacing) significantly reduced corn stand, but increased early growth and yield. Hoeft et al. (1975) conducted a study, in Wisconsin, to evaluate various in-furrow rates of N-P-K on soybean (76 cm row spacing) with respect to salt index. The sources were ammonium nitrate, monoammonium phosphate, concentrated superphosphate, and potassium chloride and rates ranged from 0 to 6.8 kg ha^{-1}. They found that stand was reduced 50% when the salt index reached 2.32. They concluded that as salt index increased, stand decreased.

Another concern when using the in-furrow placement method or high rates close to the seed is ammonia toxicity by fertilizers containing urea. Urea can be converted to ammonia when applied to the soil. Ammonia toxicity will reduce plant stand or injure seedling. Ammonia and salt toxicity can be reduced by using other placement methods such as 2x2 or 2x4 placement.

Starter Fertilizer Rates

Starter fertilizers are formulated as liquid or granule mixtures, which commonly contain N, P, K, and additional nutrients that may be needed in the soil. Soil test analysis provides the information needed to decide the proper ratio of elemental nutrients needed to get the plant off to a good start. A portion of the nutrients may be applied in a band near the seed, which has been shown to improve early growth and grain yield. Starter fertilizer in corn has been found to increase biomass but does not necessarily translate to an increase in yield when soil test phosphorus is high (Mengel, 1998; Bermudez and Mallarino, 2002; Wortmann et al., 2006; and Niehues et al., 2004). Mengel (1998) conducted a corn study in Indiana and determined the effect of in-furrow starter (67 kg ha^{-1}; source: 10-34-0) applied at planting on two different rates of pre-plant P and K fertilizer (560 and 1120 kg ha^{-1}; source: 3-5-10 suspension). Additional N was broadcast applied across all treatments so N would not be limited. The initial soil test had 56 kg ha^{-1} of extractable P (Bray P_1) and 224 kg ha^{-1} of exchangeable K. He found the in-furrow starter significantly increased early growth and grain yield when a low rate of pre-plant P and K (227 kg ha^{-1} of a 1.4-2.3-10 suspension) was applied. When the in-furrow starter was applied to the higher pre-plant rate only the early growth increased. Bermudez and Mallarino (2002) conducted a corn study, in Iowa, to determine starter fertilizer (2x2 placement) effect on early growth and yield. They found that starter fertilizer significantly increased early growth in both high and low P testing soils. Starter fertilizer increased yield (200 to 671 kg ha^{-1}) when STP was below 16 mg P kg^{-1}, (Bray-P_1). They found starter fertilizer yield response was lower in high STP and that in-furrow increased yield less than 2x2 where higher amounts of N was applied. Wortmann et al. (2006) found, in eastern Nebraska, that starter fertilizer increased early biomass by 10% at 3 of the 5 rainfed corn sites (4 of the 5 sites had Bray-P_1 greater than 15 mg kg^{-1}). They found starter fertilizer placed in-furrow, 2x2, and over the row at rates of 11-5-0-6, 22-10-0-11, and 22-10-0-11 (N-P-K-S), had minimal effect on yield. Niehues et al. (2004) found, in Kansas, that in-furrow and 2x2 starter fertilizer placements in corn, at rates of 11 kg N ha^{-1} and 34 kg N ha^{-1} with a top dress of ammonium-nitrate to reach 168 kg N ha^{-1} increased yield in a silt loam soil, high in STP (45 mg kg^{-1}).

Previous soybean studies have been inconsistent on whether or not it increases early growth and grain yield. Sij et al. (1979) conducted a study in Texas to determine if starter nitrogen would increase early growth and yield. They applied N rates from 0 to 50.4 kg ha^{-1} and placed the fertilizer 8 cm beside the seed bed and 10 cm deep. They found that starter N did not increase early growth or grain yield. Osborn and Riedell (2006) conducted a soybean study, in South Dakota, to evaluate the effects of various N rates in a 2x2 placement method. They found after averaging all experiments together that 16 kg N ha^{-1} increased grain yield by 6% compared to the no N treatment. They also found that plant biomass increased linearly as the N rate (0-24 kg N ha^{-1}) increased at V3-V4 and R1 but not at R3. The linear response not occurring at R3 was likely due to increased N fixation (Osborn and Riedell, 2006).

Scharf and William (2003) conducted a state wide N application soybean study, in Missouri, that consisted of 48 locations. They evaluated the effect of soybean yield on the broadcast application of 28 kg N ha^{-1} (source: ammonium nitrate) prior to planting. The overall average across all locations increased grain yield 34 kg ha^{-1}, which they concluded not profitable. They observed the locations that responded to N at planting to determine site characteristics that likely caused the response. They found that the sites with a low pH (salt pH less than 6) or low soil nitrate (less than 56 kg ha^{-1}) increased grain yield 61 or 67 kg ha^{-1}. They found the N response in sites with low pH was likely due to inhibited nodulation of soybeans, which they found correlated with Alva et al. (1987). Scharf and William (2003) found the N response to low soil nitrate correlated with a study conducted in Minnesota by Lamb et al. (1990), which observed the effect of N on soybean with short growing seasons. The study in Minnesota had larger yield increases than Scharf and William (2003), which they assumed was from Minnesota having shorter soybean growing seasons. Scharf and William (2003) assumed shorter season soybean benefits more from early increased growth than longer season soybean.

A study in Alabama evaluated the effect of a starter fertilizer at the rate of 50 kg N ha^{-1} on soybean (indeterminate and determinate variety) planted after corn (Starling et al., 2000). They found that starter N fertilizer increased plant growth and yield. They found indeterminate varieties may have more N starter response than determinate varieties. Bly et al. (1998) conducted a soybean study in South Dakota to evaluate the effects of applying N shortly after soybean emergence. The treatments were 0, 28, 56, 112, and 224 kg N ha^{-1} using ammonium nitrate as the source. They found significant increase in grain yields for the 112 and 224 kg N ha^{-1} treatments. A soybean study conducted in Ohio and Shenyang evaluated the effect of starter fertilizer (N+P placed 5 cm beside the seed) on older and newer soybean cultivars (Xie et al., 2010). The starter fertilizer rates were 0, 150, and 300 kg ha^{-1} of 18% N and 46% P_2O_5. Xie et al. (2010) found starter fertilizer caused a significant linear regression between R4 leaf area per plant and lodging. The increase in R4 leaf area and lodging did not result in a significant effect on yield (Xie et al., 2010). A soybean study in Nebraska looked at broadcast incorporated N prior to planting and found it increased soybean yield (Sorensen and Penas, 1978). The authors evaluated 4 factors (pH, residual NO_3^-, SOM, and yield level) to see how they related to N response (Sorensen and Penas, 1978). Since pH can affect Rhizobium activity, N response is more likely if N fixation is limited. Higher amounts of residual NO_3^- in the soil should cause the N response to decrease (Sorensen and Penas, 1978). The SOM affects soil structure, so soil with low OM (poor structure) may decrease N response because the roots and water poorly penetrate the soil (Sorensen and Penas, 1978). The yield level being low may show poor environmental conditions, which affects Rhizobium, therefore decreasing N fixation (Sorensen and Penas, 1978).

A major concern with starter fertilizer in soybean is in-furrow placement of fertilizer. Unlike corn, soybean is much more sensitive to in-furrow placement of fertilizer and many studies have shown that any fertilizer placed in-furrow will significantly decrease stand and grain yield. Clapp and Small (1970) found, in North Carolina, in loam, fine sandy loam, and sandy loam soils, that both liquid and granular fertilizer placed in-furrow decreased plant stand and yield. They found liquid fertilizer rates as low as 35.5 liters ha^{-1} of 5-8.8-4.2 (N-P-K) material significantly decreased stand and yield. They also found granular fertilizer rates as low as 11.2 kg ha^{-1} of 10-15-5 (N-P-K) material to significantly decrease stand, but not grain yield. Although grain yields did decrease at rates higher than 11.2 kg ha^{-1} of 10-15-5 (N-P-K) material. They showed that even though the stand was significantly reduced the soybean plants were able to produce more pods and not significantly decrease yield (Clapp and Small, 1970). Ham et al. (1973) found, in Minnesota, in silt loam, and silty clay loam soils, that broadcast (single rate depending on location; 0-26-25 to 0-44-125 N-P-K) or 2x2 placement (single rate depending on location; 10-20-10 to 16-40-53 N-P-K) with broadcast increased yield in soybean. The in-furrow placement (single rate depending on location; 4-8-1 to 4-8-12 N-P-K) effect on stand was less detrimental in this study than in Clapp and Small’s, which was likely due to the soil texture and soil moisture differences (Ham et al., 1973).

Fertilizer Sources

Urea is the most commonly used fertilizer in the world mainly because of its high N analysis and because it is safer than using Anhydrous Ammonia. The major disadvantage of urea is that up to 50% of the N applied can be lost to volatilization when surface applied (Raun and Zhang, 2006). The chemical form of urea, $CO(NH_2)_2$, converts to ammonium (NH_4^+) and then may convert to ammonia (NH_3) if soil pH is high (Tisdale et al. 1993). Ammonia is a gas which is prone to volatilization if not incorporated. Surface application of urea is not recommended because of its high rates of volatilization, but some farming operations may not be set up for subsurface banding. If applied to the surface, the following conditions should be avoided: temperatures higher than 21^{o}C, high pH soils, and high wind (Raun and Zhang, 2006).

$$CO(NH_2)_2 + H^+ + 2H_2O \xrightarrow{\text{Urease}} 2NH_4^+ + HCO_3^-$$

$$NH_4^+ \rightarrow NH_3 + H^+$$

Urea ammonium-nitrate (UAN) is the most popular liquid fertilizer sold in Oklahoma. Urea ammonium-nitrate is made of 1 part urea, 1 part ammonium nitrate (AN), and 1 part water. Since 1 part of UAN is made of urea all the weather and soil conditions which favor ammonia volatilization should be avoided. Also since 1 part of UAN is made of AN, areas that receive high amounts of rainfall may experience leaching. Ammonium nitrate is prone to leaching because half of the N is nitrate (NO_3^-) which does not bind to the soil like ammonium (NH_4^+).

Ammonium poly-phosphate (APP, 10% N and 34% P_2O_5) is a common liquid fertilizer that provides both N and P. Ammonium poly-phosphate is commonly used in starter fertilizer mixtures.

CHAPTER III

CORN RESPONSE TO STARTER FERTILIZER

Introduction

Corn [Zea mays] harvested for grain makes up 28% of harvested cropland acres in the United States (NASS, 2011). Corn is planted on more acres of land than any other crop in the United States. According to the 2007 Census, corn ranked the 2nd for the largest harvested acres of grain in Oklahoma, with wheat being the 1st (NASS, 2011).

No-till is a farming practice becoming more common in the state of Oklahoma. Producers' have started looking to no-till for a number of reasons: moisture conservation, high fuel prices, and government programs to name a few. The increasing number of acres planted to corn in Oklahoma, along with the increasing number of acres in no-till has raised questions about the need for starter fertilizers in these systems because early plant growth and grain yield may be depressed in no-till cropping systems compared to conventional tillage. The soil temperature near the surface in a no-till cropping system will generally be 28% lower than in a conventional tillage system (Johnson and Lowery, 1985). Mackay and Barber (1984) found, in Indiana, that a high soil test P may compensate for low soil temperature (10 ^{o}C) and slow root growth. Early planted corn has been shown to benefit from starter fertilizer because it places a band of available nutrients near the root.

Starter fertilizer in corn has been found to increase biomass but does not necessarily translate to an increase in yield especially when soil test phosphorus is high (Mengel, 1998; Bermudez and Mallarino, 2002; Wortmann et al., 2006; and Niehues et al., 2004). Starter fertilizer containing N and P has been found to speed up the early growth of corn in no-till soils (Bermudez and Mallarino 2002). Mengel (1998) conducted a study in Indiana and determined the effect of in-furrow (direct contact with the seed) starter (67 kg ha^{-1}; source: 10-34-0) applied at planting on two different rates of pre-plant P and K fertilizer (560 and 1120 kg ha^{-1}; source: 3-5-10 suspension). Additional N was broadcast applied across all treatments so N would not be limited. The initial soil test had 56 kg ha^{-1} of extractable P (Bray P_1) and 224 kg ha^{-1} of exchangeable K. He found the in-furrow starter significantly increased early growth and grain yield when a low rate of pre-plant P and K (227 kg ha^{-1} of a 1.4-2.3-10 suspension) was applied. When the in-furrow starter was applied to the higher pre-plant rate only the early growth increased. Bermudez and Mallarino (2002) found, in Iowa, that 2x2 (5 cm beside and below the seed) placed starter fertilizer significantly increased early growth in both high and low P testing soils. Starter fertilizer increased yield (200 to 671 kg ha^{-1}) when STP was below 16 mg P kg^{-1} (Bray P_1). They found starter fertilizer yield response was lower in high STP and that in-furrow increased yield less than 2x2 where higher amounts of N was applied. Wortmann et al. (2006) found, in eastern Nebraska, that starter fertilizer increased early biomass by 10% at 3 of the 5 rainfed corn sites (4 of the 5 sites had Bray-P_1 greater than 15 mg kg^{-1}). Starter fertilizer placed in-furrow, 2x2, and dribble (on the surface over the row) at rates of 11-5-0-6, 22-10-0-11, and 22-10-0-11 (N-P-K-S), had minimal effect on yield. Niehues et al. (2004) found, in Kansas, that in-furrow and 2x2 starter fertilizer placements at rates of 11 kg N ha^{-1} and 34 kg N ha^{-1} with a top dress of ammonium-nitrate to reach 168 kg N ha^{-1} increased yield in a silt loam soil, high in STP (45 mg kg^{-1}).

In addition to N and P, earlier studies have shown significant responses to the application of S in an indirect placement method. Rehm (2005) found ammonium sulfate and ammonium thiosulfate placed in-furrow in sandy textured soils to have lower S uptake than when placed 2.5 cm to the side and 5 cm below the seed. He explained the reduced S uptake from in-furrow S treatments in sandy soils was due to restricted proper root growth (Rehm, 2005). Niehues et al. (2004) found, in Kansas, that the addition of 11 kg S ha^{-1} to 34-34-11 kg NPK ha^{-1} starter fertilizer in a 2x2 placement increased nutrient uptake, likely due to the increased early growth. The increased early growth response was in a no-till system with heavy residue and cool soil temperatures. This situation perhaps slowed S mineralization (Niehues et al., 2004).

A concern that must be addressed prior to applying a starter fertilizer near the seed is the maximum amount of fertilizer without seedling injury. Factors to consider when applying fertilizer near the seed are soil texture, soil moisture, type of crop, distance from the seed, and salt index of the fertilizer. These factors determine the allowable amount of fertilizer that can be placed near the seed. Placing fertilizer with the seed at planting is the most sensitive starter fertilizer placement because too high of a concentration will prevent the seed or seedling from taking in moisture. A study conducted by Niehues et al. (2004) found, in Kansas, that starter fertilizer placed with the seed at planting at rates above 22 kg N ha^{-1} reduced stand. Raun et al. (1986) concluded, in Nebraska, that 8 kg ha^{-1} of N+K_2O starter fertilizer in-furrow (76 cm row spacing) was a safe rate in a silty clay loam soil. Mengel et al. (1988) found, in Indiana, in a silt loam, that 7 kg N ha^{-1} in-furrow (76 cm row spacing) significantly reduced stand, but increased early growth and yield. Fertilizer placed near, but not in direct contact to the seed can still cause injury (Rehm and Lamb, 2009). Rehm and Lamb (2009) found, in Minnesota, in a loamy fine sandy soil, starter fertilizer placed approximately 2 cm below the seed at planting, at the rate of 13-20-0 kg ha^{-1}, significantly reduced stand emergence. The same placement in the same soil texture at the rate of 5-5-10 kg ha^{-1} and 2-5-10 kg ha^{-1} had no effect on stand emergence. They also found all three starter rates to have no effect on emergence when applied to a silty clay loam. They concluded that the rate of N had a larger impact on emergence than the rate of K.

The purpose of this study is to evaluate various starter fertilizer placements and nitrogen (N) rates in Oklahoma to determine if it is an effective way to maximize early plant vigor, grain yield, and economic return in corn.

Material and Methods

In 2011 and 2012, experiments were established to evaluate various N rates and fertilizer placement methods in corn. Five experimental sites were selected in various parts of North Central and North East Oklahoma (Table 1).

The first early season corn starter fertilizer study was located NE of Covington, OK (36.3215N,-97.5690W, elevation 354 m) in a 6 year no-till/strip till cropping system. The predominant soil type at this location was a Kirkland-Renfrow complex (fine, mixed, superactive, thermic Udertic Paleustolls) with a 1 to 3% slope. This site was planted on

18 March 2011 with a 5 cm soil temperature of 13^{o}C and 7.6 cm soil volumetric water content of 27%.

Another early season corn study was conducted north of Red Rock, OK (36.5078N,-97.1588W, elevation 287m) in a 10 year continuous no-till cropping system. The predominant soil type at this location was a Kirkland silt loam (fine, mixed, superactive, thermic Udertic Paleustolls) with a 1 to 3% slope. This site was planted on 29 March 2011 with a 5 cm soil temperature of 8^{o}C and 7.6 cm soil volumetric water content of 33%.

For the second year, a corn study was located east of Covington, OK (36.3029N,-97.5674W, elevation 354m) in a 13 year continuous no-till cropping system. The predominant soil type at this location was a Kirkland silt loam (fine, mixed, superactive, thermic Udertic Paleustolls) with a 0 to 1% slope. This site was planted on 15 March 2012 with a 5 cm soil temperature of 28^{o}C and 7.6 cm soil volumetric water content of 31%.

Another early season corn study planted the second year was located NE of Miami, OK (36.9334N,-94.7868W, elevation 263m) in a conventional tillage cropping system. The predominant soil type at this location was a Taloka silt loam (fine, mixed, active, thermic Mollic Albaqualfs) with a 0 to 1% slope. This site was planted on 4 April 2012 with a 5 cm soil temperature of 28^{o}C and 7.6 cm soil volumetric water content of 34%.

The experimental design was a randomized complete block design (RCBD) with four replications. Fertilizer placement and N rate were the main effects evaluated.

Fertilizer placements evaluated included: in-furrow, 2x2, and 2x4, while N rates varied from 0 to 168 kg N ha^{-1} (Table 2). Not all N rates were used with each placement method. The corn in-furrow treatments received N rates of 11, 22, and 45 kg ha^{-1}. Three additional corn in-furrow treatments include 11 kg N ha^{-1} with .3 kg Zn ha^{-1} (11-22-0-0-0.3), 11 kg N ha^{-1} with 10 kg S ha^{-1} (11-22-0-10), and 11 kg N ha^{-1} with 10 kg S ha^{-1} and 0.3 kg Zn ha^{-1} (11-22-0-10-0.3). The N was balanced to 168 kg ha^{-1} on all in-furrow corn treatments. The 2x2 treatments received N rates of 101, 134, and 168 kg N ha^{-1}. The 2x4 treatments received N rates of 134, and 168 kg N ha^{-1}. In-furrow, 2x2, and 2x4 treatments received equal amounts of P and 0 kg K ha^{-1} except for 2012, Covington and Miami locations.

In 2012, Covington and Miami had one K treatment added to the study. The K treatment was added in 2012 because the STK levels were below optimum (<125 ppm) (Zhang and Raun, 2006). The amount of K applied was based off of the soil test recommendations and was added to 120 kg N ha^{-1} in a 2x2 placement method.

A full broadcast treatment of 168 kg N ha^{-1} of urea was placed at all locations. All urea applied was coated with Agrotain Ultra® (Agrotain International St. Louis, MO), a urease inhibiter that slows urea from breaking down into ammonia, reducing the risk of volatilization. An unfertilized check treatment was placed at all but the 2011 Covington location.

The fertilizer sources used for this experiment to obtain the correct nutrient amounts were urea ammonium-nitrate (UAN, 28% N), ammonium polyphosphate (APP, 10% N and 34% P_2O_5), ammonium thiosulfate (ATS, 12% N and 26% S), zinc chelate

(Zn-chelate, 8% N and 10% Zn), urea (46% N), and muriate of potash (soluble potash, 60% K_2O).

All treatments were applied during planting with a Monosem NG plus 4 (Monosem Inc., Edwardsville, KS) row vacuum planter. The planter was capable of applying one starter fertilizer mixture at a time. Treatments with the same mixture were completed before switching to a different mixture, which prevented contamination. The rate of application was controlled by tractor speed, a variable speed electric pump, and in-line orifices. A four column RedBall Spray Monitor (Horvick Inc., Fargo, ND) was placed in-line so the flow rate of each starter fertilizer row could be monitored. Commercial attachments for the Monosem NG plus 4 vacuum planter were used to apply the starter fertilizer. The attachments for applying the in-furrow placement were Keeton Seed Firmers (Precision Planting, Inc., Trentmont, IL), which were mounted onto the seed tube of the planter.

Table 1. Corn starter fertilizer, site years, locations, tillage practice, planting date, taxonomic names, texture classes, GPS coordinates, and slopes.

Year	Location	NT[†]	Planting Date	Taxonomic Name	Texture class	GPS Coordinates	Slope
		--yr--					--%--
2011	Covington, OK	6	18 Mar.	Udertic Paleustolls	Silt Loam	36^o32 N, -97^o57 W	1-3
2011	Red Rock, OK	10	29 Mar.	Udertic Paleustolls	Silt Loam	36^o51 N, -97^o16 W	1-3
2012	Covington, OK	13	15 Mar.	Udertic Paleustolls	Silt Loam	36^o30 N, -97^o57 W	0-1
2012	Miami, OK	0	4 Apr.	Mollic Albaqualfs	Silt Loam	36^o93 N, -94^o79 W	0-1

† NT, year in a no-till management system, 0 means conventional tillage.

Table 2. Corn starter fertilizer rates and placements

In-Furrow†	2x2 placement	2x4 placement	Broadcast	No Fertilizer
-kg ha^{-1}-	-kg ha^{-1}-	-kg ha^{-1}-	-kg ha^{-1}-	-kg ha^{-1}-
11-22-0	101-22-0	134-22-0	168-0-0	0-0-0
22-22-0	134-22-0	168-22-0		
45-22-0	134-22-36§			
11-22-0-0-0.3‡	134-22-67§			
11-22-0-10	168-22-0			
11-22-0-10-0.3				

† N was balanced to 168 kg ha^{-1} on all In-Furrow treatments.
‡N-P-K-S-Zn
§ 134-22-36 was placed in Covington 2012 only and 134-22-67 was placed in Miami 2012 only.

The attachments used for the 2x2 and 2x4 treatments were Yetter (Yetter Manufacturing Inc., Colchester, Illinois) side dress fertilizer coulters, which were mounted onto the tool bar of the planter. The starter fertilizer output was calibrated initially and checked before each location. The equation used to find the speed, gallons per acre, and gallons per minute is shown below.

$$MPH = \frac{5940*GPM}{GPA*W} \quad \text{(Eq. 1)}$$

The hybrid seed corn used for all sites was Dekalb DKC53-45, 103 day, *Roundup Ready.* The seed population for all corn locations was 8,499 seeds ha^{-1} and planted at a depth of 5 cm. Individual plot size for all sites measured 7.6 m by 3 m with four rows in each plot spaced 76 cm apart. Weeds were controlled using glyphosate according to weed pressure and rate recommendations. Two inside rows, an area of 7.6 m by 1.5 m, were harvested per plot. The first year the corn was hand-picked, ran through a stationary thrasher, and then weighed. The test weight and moisture was measured using a GAC® 2100 Agri (DICKEY-john, Minneapolis, MN) grain analysis computer. The second year the corn was harvested using a Delta Wintersteiger (Wintersteiger, Salt Lake City, UT) small plot combine, where the grain weight, test weight, and moisture were measured.

Soil Sampling

Prior to planting, soil samples were collected at depths of 0 to 15 cm and 15 to 30 cm. Analyses from 0 to 15 cm sample were used to formulate starter fertilizer treatments. The 0 to 15 cm depth sample was analyzed for pH, NO_3-N, soil test phosphorus (STP), soil test potassium (STK), SO_4-S, Ca, Mg, Fe, Zn, B, Cu, texture class, and organic matter. The 15 to 30 cm depth sample was analyzed for NO_3-N and SO_4-S. Soil Sampling was conducted using a hand probe and each composite sample consisted of 15 cores. Analyses were conducted by OSU Soil, Water, and Forage Analytical Laboratory. The soil pH was analyzed with a pH meter. The procedure for NO_3-N soil analysis was conducted by the use of calcium sulfate and flow injection analyzer. Soil test P, K, Ca, and Mg were analyzed using Mehlich 3 (Mehlich, 1984) and inductively coupled plasma (ICP) spectrometer. Soil SO_4-S was analyzed using calcium monophosphate and ICP. Soil test Fe, Zn, Cu, and B were analyzed using DTPA-sorbitol solution and ICP (Procedures Used by OSU Soil, Water, and Forage Analytical Laboratory Fact Sheet F-2901). The growing degree days were obtained from the closest Oklahoma Mesonet Station. The climatic conditions were measured using the Oklahoma Mesonet Stations, soil thermometer, and FieldScout TDR 300 soil moisture meter (Spectrum Technologies, Plainfield, IL).

The soil moisture meter measured the percent volumetric water content from 0 to 7.5 cm and 0 to 20 cm in depth. The soil moisture meter uses an electrical signal to measure the percent volumetric water content. The speed at which the electrical signal travels from the soil probe to the instrument determines the percent volumetric water content. The accuracy of the FieldScout TDR 300 soil moisture meter (Spectrum Technologies, Plainfield, IL) is ±3.0% volumetric water content.

Stand-Emergence

Initial stand counts were measured for each plot at V3 and maturity growth stages on the two inside rows of a randomly selected area of 1.52 m by 3.05 m. Stand counts were taken at V3 to compare emergence and at maturity to compare survival throughout the season.

Early Growth

A GreenSeeker™ was used to determine Normalized Difference Vegetative Index (NDVI) values which compared early growth among treatments. Normalized Difference Vegetative Index is calculated by subtracting Red reflected from Near infrared reflected (NIR) and dividing it by the sum of NIR reflected and Red reflected as shown below. The NDVI readings were taken initially at V3 and other various times on each plot during the growing season to observe vigor during the early and late vegetative stages. The NDVI measurements were taken on the two inside harvest rows, the entire length of the plot on all locations.

$$\text{NDVI} = \frac{\text{NIR}-\text{Red}}{\text{NIR}+\text{Red}} \qquad \text{(Eq. 2)}$$

Tissue Analysis

Plant tissue samples were taken on each individual corn plot to quantify the nutrient concentration and to observe the differences in the treatments. The plants selected for collecting plant tissue samples were from the two outside non-harvest rows between V4 and V7 growth stages. Approximately 10 plants were clipped at ground level in each plot. The samples were dried at approximately 60^{o}C for 36 hours, weighed, and ground to pass through a 1 mm screen. The plant tissue samples were analyzed for total nitrogen (TN), P, K, Ca, Na, Mg, S, Mn, Cu, Fe, Zn, and B. The plant nutrient uptake was also calculated by multiplying tissue sample dry weight by elemental concentration.

Statistical Analysis

Statistical analysis was conducted to analyze the main effects of starter fertilizer placements and rates. Main effects were analyzed using analysis of variances at the 5% probability level of significance. PROC GLM (SAS® Institute Inc., 2001) was used to analyze treatment differences in stand counts, NDVI, tissue nutrient concentrations and uptake, and grain yield. PROC MIXED (SAS® Institute Inc., 2001) was used to analyze treatment differences in stand counts, NDVI, tissue nutrient concentrations and uptake, and grain yield that had missing data. PROC GLM and contrasts were used to evaluate selected treatments and better determine specific trends from NDVI and tissue sample data. The contrasts of the selected treatments were linear 2x2, quadratic 2x2, linear in-furrow, quadratic in-furrow, main effect Zn, main effect S, and interaction Zn and S.

Results and Discussion

Grain yields were low in both years due to environmental conditions. The 2011 growing conditions were unseasonably hot and dry for the later summer months as shown in Table 4. There was adequate moisture during the early part of the growing season while the plants were establishing but conditions quickly deteriorated. The dry conditions of 2011, at Red Rock, OK resulted in an average grain yield of 620 kg ha^{-1}. The 2012 growing conditions were better than the previous year because of the above average moisture received during the months of February, March, and April (Table 5). The later part of the 2012 growing season was hot and dry. The 2012 average grain yields for Covington and Miami, OK were 4206 and 980 kg ha^{-1}, respectively.

Table 3. Selected soil characteristics for corn sites.

			NO_3-N		STP	STK	SO_4-S		Zn	OM	Sand	Silt	Clay
Year	Location	pH	0-15[†]	15-30	0-15	0-15	0-15	15-30	0-15	0-15	0-15	0-15	0-15
			--kg ha^{-1}--		--mg kg^{-1}--		--kg ha^{-1}--		--mg kg^{-1}--	---------------%---------------			
2011	Covington, OK	6.0	18	19	23	138	34	44	1.05	1.79	21.9	59.4	18.8
2011	Red Rock, OK	5.6	13	9	15	144	41	78	0.88	2.16	17.5	56.3	26.3
2012	Covington, OK	5.2	19	38	31	111	30	45	1.50	1.47	20.1	53.2	26.9
2012	Miami, OK	7.4	40	40	28	74	25	318	6.10	1.63	28.8	58.8	12.5

† Soil sampling depth units are in centimeters.

Table 4. Temperature, rainfall, and 30 year average for corn at Covington, OK and Red Rock, OK, 2011.

Month	Covington				Red Rock			
	Temperature	Rainfall	30 yr. avg.		Temperature	Rainfall	30 yr. avg.	
	--C^o--	--mm--	--C^o--	--mm--	--C^o--	--mm--	--C^o--	--mm--
January	-1	4	1	29	0	5	1	28
February	2	6	4	41	3	42	4	40
March	10	34	8	68	10	32	9	75
April	16	35	14	84	17	29	14	88
May	20	128	20	123	20	80	20	131
June	29	67	25	111	29	66	25	113
July	32	17	28	71	32	6	28	77
August	30	67	27	84	31	52	27	79
8 month total		358		610		313		630

Source: OK Mesonet, 2012

Table 5.Temperature, rainfall, and 30 year average for corn at Covington, OK and Miami, OK, 2012.

	Covington				Miami			
Month	Temperature	Rainfall	30 yr. avg.		Temperature	Rainfall	30 yr. avg.	
	--C^{o}--	--mm--	--C^{o}--	--mm--	--C^{o}--	--mm--	--C^{o}--	--mm--
January	4	22	1	29	5	11	1	45
February	5	79	4	41	6	49	4	53
March	14	70	8	68	16	178	9	97
April	17	174	14	84	17	192	14	102
May	23	14	20	123	22	76	19	140
June	26	86	25	111	26	18	24	110
July	31	3	28	71	30	36	26	90
August	27	31	27	84	26	68	26	86
8 month total		480		610		626		723

Source: OK Mesonet, 2012

Table 6. Five cm soil temperature, 7.5 cm soil volumetric water content, and 20 cm soil volumetric water content readings taken between 12 pm to 5 pm for the first month from corn planting.

	Soil temperature	Soil moisture	
Reading date†	5 cm, ^{o}C	7.5 cm, %	20 cm, %
Covington, 2011			
18-Mar-11	14	27	38
24-Mar-11	14	29	38
7-Apr-11	21	26	35
18-Apr-11	34	21	na
Red Rock, 2011			
29-Mar-11†	8	33	42
18-Apr-11	33	25	48
Covington, 2012			
15-Mar-12†	28	31	51
27-Mar-12	27	29	46
12-Apr-12	24	48	64
Miami, 2012			
2-Apr-12†	28	26	34
10-May-12	36	na	na

† Planting date

Initial Stand Counts

No differences in initial stand counts were observed at Covington (2011), Covington (2012), or Red Rock (Table 7). Soil moisture was high at planting, which most likely reduced the risk of salt injury from the fertilizer in the higher N fertilizer rates. Miami had lower initial stand counts in the 22 and 45 kg N ha^{-1} in-furrow treatments compared to the other treatments. The reason for the difference between locations is likely due to soil texture and soil moisture conditions. Miami was a lighter textured soil (higher sand content) compared to the other locations (Table 3). In addition to the texture, it was warmer when the Miami location was planted so the surface soil moisture may have evaporated quicker than the other locations thereby increasing the chances of salt injury. Placing fertilizer in-furrow increases salt concentration around the seed, if salt concentration is excessive the seed is unable to germinate (Raun et al., 1986; Mengel et al., 1988; and Niehues et al., 2004). Perhaps the main factors that can alter the effect of seed germination when high rates of fertilizers are applied in-furrow are soil texture and soil moisture during the germination process.

No differences, for any locations, in initial stand counts were observed for 2x2 and 2x4 treatments even at rates of 168 kg N ha^{-1}. Fertilizer at a rate of 168 kg N ha^{-1} in a 2x2 placement method allows enough distance between the seed and the band to prevent salt injury. These results are similar to the results found in previous research (Niehues et al., 2004), which indicated no negative effects on population with high rates of N applied with the 2x2 method.

NDVI Readings

At Covington (2011), Red Rock, and Miami, the in-furrow treatments generally had higher NDVI readings than the 2x2, 2x4, and full broadcast treatments (Table 8). This may be due to the in-furrow treatments seedlings having immediate nutrient availability.

Both locations, in 2011 had no NDVI difference among the in-furrow treatments, however; both locations, in 2012 had significantly lower NDVI in the 45 kg N ha^{-1} in-furrow treatment. The lower NDVI of the 45 kg N ha^{-1} in-furrow treatment at Miami corresponds to the stand counts at Miami (Table 7). At Covington (2012) the stand counts did not show a significant decrease, but the NDVI did show a significant decrease in the 45 kg N ha^{-1} in-furrow treatment. The Miami and Covington sites in 2012, soil moisture declined rapidly after planting and may have prevented the dispersion of N. This could have potentially slowed down root growth due to root injury caused by the 45 kg N ha^{-1} in-furrow rate. These results agree with the initial stand counts.

No benefits in the S treatments were observed for any location. Nitrogen and S mineralization is slower in cold soils which increases the probability of seeing a yield response to starter fertilizers containing these elements. Our environment in Oklahoma may generally be warm enough to provide S to the plant. Our results contradicts what Niehues et al. (2004) found, in Kansas, that early growth responds to starter fertilizer containing S in a 2x2 placement in a continuous no-till system. The difference between the findings may be a result of the environment, especially early-season soil temperatures or the difference in sulfate-S in the soil. Soils in north central Kansas are most likely slower to warm up compared to the soils at our locations and our soil test showed high SO_4-S in the top 46 cm of soil.

At Covington (2011), Red Rock, and Miami, the NDVI of 2x2 treatments decreased as the N rate increased from 101 to 168 kg ha^{-1} (Table 9). The 168 kg N ha^{-1} 2x2 treatment may have caused the significant yield reduction because the salt concentration in the root zone was perhaps too high. The decrease of 2x2 treatments in NDVI occurred at rates higher that 134 kg N ha^{-1} in three of the four locations (Table 8). Our results are perhaps similar to what Niehues et al. (2004) found, in Kansas, where they did not see a decrease in V6 dry weight at a rate of 134 kg N ha^{-1} in a 2x2 placement. If they had a 168 kg N ha^{-1} treatment they may have shown similar results to ours, which was a decrease after 134 kg N ha^{-1}.

Grain Yield

The lack of rainfall in the latter half of the growing season in both years caused grain yield to be significantly reduced, potentially masking results of the starter fertilizer treatments (Table 10). In general, the in-furrow treatments had an overall higher yield compared to the 2x2 and 2x4 placement methods, which may be due to the nutrient solutions being placed in contact with the seed. Covington (2012) was the highest yielding location at an average of 4206 kg ha^{-1} and few differences were shown across treatments. At this location the no fertilizer treatment was the highest yielding, which was likely due to the warm temperatures at planting and throughout the season. Past research has shown that warm temperature at planting reduces stress on the plant, minimizing the response of starter fertilizers (Mackay and Barber, 1984; Niehues et al., 2004).

At Red Rock, the treatment with 168 kg N ha^{-1} 2x2 treatment had a significantly lower yield than treatments with 22 and 45 kg N ha^{-1} in-furrow treatments (Table 10). At Covington, the 168 kg N ha^{-1} 2x2 and 2x4 treatments were significantly lower than the 11 kg N ha^{-1} in-furrow treatment. The 168 kg N ha^{-1} 2x2 and 2x4 treatments significant yield reductions correlate with 2x2 treatments NDVI decrease.

The treatments with K did not show any difference in yield in either site year. These results coincide with previous studies which have concluded that banding K alone as a starter perhaps does not increase early growth (Bordoli and Mallarino, 1998; Mallarino et al., 1999; Mallarino et al., 2011).

No yield benefits in the S treatments were observed for any location. The soil test SO_4-S was optimum for all locations assuming a 1:20 S to N ratio. Optimum soil test SO_4-S minimizes the likelihood of seeing a response. Nitrogen and S mineralization is slower in cold soils which increases the probability of seeing a yield response to starter fertilizers containing these elements. Our results contradict both Rehm (2005) and Niehues et al. (2004), although our yields, in all locations were low. In Minnesota, Rehm (2005) found a positive yield response to starter fertilizer containing N and S in sandy loam and silt loam textures, low in organic matter, with no-till systems. In Kansas, Niehues et al. (2004) found the addition of S in a 2x2 placement increased yield in a no-till system.

The treatments containing Zn did not show any yield benefit for any location. This would be expected since soil test Zn levels were adequate, thereby, minimizing the likelihood of seeing a response.

Table 7. Evaluation of stand emergence in corn starter fertilizer rates and placements at V3 at Covington, Red Rock, and Miami, OK, in 2011 and 2012.

N-P-K-S-Zn	2011				2012			
	Covington		Red Rock		Covington		Miami	
kg ha^{-1}	---------------------------------------plants ha^{-1}---------------------------------------							
0-0-0†	na		47,366	ab	54,902	a	52,749	a
In-Furrow‡								
11-22-0	45,213	a¶	45,213	ab	52,749	a	52,210	a
22-22-0	45,213	a	45,213	ab	53,287	a	44,675	b
45-22-0	40,907	a	51,672	a	51,134	a	31,219	c
11-22-0-0-0.3§	43,060	a	45,213	ab	52,210	a	50,596	ab
11-22-0-10	43,060	a	43,060	ab	54,902	a	51,134	ab
11-22-0-10-0.3	40,907	a	43,060	ab	50,596	a	51,134	ab
2x2 placement								
101-22-0	45,213	a	45,213	ab	53,825	a	53,825	a
134-22-0	47,366	a	38,754	b	55,440	a	54,363	a
134-22-K#					55,440	a	53,825	a
168-22-0	43,060	a	38,754	b	55,440	a	54,902	a
2x4 placement								
134-22-0	38,754	a	43,060	ab	55,440	a	54,363	a
168-22-0	43,060	a	38,754	b	55,978	a	50,057	ab
Broadcast								
168-0-0	47,366	a	45,213	ab	54,902	a	52,749	a

† The first number represents N, second P_20_5, and third K_20.

‡ N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

§ The 4th and 5th number represents S and Zn.

¶ Values followed by the same letter within the same column do not differ ($p>0.05$).

36 kg K ha^{-1} was applied in Covington 2012 and 67 kg K ha^{-1} was applied in Miami 2012.

Table 8. Evaluation of NDVI in corn starter fertilizer rates and placements at V4-V7 at Covington, Red Rock, and Miami, OK in 2011 and 2012.

N-P-K-S-Zn	2011				2012			
	Covington		Red Rock		Covington		Miami	
kg ha[-1]	---------------V7---------------				---------------V4---------------			
0-0-0†	na		0.43	bc	0.29	bc	0.27	bcde
In-Furrow‡								
11-22-0	0.60	a¶	0.50	a	0.33	a	0.30	a
22-22-0	0.56	ab	0.49	ab	0.33	a	0.30	ab
45-22-0	0.57	ab	0.52	a	0.29	c	0.23	f
11-22-0-0-0.3§	0.58	ab	0.52	a	0.32	a	0.31	a
11-22-0-10	0.60	a	0.47	ab	0.31	abc	0.30	ab
11-22-0-10-0.3	0.59	ab	0.48	ab	0.32	a	0.29	abc
2x2 placement								
101-22-0	0.56	ab	0.48	ab	0.32	a	0.28	abcd
134-22-0	0.54	bc	0.50	a	0.32	a	0.27	bcde
134-22-K#					0.33	a	0.25	ef
168-22-0	0.46	de	0.37	c	0.31	abc	0.25	ef
2x4 placement								
134-22-0	0.44	e	0.47	ab	0.32	ab	0.26	def
168-22-0	0.49	cde	0.43	bc	0.32	a	0.26	cde
Broadcast								
168-0-0	0.50	cd	0.40	c	0.33	a	0.27	bcde

† The first number represents N, second P_2O_5, and third K_2O

‡ N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

§ The 4th and 5th number represents S and Zn.

¶ Values followed by the same letter within the same column do not differ ($p>0.05$).

36 kg K ha^{-1} was applied in Covington 2012 and 67 kg K ha^{-1} was applied in Miami 2012.

Table 9. Contrasts of NDVI in corn starter fertilizer rates and placements at V4-V7 at Covington, Red Rock, and Miami, OK in 2011 and 2012.

	2011		2012	
Contrasts	Covington	Red Rock	Covington	Miami
kg ha^{-1}	----------V7----------		----------V4----------	
1†, 2, and 3 (linear)	NS	*	*	*
1, 2, and 3 (quadratic)	NS	NS	NS	NS
1, 4¶, and 6 (main effect)	NS	NS	NS	NS
1, 5, and 6 (main effect)	NS	NS	NS	NS
1, 4, 5, and 6 (interaction)	NS	NS	NS	NS
7‡, 8, and 9 (linear)	*	NS	NS	*
7, 8, and 9 (quadratic)	NS	NS	NS	NS

† In-furrow starter fertilizer treatments: 11-22-0, 22-22-0, 45-22-0, 11-22-0-0-0.3, 11-22-0-11, 11-22-11-0.3 are represented as 1, 2, 3, 4, 5, and 6 in this table.

‡ Two by two starter fertilizer treatments: 101-22-0, 134-22-0, and 168-22-0 are represented as 7, 8, and 9 in this table.

§ The N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

¶ The 4th and 5th number represents S and Zn.

* Denotes significant at the 5% level.

Table 10. Evaluation of grain yield in corn starter fertilizer rates and placements at Covington, Red Rock, and Miami, OK in 2011 and 2012.

N-P-K-S-Zn	2011		2012			
	Red Rock		Covington		Miami	
kg ha^{-1}	------------------------------kg ha^{-1}------------------------------					
0-0-0[†]	486	c[¶]	4513	a	1077	ab
In-Furrow[‡]						
11-22-0	596	abc	4267	ab	696	ab
22-22-0	737	a	4206	abc	836	ab
45-22-0	737	a	4232	ab	1032	ab
11-22-0-0-0.3[§]	627	abc	4306	ab	1256	ab
11-22-0-10	706	ab	4401	ab	1069	ab
11-22-0-10-0.3	690	abc	4364	ab	705	ab
2x2 placement						
101-22-0	580	abc	4052	bcd	757	ab
134-22-0	596	abc	4111	bc	1370	a
134-22-K[#]			4055	bcd	1097	ab
168-22-0	502	cb	3787	cd	1156	ab
2x4 placement						
134-22-0	564	abc	4342	ab	952	ab
168-22-0	533	abc	3702	d	991	ab
Broadcast						
168-0-0	674	abc	4284	bcd	664	b

† The first number represents N, second P_20_5, and third K_20

‡ N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

§ The 4th and 5th number represents S and Zn.

¶ Values followed by the same letter within the same column do not differ ($p>0.05$).

36 kg K ha^{-1} was applied in Covington 2012 and 67 kg K ha^{-1} was applied in Miami 2012.

Tissue Analysis

The N concentrations at both Covington site-years were generally higher in the 2x2 and 2x4 treatments compared to the in-furrow treatments (Table 11 and Table 13). The 2x2 and 2x4 may have higher N concentrations because the N was applied below the soil surface thus preventing volatilization compared to the in-furrow that had urea broadcasted on the surface. At both Covington site-years, the 101, 134, and 168 kg N ha^{-1} 2x2 treatments N concentrations increased as the N rates increased. This was shown in the plant N concentration contrasts; significant increasing linear trends, at both Covington site-years (Table 15 and Table 17).

The N concentrations at Covington (2012) and Miami were significantly higher in the 45 kg N ha^{-1} treatment compared to the other in-furrow treatments (Table 13 and Table 14). The in-furrow 11-22-0, 22-22-0, and 45-22-0 treatments N concentration contrasts, increased linearly, which was significantly different at Covington (2012) and Miami (Table 17 and Table 18). Soil temperatures (Table 6) were much warmer during planting in 2012 than in 2011, which increased plant growth, likely increasing N concentration differences.

The P concentrations were variable depending on location. At Covington (2012), the 2x2 and 2x4 treatments generally had higher P concentrations than the other treatments (Table 13). At Miami, the 2x2 and 2x4 treatments generally had lower P concentrations than the other treatments (Table14). The pH was the major difference between Covington (2012) (5.2 pH) and Miami (7.4 pH) (Table 3). Miami was conventional tillage. Covington (2011) and Red Rock did not show any differences in P concentration (Table 11 and Table 12).

The plant K concentrations did not show any trends at Covington (2011), Red Rock, or Covington (2012) (Tables 11-13). At Miami, the 2x2 and 2x4 treatments had higher K and lower Mg concentrations than the other treatments (Table 14). The plant K concentrations at Miami were significantly higher in the 2x2 and 2x4 treatments than in all other treatments except for 11-22-0-11 (N-P-K-S) kg ha^{-1} in-furrow treatment. The soil test potassium (STK) was low in Miami. The large amount (average of 425 L ha^{-1}) of liquid fertilizer in the 2x2 and 2x4 placements perhaps aided in the plant K concentration.

At Red Rock, the in-furrow treatments had lower Zn concentrations than the other treatments (Table 12). The major differences Red Rock had from the other locations were the highest OM and lowest STZn.

At Red Rock and Covington (2012) the no fertilizer check was significantly lower than all other treatments, which would be expected. No differences were found in the plant N concentrations of the 2x4 treatments at all locations. Overall the starter fertilizer treatments do not have a major effect on nutrient concentration.

The nutrient uptake of the in-furrow treatments at Covington (2011), Red Rock, and Miami were generally higher than the 2x2 and 2x4 treatments (Table 11, Table 12, and Table 14). The 11 kg N ha^{-1} treatment within the in-furrow placements generally had the highest nutrient uptake, although at Covington (2011) and Red Rock the 45 kg N ha^{-1} treatment was not different.

Among the 2x2 treatments, 101, 134, and 169 kg N ha^{-1}, nutrient uptake decreased as N rates increased at Covington (2011) and Red Rock which correlates with the decreasing biomass (Table 11 and Table 12). There was no difference at Covington (2012) and Miami which correlates with biomass not being different (Table 13 and Table

14). The plant N uptake decreased as biomass decreased. The 2x2 and 2x4 treatments, plant N uptakes were generally lower than the in-furrow treatments because the biomasses were lower. Our results confirm what Kaiser et al. (2005) found, in Iowa, that when fertilization increased early P and K uptake the early growth responses typically corresponded.

The concentrations, in-furrow S treatments did not show any differences from the other treatments in all locations (Tables 11-14). Earlier studies have shown significant responses to the application of S in an indirect placement method. Rehm (2005) found ammonium sulfate and ammonium thiosulfate placed in-furrow in sandy textured soils to have lower S uptake than when placed 2.5 cm to the side and 5 cm below the seed. He explained the reduced S uptake from in-furrow S treatments in sandy soils restricted proper root growth (Rehm, 2005). Niehues et al. (2004) found, in Kansas, that the addition of 11 kg S ha^{-1} to 34-34-11 kg NPK ha^{-1} starter fertilizer in a 2x2 placement increased nutrient uptake, likely due to the increased early growth. The increased early growth response was in a no-till system with heavy residue and cool soil temperatures. This situation perhaps slowed S mineralization (Niehues et al., 2004).

Table 11. Nutrient concentration and uptake for V7 corn starter fertilizer rates at Covington, OK in 2011.

	Plant Concentration						Plant Uptake				
N-P-K-S-Zn	N	P	K	S	Zn	Plant dry weight	N	P	K	S	Zn
kg ha^{-1}	-------------------------%-------------------------				--ppm--	------------------------------kg ha^{-1}------------------------------					--mg ha^{-1}--
In-Furrow[†]											
11-22-0	4.10 d[§]	0.27 abc	1.86 a	0.21 ab	24.3 ab	140.47 ab[§]	5.71 ab	0.38 ab	2.63 ab	0.30 ab	3423 abc
22-22-0	4.27 bcd	0.28 abc	1.85 a	0.23 a	25.4 ab	102.53 bcd	4.34 bcd	0.29 bcde	1.93 bcde	0.23 bc	2555 bcde
45-22-0	4.21 bcd	0.28 abc	1.88 a	0.23 a	24.8 ab	124.19 abc	5.23 abc	0.35 abcd	2.35 abc	0.28 ab	3078 abcd
11-22-0-0-0.3[‡]	4.23 bcd	0.26 abc	1.85 ab	0.22 ab	27.6 a	134.28 ab	5.68 ab	0.35 abc	2.46 ab	0.29 ab	3679 ab
11-22-0-11	4.27 bcd	0.30 a	1.87 a	0.24 a	27.2 a	158.23 a	6.72 a	0.49 a	3.00 a	0.38 a	4481 a
11-22-0-11-0.3	4.19 cd	0.28 abc	1.82 ab	0.23 a	28.3 a	125.53 ab	5.21 abc	0.35 abc	2.28 abcd	0.29 ab	3565 ab
2x2 placement											
101-22-0	4.16 cd	0.26 c	1.60 b	0.19 b	21.3 b	122.98 abc	5.11 abc	0.32 bcd	2.01 bcde	0.24 bc	2650 bcde
134-22-0	4.36 abc	0.30 ab	1.80 ab	0.22 ab	24.7 ab	95.26 bcd	4.16 bcd	0.29 bcde	1.71 bcdef	0.20 bcd	2373 bcde
168-22-0	4.56 a	0.28 abc	1.60 b	0.21 ab	25.4 ab	56.78 d	2.59 d	0.16 e	0.93 f	0.12 d	1461 e
2x4 placement											
134-22-0	4.54 a	0.30 ab	1.73 ab	0.22 a	25.2 ab	75.35 cd	3.41 cd	0.23 cde	1.34 def	0.17 cd	1889 de
168-22-0	4.43 ab	0.30 a	1.78 ab	0.21 ab	26.2 a	65.12 d	2.85 d	0.19 de	1.15 ef	0.13 cd	1653 de
Broadcast											
168-0-0	4.13 d	0.26 bc	1.95 a	0.23 a	28.3 a	72.39 d	2.99 d	0.19 de	1.42 cdef	0.17 cd	2003 cde

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ ($p>0.05$)

Table 12. Nutrient concentration and uptake for V7 corn starter fertilizer rates at Red Rock, OK in 2011.

	Plant Concentration					Plant Uptake					
N-P-K-S-Zn	N	P	K	S	Zn	Plant dry weight	N	P	K	S	Zn
kg ha^{-1}	---%---				--ppm--	---kg ha^{-1}---					--mg ha^{-1}--
0-0-0 (Check)	3.94 e[§]	0.33 abc	1.38 a	0.27 a	49.7 a	42.38 e[§]	1.68 e	0.14 de	0.58 cd	0.11 ef	2115 cd
In-Furrow[†]											
11-22-0	4.31 abc	0.33 ab	1.28 ab	0.23 c	35.3 efg	102.12 a	4.40 a	0.33 a	1.31 a	0.24 a	3595 a
22-22-0	4.17 cd	0.28 de	1.34 ab	0.24 c	40.5 bcde	60.41 bcde	2.52 bcde	0.18 cde	0.79 bcd	0.14 cdef	2382 bcd
45-22-0	4.36 ab	0.28 cde	1.21 ab	0.23 c	36.9 cdefg	75.75 abcd	3.29 abcd	0.21 bcd	0.90 bc	0.17 abcde	2756 abcd
11-22-0-0-0.3[‡]	4.28 abcd	0.33 ab	1.21 ab	0.25 bc	36.4 defg	86.65 ab	3.68 ab	0.28 ab	1.04 ab	0.21 ab	3169 abc
11-22-0-11	4.45 a	0.34 a	1.25 ab	0.27 ab	35.1 fg	73.87 bcd	3.28 abcd	0.25 abc	0.93 bc	0.20 abcd	2588 abcd
11-22-0-11-0.3	4.44 a	0.30 abcde	1.12 b	0.24 bc	33.8 g	70.37 bcd	3.13 bcd	0.21 bcd	0.78 bcd	0.17 bcde	2380 bcd
2x2 placement											
101-22-0	4.31 abc	0.32 abcd	1.27 ab	0.25 abc	39.8 bcdef	81.81 abc	3.53 abc	0.26 abc	1.03 ab	0.20 abc	3275 ab
134-22-0	4.20 bcd	0.30 abcde	1.24 ab	0.25 abc	42.2 b	74.54 abcd	3.12 bcd	0.23 bcd	0.95 abc	0.19 abcd	3152 abc
168-22-0	4.22 bcd	0.27 e	1.17 ab	0.24 bc	41.8 bc	50.99 de	2.15 de	0.13 de	0.59 cd	0.12 ef	2141 cd
2x4 placement											
134-22-0	4.43 a	0.29 bcde	1.16 ab	0.25 abc	41.9 bc	54.22 cde	2.40 cde	0.16 de	0.62 cd	0.13 def	2278 bcd
168-22-0	4.41 a	0.27 e	1.20 ab	0.26 ab	41.5 bcd	58.26 cde	2.59 bcde	0.16 de	0.72 bcd	0.15 bcdef	2408 bcd
Broadcast											
168-0-0	4.12 d	0.29 bcde	1.35 ab	0.27 ab	48.5 a	37.81 e	1.56 e	0.11 e	0.51 d	0.10 f	1835 d

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ (p>0.05)

Table 13. Nutrient concentration and uptake for V4 corn starter fertilizer rates at Covington, OK in 2012.

	Plant Concentration					Plant Uptake					
N-P-K-S-Zn	N	P	K	S	Zn	Plant dry weight	N	P	K	S	Zn
kg ha^{-1}	--------------------------%--------------------------				--ppm--	--------------------------------kg ha^{-1}--------------------------------					--mg ha^{-1}--
0-0-0 (Check)	3.39 f§	0.44 abcd	1.36 bc	0.23 abcd	52.2 a	189.44 b§	6.40 c	0.84 cd	2.57 c	0.43 cb	10068 bc
In-Furrow†											
11-22-0	3.77 e	0.38 d	1.36 bc	0.21 cd	49.4 abc	312.29 a	11.60 a	1.16 abc	4.22 ab	0.66 a	15660 a
22-22-0	3.86 de	0.40 bcd	1.35 c	0.22 bcd	49.2 abcd	283.36 a	10.86 a	1.11 abcd	3.76 abc	0.60 ab	13841 ab
45-22-0	4.13 abc	0.39 cd	1.41 bc	0.21 d	44.6 cd	193.35 b	7.88 bc	0.75 d	2.64 c	0.40 c	8840 c
11-22-0-0-0.3‡	3.88 de	0.39 cd	1.34 c	0.21 d	45.3 bcd	262.24 ab	10.11 ab	1.02 abcd	3.44 abc	0.54 abc	11789 abc
11-22-0-11	3.89 de	0.45 abc	1.56 abc	0.25 a	47.9 abcd	267.35 ab	10.37 ab	1.20 abc	4.18 ab	0.68 a	12802 abc
11-22-0-11-0.3	3.95 cde	0.39 cd	1.47 abc	0.24 abcd	42.6 d	243.53 ab	9.58 ab	0.95 bcd	3.50 abc	0.58 abc	10431 bc
2x2 placement											
101-22-0	4.01 bcd	0.45 abc	1.38 bc	0.23 abcd	51.3 ab	267.89 ab	10.73 ab	1.19 abc	3.70 abc	0.61 ab	13559 ab
134-22-0	4.15 ab	0.46 ab	1.53 abc	0.23 abcd	45.3 bcd	261.29 ab	10.79 a	1.22 abc	4.03 ab	0.61 ab	11783 abc
134-22-36	4.13 abc	0.47 ab	1.68 a	0.25 abc	51.0 abc	268.02 ab	11.05 a	1.25 ab	4.51 a	0.66 a	13801 ab
168-22-0	4.26 a	0.49 a	1.61 ab	0.25 ab	47.3 abcd	246.36 ab	10.45 ab	1.20 abc	3.95 ab	0.61 ab	11686 abc
2x4 placement											
134-22-0	4.12 abc	0.44 abcd	1.40 bc	0.23 abcd	46.2 abcd	248.11 ab	10.16 ab	1.08 abcd	3.44 abc	0.58 abc	11494 abc
168-22-0	4.09 abc	0.49 a	1.57 abc	0.25 a	47.5 abcd	275.96 a	11.27 a	1.35 a	4.33 ab	0.70 a	13068 abc
Broadcast											
168-0-0	3.78 e	0.42 bcd	1.35 c	0.22 bcd	47.8 abcd	240.44 ab	9.05 abc	0.99 abcd	3.24 bc	0.51 abc	11456 abc

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ (p>0.05)

Table 14. Nutrient concentration and uptake for V4 corn starter fertilizer rates at Miami, OK in 2012.

	Plant Concentration						Plant Uptake				
N-P-K-S-Zn	N	P	K	S	Zn	Plant dry weight	N	P	K	S	Zn
$kg\ ha^{-1}$	--------------%				--ppm--	--------------$kg\ ha^{-1}$					--$mg\ ha^{-1}$--
0-0-0 (Check)	3.67 bcde§	0.29 abc	0.91 cd	0.24 abc	47.9 b	108.31 cb§	3.96 cd	0.32 cde	0.96 cd	0.25 cd	5143 c
In-Furrow†											
11-22-0	3.63 cde	0.30 abc	0.83 d	0.24 abc	48.5 ab	185.95 a	6.73 a	0.55 a	1.57 a	0.45 a	9197 a
22-22-0	3.68 bcde	0.28 bcd	0.86 d	0.24 bc	48.3 ab	176.12 a	6.47 a	0.49 ab	1.50 ab	0.42 a	8404 ab
45-22-0	3.92 a	0.31 ab	0.88 d	0.26 a	51.1 ab	87.73 bc	3.44 cd	0.27 def	0.79 d	0.23 cd	4674 c
11-22-0-0-0.3‡	3.61 de	0.29 abc	0.82 d	0.24 abc	49.5 ab	184.2 a	6.63 a	0.53 a	1.53 a	0.44 a	9196 a
11-22-0-11	3.58 de	0.27 bcdef	0.92 cd	0.25 ab	47.0 b	165.23 a	5.95 ab	0.46 abc	1.53 a	0.42 a	7904 ab
11-22-0-11-0.3	3.56 e	0.28 bcde	0.78 d	0.24 bc	47.1 b	169.53 a	6.03 ab	0.47 ab	1.32 abc	0.40 ab	8168 ab
2x2 placement											
101-22-0	3.76 abcde	0.28 bcd	1.20 b	0.25 ab	53.1 ab	94.45 bc	3.58 cd	0.28 def	1.14 abcd	0.24 cd	5143 c
134-22-0	3.69 bcde	0.24 efg	1.08 bc	0.22 c	48.7 ab	84.9 bc	3.13 cd	0.21 ef	0.92 cd	0.19 cd	4198 c
134-22-67	3.73 abcde	0.22 g	1.54 a	0.22 c	47.1 b	65.66 c	2.44 d	0.15 f	1.02 bcd	0.15 d	3143 c
168-22-0	3.69 bcde	0.24 fg	1.08 bc	0.22 c	52.9 ab	75.89 bc	2.76 d	0.18 ef	0.80 d	0.17 d	4092 c
2x4 placement											
134-22-0	3.80 abcd	0.27 cdef	1.25 b	0.23 bc	54.9 a	80.33 bc	3.05 cd	0.22 ef	0.99 cd	0.19 cd	4416 c
168-22-0	3.85 abc	0.26 defg	1.22 b	0.24 abc	51.4 ab	77.9 bc	3.03 cd	0.21 ef	0.97 cd	0.19 cd	4100 c
Broadcast											
168-0-0	3.88 ab	0.32 a	0.84 d	0.25 ab	49.2 ab	117.73 b	4.57 bc	0.38 bcd	0.98 cd	0.29 bc	5798 bc

†N was balanced to 168 $kg\ ha^{-1}$ on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ ($p>0.05$)

Table 15. Contrasts for V7 above-ground tissue elemental concentrations for corn starter fertilizer rates at Covington, OK in 2011.

Contrast	N	P	K	S	Zn
kg ha^{-1}	-------------------------	-------------------------	%	-------------------------	--ppm--
1[†§], 2, and 3 (linear)	NS	NS	NS	NS	NS
1, 2, and 3 (quadratic)	NS	NS	NS	NS	NS
1, 4[¶], and 6 (main effect)	NS	NS	NS	NS	NS
1, 5, and 6 (main effect)	NS	NS	NS	NS	NS
1, 4, 5, and 6 (interaction)	NS	NS	NS	NS	NS
7[‡], 8, and 9 (linear)	*	NS	NS	NS	NS
7, 8, and 9 (quadratic)	NS	NS	NS	NS	NS

† In-furrow starter fertilizer treatments: 11-22-0, 22-22-0, 45-22-0, 11-22-0-0-0.3, 11-22-0-11, 11-22-11-0.3 are represented as 1, 2, 3, 4, 5, and 6 in this table.

‡ Two by two starter fertilizer treatments: 101-22-0, 134-22-0, and 168-22-0 are represented as 7, 8, and 9 in this table.

§ N was balanced to 168 kg ha^{-1} on all in-Furrow treatments.

¶ The 4th and 5th number represents Sulfur and Zinc.

* Denotes significance at the 5% level.

Table 16. Contrasts for V7 above-ground tissue elemental concentrations for corn starter fertilizer rates at Red Rock, OK in 2011.

Contrast	N	P	K	S	Zn
kg ha^{-1}	-------------------------	-------------------------	%	-------------------------	--ppm--
1[†§], 2, and 3 (linear)	NS	NS	NS	NS	NS
1, 2, and 3 (quadratic)	NS	NS	NS	NS	*
1, 4¶, and 6 (main effect)	NS	NS	NS	NS	NS
1, 5, and 6 (main effect)	*	NS	NS	NS	NS
1, 4, 5, and 6 (interaction)	NS	NS	NS	*	NS
7[‡], 8, and 9 (linear)	NS	*	NS	NS	NS
7, 8, and 9 (quadratic)	*	NS	NS	NS	NS

† In-furrow starter fertilizer treatments: 11-22-0, 22-22-0, 45-22-0, 11-22-0-0-0.3, 11-22-0-11, 11-22-11-0.3 are represented as 1, 2, 3, 4, 5, and 6 in this table.

‡ Two by two starter fertilizer treatments: 101-22-0, 134-22-0, and 168-22-0 are represented as 7, 8, and 9 in this table.

§ N was balanced to 168 kg ha^{-1} on all in-Furrow treatments.

¶ The 4th and 5th number represents Sulfur and Zinc.

* Denotes significance at the 5% level.

Table 17. Contrasts for V4 above-ground tissue elemental concentrations for corn starter fertilizer rates at Covington, OK in 2012.

Contrast	N	P	K	S	Zn
kg ha^{-1}	--------------------------%--------------------------				--ppm--
1[†§], 2, and 3 (linear)	*	NS	NS	NS	NS
1, 2, and 3 (quadratic)	NS	NS	NS	NS	NS
1, 4¶, and 6 (main effect)	NS	NS	NS	NS	*
1, 5, and 6 (main effect)	NS	NS	NS	*	NS
1, 4, 5, and 6 (interaction)	NS	NS	NS	NS	NS
7[‡], 8, and 9 (linear)	*	NS	NS	NS	NS
7, 8, and 9 (quadratic)	NS	NS	NS	NS	NS

† In-furrow starter fertilizer treatments: 11-22-0, 22-22-0, 45-22-0, 11-22-0-0-0.3, 11-22-0-11, 11-22-11-0.3 are represented as 1, 2, 3, 4, 5, and 6 in this table.

‡ Two by two starter fertilizer treatments: 101-22-0, 134-22-0, and 168-22-0 are represented as 7, 8, and 9 in this table.

§ N was balanced to 168 kg ha^{-1} on all in-Furrow treatments.

¶ The 4th and 5th number represents Sulfur and Zinc.

* Denotes significance at the 5% level.

Table 18. Contrasts for V4 above-ground tissue elemental concentrations for corn starter fertilizer rates at Miami, OK in 2012.

Contrast	N	P	K	S	Zn
kg ha^{-1}	--------------------------%--------------------------				--ppm--
1[†§], 2, and 3 (linear)	*	NS	NS	*	NS
1, 2, and 3 (quadratic)	NS	NS	NS	NS	NS
1, 4¶, and 6 (main effect)	NS	NS	NS	NS	NS
1, 5, and 6 (main effect)	NS	NS	NS	NS	NS
1, 4, 5, and 6 (interaction)	NS	NS	NS	NS	NS
7[‡], 8, and 9 (linear)	NS	*	NS	*	NS
7, 8, and 9 (quadratic)	NS	NS	NS	NS	NS

† In-furrow starter fertilizer treatments: 11-22-0, 22-22-0, 45-22-0, 11-22-0-0-0.3, 11-22-0-11, 11-22-11-0.3 are represented as 1, 2, 3, 4, 5, and 6 in this table.

‡ Two by two starter fertilizer treatments: 101-22-0, 134-22-0, and 168-22-0 are represented as 7, 8, and 9 in this table.

§ N was balanced to 168 kg ha^{-1} on all in-Furrow treatments.

¶ The 4th and 5th number represents Sulfur and Zinc.

* Denotes significance at the 5% level.

Conclusion

The 2011 and 2012 growing seasons were suitable for the first of the summer, but midsummer minimal precipitation was received which significantly reduced yields. The drought caused the grain yields to be low, which may have affected the response of the starter fertilizer treatments. However, the results from this study show that in-furrow placement may have potential to increase grain yield because of the early increased biomass compared to the 2x2, 2x4, and full broadcast treatments. Oklahoma State University's current recommendation for corn in-furrow placement is 8 kg ha^{-1} of $N+K_2O$ (Zhang and Raun, 2006). Our results showed that in-furrow placement at 11 kg N ha^{-1} increased early growth without decreasing stand emergence even in lighter textured soils. In low yielding environments (<4000 kg ha^{-1}) the use of starter fertilizer appears to be only necessary when soil test indicate a deficiency.

CHAPTER IV

SOYBEAN RESPONSE TO STARTER FERTILIZER

Introduction

Soybean [Glycine max] harvested for bean makes up 21% of harvested cropland acres in the United States (NASS, 2011). Soybean is the 2^{nd} most planted crop in the United States. According to the 2007 Census, soybean ranks 4^{th} for the most harvested crop in Oklahoma, with wheat being 1^{st}, corn 2^{nd}, and grain sorghum 3^{rd} (NASS, 2011).

The increasing number of acres planted to soybean in Oklahoma has raised questions about the need for starter fertilizers in these systems. Early season soil nutrient availability often is lower than later in the season because mineralization is depressed. Mineralization rate increases when the following occur: soil temperatures reaching 25-30^{o}C, close to neutral pH, adequate soil moisture, and good aeration (Brady and Weil, 2008). Soybean may benefit from starter fertilizer because it places a band of available nutrients near the root-zone. Starter fertilizers are formulated as liquid or granule mixtures, which commonly contain N, P, K, and additional nutrients that may be needed in the soil such as S and Zn. Soil testing provides the information needed to decide the proper ratio of nutrients required to get the plant off to a good start.

Previous work has been somewhat inconsistent on whether or not it increases early growth and grain yield. Sij et al. (1979) conducted a study in Texas to determine if starter N would increase early growth and yield. They applied N rates from 0 to 50.4 kg ha^{-1} and placed the fertilizer 8 cm beside the seed bed and 10 cm deep. They found that starter N did not increase early growth or grain yield. Scharf and William (2003) conducted a state wide N application soybean study, in Missouri, that consisted of 48 locations. They evaluated the effect of the broadcast application of 28 kg N ha^{-1} (source: ammonium nitrate) on soybean yield prior to planting. The overall average grain yield across all locations was increased by 34 kg ha^{-1}, which they concluded not profitable. In contrast, Osborn and Riedell (2006) conducted a study in South Dakota to evaluate the effects of various N rates in a 2x2 placement method. They found after averaging all experiments together that 16 kg N ha^{-1} increased grain yield by 6% compared to the no N treatment. They also found that plant biomass increased linearly as the N rate (0-24 kg N ha^{-1}) increased at V3-V4 and R1 but not at R3. The linear response not occurring at R3 was likely due to increased N fixation (Osborn and Riedell, 2006). Bly et al. (1998) conducted a study in South Dakota to evaluate the effects of applying N shortly after soybean emergence. The treatments were 0, 28, 56, 112, and 224 kg N ha^{-1} using ammonium nitrate as the source. They found the 112 and 224 kg N ha^{-1} treatments significantly increased grain yields.

A major concern with starter fertilizer in soybean is in-furrow placement of fertilizer. Unlike corn, soybean is much more sensitive to in-furrow placement of fertilizer and many studies have shown that any fertilizer placed in-furrow will significantly decrease stand and grain yield. Clapp and Small (1970) found, in North

Carolina, in loam, fine sandy loam, and sandy loam soils that both liquid and granular fertilizer placed in-furrow decreased plant stand and yield. They found liquid fertilizer rates as low as 35.5 liters ha^{-1} of 5-8.8-4.2 (N-P-K) material to significantly decrease stand and yield. They found granular fertilizer rates as low as 11.2 kg ha^{-1} of 10-15-5 (N-P-K) material to significantly decrease stand. Yield reduced at rates higher than 11.2 kg ha^{-1} of 10-15-5 (N-P-K) material. They showed that even though the stand was significantly reduced the soybean plants were able to produce more pods and not decrease yield (Clapp and Small, 1970). Ham et al. (1973) found, in Minnesota, in silt loam and silty clay loam soils that broadcast (single rate depending on location; 0-26-25 to 0-44-125 N-P-K) or 2x2 placement (single rate depending on location; 10-20-10 to 16-40-53 N-P-K) with broadcast increased yield. The in-furrow placement (single rate depending on location; 4-8-1 to 4-8-12 N-P-K) effect on stand was less detrimental in this study than in Clapp and Small's, which was likely due to the soil texture and soil moisture differences (Ham et al., 1973).

The purpose of this study is to evaluate various starter fertilizer placements and nitrogen (N) rates in Oklahoma to determine if it is an effective way to maximize early plant vigor, grain yield, and economic return in soybean.

Material and Methods

In 2011 and 2012, experiments were established to evaluate various N rates and fertilizer placement methods in soybean. Five experimental sites were established in various parts of North Central and North East Oklahoma (Table 19).

The first early season soybean starter fertilizer study was located NE of Miami, OK (36.9106N,-94.8253W, elevation 254m) in a conventional tillage cropping system. The predominant soil type at this location was a Taloka silt loam (fine, mixed, active, thermic Mollic Albaqualfs) with a 0 to 1% slope. This site was planted on 14 April 2011 with a 5 cm soil temperature of 16.9^{o}C and 7.6 cm soil volumetric water content of 27%.

The second year soybean study was located on the Oklahoma State University Agronomy Station in Perkins, OK (35.9907N,-97.0350W, elevation 286m) in a no-till cropping system. The predominant soil type at this location was a Teller fine sandy loam (Fine-loamy, mixed, active, thermic Udic Argiustolls) with a 1 to 3% slope. This site was planted on 10 April 2012 with a 5 cm soil temperature of 27.2^{o}C and 7.6 cm soil volumetric water content of 7%.

Another early season soybean study planted the second year was located on the Oklahoma State University Agronomy Station in Stillwater, OK (36.1165N,-97.0959W, elevation 274m) in a conventional tillage cropping system. The predominant soil type at this location was an Ashport silty clay loam (Fine-silty, mixed, superactive, thermic Fluventic Haplustolls) with a 0 to 1% slope. This site was planted on 2 May 2012 with a 5 cm soil temperature of 35^{o}C and 7.6 cm soil volumetric water content of 17.2%. This location was flood irrigated to meet the monthly 30 year mean rainfall to compensate for the abnormally dry season.

Table 19. Soybean starter fertilizer, years, locations, tillage practice, planting dates, taxonomic names, texture classes, GPS coordinates, and slopes.

Year	Location	NT†	Planting Date	Taxonomic Name	Texture Class	GPS Coordinates	Slope
		--yr--					--%--
2011	Miami, OK	0	14 Apr.	Mollic Albaqualfs	Silt Loam	36^o91 N, -94^o83 W	0-1
2012	Perkins, OK	4	10 Apr.	Udic Argiustolls	Sandy Loam	35^o99 N, -97^o04 W	1-3
2012	Stillwater, OK	0	2 May	Fluventic Haplustolls	Loam	36^o12 N, -97^o10 W	0-1

† NT, year in a no-till management system, 0 means conventional tillage.

The experimental design was a randomized complete block design (RCBD) with four replications. Fertilizer placement and N rate were the main effects evaluated. Fertilizer placements evaluated included; in-furrow and 2x2, while N rates varied from 0 to 34 kg N ha^{-1} (Table 20). Not all N rates were used with each placement method. The soybean in-furrow treatment received an N rate of 6 kg ha^{-1}. The 2x2 treatments received N rates of 11, 22, and 34 kg ha^{-1}. An additional 2x2 treatment was 11 kg N ha^{-1} with 10 kg S ha^{-1} and 0.3 kg Zn ha^{-1} (11-22-0-10-0.3) In-furrow and 2x2 treatments received equal amounts of P and 0 kg K ha^{-1} except for the 2012 Perkins location.

In 2012, Perkins had one K treatment added to the study. The K treatment was added in 2012 because the STK levels were below optimum (<138 ppm) (Zhang and Raun, 2006). The amount of potassium was based off of the soil test recommendations and was added to 11 kg N ha^{-1} in a 2x2 placement method. An unfertilized check treatment was placed at all locations.

Table 20. Soybean starter fertilizer rates and placements.

In-Furrow	2x2 placement	0-0-0 (Check)
--kg ha^{-1}--	--kg ha^{-1}--	--kg ha^{-1}--
6-13-0	11-13-0	0-0-0
	22-13-0	
	34-13-0	
	11-13-0-10-0.3†	
	11-13-22	

† N-P-K-S-Zn

The fertilizer sources used for this experiment to obtain the correct nutrient amounts were urea ammonium-nitrate (UAN, 28% N), ammonium polyphosphate (APP, 10% N and 34% P_2O_5), ammonium thiosulfate (ATS, 12% N and 26% S), zinc chelate (Zn-chelate, 8% N and 10% Zn), and muriate of potash (soluble potash, 60% K_2O).

All treatments were applied at planting with a Monosem NG plus 4 (Monosem Inc., Edwardsville, KS) row vacuum planter. The planter was capable of applying one starter fertilizer mixture at a time. Treatments with the same mixture were completed before switching to a different mixture, which prevented contamination. The rate of application was controlled by tractor speed, a variable speed electric pump, and in-line orifices. A four column RedBall Spray Monitor (Horvick Inc., Fargo, ND) was placed in-line so the flow rate of each starter fertilizer row could be monitored. The attachments for applying the in-furrow placement were Keeton Seed Firmers (Precision Planting, Inc., Trentmont, IL), which were mounted onto the seed tube of the planter. The attachments used for the 2x2 treatments were Yetter (Yetter Manufacturing Inc., Colchester, Illinois) side dress fertilizer coulters, which were mounted onto the front tool bar of the planter. The starter fertilizer output was calibrated initially and checked before each location. The equation used to find the speed, gallons per acre, and gallons per minute is shown below.

$$MPH = \frac{5940 * GPM}{GPA * W} \qquad \text{(Eq. 3)}$$

The soybean variety used for all sites was Asgrow AG4903, late maturity group IV, *Roundup Ready*. The seed population for all soybean locations was 24,494 seeds ha^{-1} and planted at a depth of 3.8 cm. Individual plot size for all sites measured 6.1 m by 3.0 m with four rows in each plot spaced 76 cm apart. Soybean seed was inoculated with *Rhizobium japonicum* prior to planting. Weeds were controlled using glyphosate according to weed pressure and rate recommendations. Two inside rows, an area of 6.1 m by 1.5 m were harvested per plot except for Perkins. Miami and Stillwater were harvested using a Delta Wintersteiger (Wintersteiger, Salt Lake City, UT) small plot combine, where the grain weight, test weight, and moisture were measured. The Perkins location was harvested selectively (3.0 m by 1.5 m), ran through a stationery thrasher, and then weighed. The test weight and moisture was measured using a GAC® 2100 Agri (DICKEY-john, Minneapolis, MN) grain analysis computer.

Soil Sampling

Prior to planting, soil samples were collected at depths of 0 to 15 cm and 15 to 30 cm. Analyses from 0 to 15 cm sample were used to formulate starter fertilizer treatments. The 0 to 15 cm depth sample was analyzed for pH, NO_3-N, soil test phosphorus (STP), soil test potassium (STK), SO_4-S, Ca, Mg, Fe, Zn, B, Cu, texture class and organic matter. The 15 to 30 cm depth sample was analyzed for NO_3-N and SO_4-S. Soil sampling was conducted using a hand probe and each composite sample consisted of 15 cores. Analyses were conducted by OSU Soil, Water, and Forage Analytical Laboratory. The soil pH was analyzed with a pH meter. The procedure for NO_3-N soil analysis was conducted by the use of calcium sulfate and flow injection analyzer. Soil test P, K, Ca, and Mg were analyzed using Mehlich 3 (Mehlich, 1984) and inductively coupled plasma (ICP) spectrometer. Soil SO_4-S was analyzed using calcium monophosphate and ICP. Soil test Fe, Zn, Cu, and B were analyzed using DTPA-sorbitol solution and ICP (Procedures Used by OSU Soil, Water, and Forage Analytical Laboratory Fact Sheet F-2901). The climatic conditions were measured using the Oklahoma Mesonet Stations, soil thermometer, and a FieldScout® soil moisture tester (Spectrum Technologies, Inc., Plainfield, IL).

The soil moisture meter measured the percent volumetric water content from 0 to 7.5 cm and 0 to 20 cm in depth. The soil moisture meter uses an electrical signal to measure the percent volumetric water content. The speed at which the electrical signal travels from the soil probe to the instrument determines the percent volumetric water content. The accuracy of the FieldScout TDR 300 soil moisture meter (Spectrum Technologies, Plainfield, IL) is ±3.0% volumetric water content.

Stand-Emergence

Initial stand counts were measured for each plot early in the growing season on the two inside rows of a randomly selected area of 1.5 m^{-1} by 3.1 m^{-1}. Comparisons were made among treatments to evaluate the effects of starter fertilizer rates and placements on emergence.

Early Growth

A GreenSeeker™ was used to determine Normalized Difference Vegetative Index (NDVI) values which were used to compare early growth crop biomass among treatments. Normalized Difference Vegetative Index is calculated by subtracting Red reflected from Near infrared reflected (NIR) and dividing it by the sum of NIR reflected and Red reflected as shown below. Normalized Difference Vegetative Index readings were taken at R1 on each plot to observe vigor. The NDVI measurements were taken on the two inside harvest rows, the entire length of the plot on all locations.

$$\mathrm{NDVI} = \frac{\mathrm{NIR}-\mathrm{Red}}{\mathrm{NIR}+\mathrm{Red}} \quad \text{(Eq. 2)}$$

Statistical Analysis

Statistical analysis was conducted to analyze the main effects of starter fertilizer placements and rates. Main effects were analyzed using analysis of variances at the 5% probability level of significance. PROC GLM (SAS® Institute Inc., 2001) was used to analyze treatment differences in stand counts, NDVI, and grain yield. PROC MIXED (SAS® Institute Inc., 2001) was used to analyze treatment differences in stand counts, NDVI, and grain yield that had missing data. PROC GLM and contrasts were used to evaluate selected treatments and better determine specific trends from NDVI. The contrasts of the selected treatments were linear 2x2 and quadratic 2x2.

Results and Discussion

The 2011 and 2012 growing conditions were unseasonably hot and dry for the later summer months as shown in Table 22. There was adequate moisture during the early part of the growing season while the plants were establishing. The dry conditions of 2011 resulted in an average soybean grain yield of 1028 kg ha^{-1} in Miami, OK. The 2012 average soybean grain yields for Perkins and Stillwater, OK were 355 and 3931 kg ha^{-1}, respectively.

The soil temperature was lower at planting in 2011 than in 2012 (Table 23). Nitrogen and S mineralization is slower in cold soils which increases the probability of seeing a yield response to starter fertilizers containing these elements. The soil characteristics, environmental conditions, and soil temperature at planting date is shown in Table 21, Table 22, and Table 23. The results will focus on the effects of starter fertilizer placements and rates on stand counts, NDVI, and grain yield.

Table 21. Selected soil characteristics for soybean sites.

			NO_3-N		STP	STK	SO_4-S		Zn	OM	Sand	Silt	Clay
Year	Location	pH	0-15†	15-30	0-15	0-15	0-15	15-30	0-15	0-15	0-15	0-15	0-15
			--kg ha^{-1}--		--mg kg^{-1}--		--kg ha^{-1}--		--mg kg^{-1}--	---------------%---------------			
2011	Miami, OK	7.3	91.8	71.7	10	63	15.7	78.4	2.2	1.45			
2012	Perkins, OK	6.0	14.6	17.9	55	112	37.0	58.2	1.9	0.98	76.2	13.8	10.0
2012	Stillwater, OK	6.0	21.3	85.1	89	163	17.9	33.6	1.4	0.92	37.5	40.0	22.5

† Soil sampling depth units are in centimeters.

Table 22.Temperature, rainfall, and 30 year average for soybean at Miami, Perkins, and Stillwater, OK, in 2011 and 2012.

Month	Miami				Perkins				Stillwater			
	2011		30 yr. avg.		2012		30 yr. avg.		2012		30 yr. avg.	
	--C^o--	--mm--	--C^o--	--mm--	--C^o--	--mm--	--C^o--	--mm--	--C^o--	--mm--	--C^o--	--mm--
March	15	178	9	97	16	115	10	78	16	100	10	78
April	17	192	14	102	18	129	15	89	18	156	15	88
May	22	76	19	140	23	28	20	145	23	28	20	141
June	26	18	24	110	26	74	25	112	26	55	25	109
July	30	36	26	90	31	7	28	67	31	2	28	68
August	26	68	26	86	28	86	27	70	27	67	27	76
September	22	114	21	131	24	34	23	106	24	28	23	106
October	14	97	15	96	16	22	16	85	15	15	16	83
8 month total		777		852		494		751		451		750

Source: OK Mesonet, 2012

Table 23. Five cm soil temperature, 7.5 cm soil volumetric water content, and 20 cm soil volumetric water content readings taken between 12 pm to 5 pm for the first month from soybean planting.

	Soil temperature	Soil moisture	
Reading date	5 cm, °C	7.5 cm, %	20 cm, %
Miami, 2011			
14-Apr-11†	17	27	32
Perkins, 2012.			
10-Apr-12†	27	7	15
Stillwater, 2012.			
2-May-12†	35	17	30

† Planting date

Initial Stand Counts

Stand counts were taken at V1 at Perkins and Stillwater and at R1 at Miami (Table 24). The application of 6 kg N ha^{-1} in-furrow consistently reduced stand compared to the check. Earlier studies show similar results to in-furrow fertilizer placement (Clapp and Small, 1970). The Perkins location crusted after planting so the plant stand was lower, which likely caused an unexplainable difference in the 22 kg N ha^{-1} treatment. If the stand reduction was caused by the treatment, the treatments with higher N rates would also be expected to be reduced.

Table 24. Evaluation of stand emergence in soybean starter fertilizer rates and placements at Miami, Perkins, and Stillwater, OK, 2011 and 2012.

	2011		2012			
Treatments	Miami†		Perkins		Stillwater	
kg ha^{-1}	------------------------plants ha^{-1}------------------------					
0-0-0‡	219,606	a¶	140,483	ab	209,379	a
In-Furrow						
6-22-0	157,169	c	83,429	c	114,109	b
2x2 placement						
11-22-0	183,005	bc	170,087	a	205,202	a
11-22-0-11-1§	208,841	ab	142,098	a	192,909	a
22-22-0	215,300	a	115,186	b	192,860	a
34-22-0	204,535	ab	143,175	a	190,176	a
11-22-22			144,251	a		

† The growth stages for Miami, Perkins, and Stillwater were R1, V1, and V1.
‡ The first number represents N, second P_20_5, and third K_20.
§ The 4th and 5th number represents S and Zn.
¶Values followed by the same letter within the same column do not differ ($p>0.05$).

NDVI Readings

NDVI readings were taken at R1 at all locations for each individual plot to compare early-season vigor (Table 25). The 6 kg N ha^{-1} in-furrow treatment was significantly lower than the check in Miami and Stillwater which agrees with the stand counts. No differences were found among the 2x2 treatments. In Perkins, the results were variable because the soil crusted after planting causing a poor stand and inconsistencies. Earlier studies have shown conflicting results on whether or not starter fertilizers increase early growth in soybean. Sij et al. (1979) found, in Texas, that N rates from 0 to 50.4 kg ha^{-1} placed 8 cm beside and 10 cm below the seed bed did not increase early growth. In contrast, Osborn and Riedell (2006) found, in Nebraska, that 16 kg N ha^{-1} increased early growth at V3-V4 and R1. In addition, Xie et al. (2010) found, in Ohio and Shenyang, that rates of 150 and 300 kg ha^{-1} of 18% N and 46% P_2O_5 to linearly increase R4 leaf area.

Table 25. Evaluation of NDVI in soybean starter fertilizer rates and placements at R1 at Miami, Red Rock, and Stillwater, OK in 2011 and 2012.

	2011		2012			
Treatments	Miami		Perkins		Stillwater	
kg ha^{-1}	--------------------R1--------------------					
0-0-0†	0.67	a§	0.27	bc	0.84	a
In-Furrow						
6-22-0	0.64	b	0.25	c	0.72	b
2x2 placement						
11-22-0	0.67	a	0.28	abc	0.83	a
11-22-0-11-1‡	0.68	a	0.27	bc	0.80	a
11-22-22			0.30	a		
22-22-0	0.69	a	0.27	bc	0.81	a
34-22-0	0.69	a	0.28	ab	0.81	a

† The first number represents N, second P_20_5, and third K_20.
‡ The 4th and 5th number represents S and Zn.
§Values followed by the same letter within the same column do not differ ($p>0.05$).

Grain Yield

The lack of rainfall in the latter half of the growing season caused the soybean yield to be significantly reduced in the two locations that were not irrigated (Miami and Perkins), potentially masking results of the starter fertilizer treatments (Table 26). In Perkins, the results were variable because the soil crusted after planting causing a poor stand and inconsistencies. No significant differences in grain yield were found among any of the treatments. Earlier studies have shown conflicting results on whether or not starter fertilizers increase early growth in soybean. Sij et al. (1979) found, in Texas, that N rates from 0 to 50.4 kg ha^{-1} placed 8 cm beside and 10 cm below the seed bed did not increase grain yield. However, Scharf and William (2003) found, in Missouri, that 28 kg N ha^{-1} (source-ammonium nitrate) increased grain yield 34 kg ha^{-1} when averaged across all 48 locations. Also, Osborn and Riedell (2006) found, in South Dakota, that 16 kg N ha^{-1} in a 2x2 placement method increased grain yield by 6% compared to the no N treatment. Bly et al. (1998) found, in South Dakota, that 112 and 224 kg N ha^{-1} applied shortly after soybean emergence significantly increased grain yield. A study in Nebraska found, broadcast incorporated N (0 to 224 kg ha^{-1}) prior to planting to linearly increase grain yield as N rate increased in 9 of the 13 (1 of the 9 site years were not linear from 0 to 224 kg N ha^{-1}) site years (Sorensen and Penas, 1978). The soybeans that respond to N may be more likely in the northern part of the US or under irrigation where yields are typically higher.

No yield benefits in the S treatments were observed for any location. The soil test SO_4-S was optimum for all locations assuming a yield goal of 2688 kg ha^{-1}. Optimum soil test SO_4-S minimizes the likelihood of seeing a response.

The treatments containing Zn did not show any yield benefit for any location. This would be expected since soil test Zn levels were adequate, thereby, minimizing the likelihood of seeing a response.

Table 26. Evaluation of grain yield in soybean starter fertilizer rates and placements at Miami, Perkins, and Stillwater, OK in 2011 and 2012.

	2011		2012			
Treatments	Miami		Perkins		Stillwater	
kg ha^{-1}	------------------------		kg ha^{-1}		------------------------	
0-0-0†	1001	a§	354	ab	3772	a
In-Furrow						
6-22-0	995	a	337	ab	4008	a
2x2 placement						
11-22-0	1010	a	439	a	3743	a
11-22-0-11-0.3‡	1037	a	404	a	4004	a
11-22-22			314	ab		
22-22-0	1065	a	292	b	4153	a
34-22-0	1063	a	347	ab	3911	a

† The first number represents N, second P_20_5, and third K_20

‡ The 4th and 5th number represents S and Zn.

§ Values followed by the same letter within the same column do not differ ($p>0.05$).

Conclusion

The results from this study showed that placement of starter fertilizer in-furrow at rates as low as 6 kg N ha^{-1} significantly reduced stand but not yield. This confirmed an earlier study conducted by Clapp and Small (1970). The stand, early growth, and grain yield were not affected by any of the 2x2 treatments which were consistent with the results found by Sij et al. (1979). When yield potential is low the soybean response to starter N fertilizer is likely minimal (Salvagiotti et al., 2008). In the case that soybean grain yield responds to N fertilizer, the N application method must be low cost (fertigation) or it will perhaps be uneconomical (Wortmann et al., 2012).

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APPENDICES

Appendix A. Soil characteristics for corn sites.

			NO3-N		STP	STK	SO4-S		Ca	Mg	Zn	Fe	B	Cu	OM	Sand	Silt	Clay
Year	Location	pH	0-15†	15-30	0-15	0-15	0-15	15-30	0-15 cm	0-15 cm	0-15	0-15 cm	0-15 cm	0-15 cm	0-15	0-15	0-15	0-15
			---kg ha^{-1}---		---mg kg^{-1}---		---------------kg ha^{-1}---------------				---------------mg kg^{-1}---------------				-----------------%------------------			
2011	Covington, OK	6.0	18	19	23	138	34	44	2956	783	1.05	59	0.40	1.30	1.79	21.9	59.4	18.8
2011	Red Rock, OK	5.6	13	9	15	144	41	78	4629	774	0.88	54	0.17	1.13	2.16	17.5	56.3	26.3
2012	Covington, OK	5.2	19	38	31	111	30	45	3629	823	1.50	64	0.25	1.50	1.47	20.1	53.2	26.9
2012	Miami, OK	7.4	40	40	28	74	25	318	5281	170	6.10	23	0.20	0.50	1.63	28.8	58.8	12.5

† Soil sampling depth units are in centimeters

Appendix B. Nutrient concentration for V7 corn at Covington, OK in 2011.

Plot	Dry Weight (g)	Adj. Weight (kg)	Rep	Trt	N Conc. (%)	P Conc. (%)	Ca Conc. (%)	K Conc. (%)	Mg Conc. (%)	S Conc. (%)	Na Conc. (%)	Fe Conc. (ppm)	Zn Conc. (ppm)	Cu Conc. (ppm)	Mn Conc. (ppm)	B Conc. (ppm)
101	33.70	0.0337	1	6	3.915	0.285	0.452	1.831	0.274	0.228	0.013	360.002	28.550	9.360	171.843	14.792
102	11.20	0.0112	1	9	4.548	0.289	0.453	1.795	0.235	0.221	0.010	210.694	27.731	7.290	200.636	15.055
103	18.60	0.0186	1	10	4.354	0.291	0.419	1.656	0.224	0.200	0.011	385.105	25.302	6.226	193.229	14.708
104	9.20	0.0092	1	11	4.249	0.299	0.415	2.140	0.240	0.240	0.014	581.332	29.923	9.955	171.588	14.511
105	32.40	0.0324	1	3	4.218	0.286	0.380	1.943	0.231	0.226	0.015	164.816	25.212	9.798	134.319	15.693
106	29.70	0.0297	1	2	4.044	0.276	0.337	2.011	0.194	0.217	0.010	128.357	23.016	9.254	134.552	15.082
107	18.10	0.0181	1	1	4.194	0.269	0.415	1.946	0.218	0.227	0.010	215.791	23.936	7.878	180.261	13.088
108	15.90	0.0159	1	8	4.643	0.331	0.432	1.898	0.226	0.231	0.012	291.760	26.205	7.294	234.664	13.428
109	25.30	0.0253	1	4	4.363	0.291	0.402	1.919	0.231	0.230	0.014	377.451	30.412	8.311	214.520	13.073
110	20.60	0.0206	1	12	4.171	0.274	0.382	1.965	0.248	0.224	0.013	261.596	25.752	10.245	167.826	12.717
111	23.60	0.0236	1	7	4.030	0.286	0.378	1.806	0.239	0.222	0.010	429.821	22.315	9.221	194.061	13.214
112	37.60	0.0376	1	5	4.132	0.392	0.609	2.026	0.454	0.290	0.014	847.639	40.596	11.647	194.393	13.652
201	14.20	0.0142	2	7	4.183	0.203	0.308	1.252	0.197	0.160	0.008	359.997	18.585	6.491	105.632	10.852
202	15.00	0.0150	2	8	4.105	0.241	0.399	1.846	0.203	0.212	0.009	309.593	22.685	7.048	216.535	11.651
203	22.60	0.0226	2	6	4.230	0.291	0.436	1.799	0.237	0.236	0.011	561.616	28.898	8.691	182.923	12.626
204	21.60	0.0216	2	3	4.265	0.286	0.383	1.912	0.217	0.229	0.010	271.337	23.644	8.800	166.658	12.152
205	11.40	0.0114	2	12	4.158	0.249	0.415	2.077	0.255	0.224	0.013	256.635	25.866	9.677	150.350	16.630
206	21.40	0.0214	2	5	4.322	0.280	0.438	1.745	0.264	0.230	0.010	344.445	23.666	8.483	141.305	15.558
207	13.40	0.0134	2	2	4.491	0.299	0.466	1.992	0.258	0.246	0.011	340.379	26.188	9.115	174.360	16.569
208	12.00	0.0120	2	9	4.666	0.320	0.468	1.641	0.243	0.224	0.011	426.593	25.671	7.028	187.009	14.641
209	17.80	0.0178	2	10	4.724	0.323	0.447	1.867	0.253	0.228	0.013	531.661	23.641	8.328	180.580	15.818
210	41.20	0.0412	2	1	3.928	0.282	0.408	1.970	0.261	0.207	0.010	286.433	25.133	9.032	142.254	14.664
211	22.10	0.0221	2	4	4.154	0.274	0.413	1.978	0.248	0.218	0.011	301.698	26.847	9.234	148.809	14.741
212	11.30	0.0113	2	11	4.516	0.324	0.418	1.779	0.236	0.220	0.011	234.843	24.702	8.122	147.575	14.148
301	14.00	0.0140	3	2	4.162	0.283	0.440	1.625	0.280	0.218	0.013	451.236	27.229	8.737	133.336	14.238
302	5.40	0.0054	3	10	4.611	0.286	0.463	1.494	0.246	0.222	0.011	371.312	25.371	6.650	212.213	13.903
303	17.30	0.0173	3	8	4.265	0.321	0.444	1.713	0.267	0.215	0.010	442.281	23.462	7.878	163.695	14.572
304	12.50	0.0125	3	12	3.940	0.265	0.415	1.922	0.301	0.214	0.012	468.196	28.359	9.506	117.447	13.568
305	16.90	0.0169	3	3	4.220	0.269	0.411	1.882	0.262	0.222	0.013	396.224	27.017	9.201	157.882	14.032

306	35.70	0.0357	3	5	4.227	0.276	0.380	1.952	0.231	0.214	0.010	326.559	21.625	8.579	141.660	14.232
307	6.90	0.0069	3	11	4.667	0.319	0.472	1.548	0.243	0.222	0.010	354.813	26.883	6.820	189.847	13.727
308	10.70	0.0107	3	9	4.297	0.279	0.423	1.878	0.225	0.223	0.012	423.684	28.351	8.457	176.505	14.247
309	20.70	0.0207	3	1	4.126	0.291	0.396	1.898	0.237	0.222	0.011	477.030	25.943	8.196	162.427	14.199
310	21.00	0.0210	3	6	4.297	0.278	0.431	1.790	0.242	0.225	0.012	399.295	28.489	7.623	212.866	13.142
311	21.50	0.0215	3	4	4.259	0.261	0.389	1.842	0.212	0.211	0.013	306.932	28.732	7.398	170.640	12.592
312	30.10	0.0301	3	7	4.188	0.250	0.354	1.576	0.205	0.183	0.009	214.684	21.556	6.700	131.864	11.875
401	9.30	0.0093	4	12	4.235	0.258	0.494	1.829	0.312	0.271	0.018	353.572	33.197	11.410	155.038	20.660
402	8.30	0.0083	4	9	4.735	0.224	0.332	1.103	0.174	0.180	0.011	223.148	19.673	4.810	176.313	10.945
403	30.90	0.0309	4	4	4.156	0.230	0.372	1.651	0.217	0.204	0.009	191.129	24.393	8.449	146.365	13.382
404	19.10	0.0191	4	2	4.383	0.269	0.420	1.776	0.257	0.224	0.011	349.927	25.271	8.692	166.594	13.422
405	16.00	0.0160	4	6	4.336	0.266	0.405	1.858	0.243	0.217	0.011	344.239	27.236	8.067	161.727	11.931
406	14.20	0.0142	4	10	4.460	0.299	0.416	1.913	0.239	0.237	0.010	263.035	26.426	8.577	172.302	12.900
407	24.40	0.0244	4	1	4.159	0.250	0.383	1.628	0.236	0.198	0.009	310.219	22.046	7.769	143.845	11.944
408	23.50	0.0235	4	7	4.230	0.282	0.409	1.778	0.227	0.203	0.011	271.922	22.555	6.975	195.353	15.939
409	21.40	0.0214	4	3	4.151	0.272	0.387	1.796	0.205	0.225	0.010	265.270	23.516	8.514	168.646	16.837
410	22.60	0.0226	4	8	4.429	0.313	0.424	1.760	0.257	0.202	0.014	415.487	26.581	8.070	146.938	14.967
411	22.90	0.0229	4	5	4.382	0.267	0.399	1.742	0.210	0.218	0.012	275.902	22.958	7.677	149.144	14.217
412	21.00	0.0210	4	11	4.272	0.270	0.384	1.658	0.225	0.175	0.009	213.854	23.253	6.535	143.257	12.679

Appendix C. Nutrient concentration for V7 at Red Rock, OK in 2011.

Plot	Dry Weight (g)	Adj. Weight (kg)	Rep	Trt	N Conc. (%)	P Conc. (%)	Ca Conc. (%)	K Conc. (%)	Mg Conc. (%)	S Conc. (%)	Na Conc. (%)	Fe Conc. (ppm)	Zn Conc. (ppm)	Cu Conc. (ppm)	Mn Conc. (ppm)	B Conc. (ppm)
101	9.20	0.0092	1	6	4.470	0.297	0.560	1.212	0.308	0.245	0.016	392.339	33.376	8.976	70.869	12.799
102	11.60	0.0116	1	9	4.322	0.269	0.659	0.985	0.384	0.226	0.017	261.585	44.139	9.928	81.185	12.713
103	12.20	0.0122	1	10	4.456	0.273	0.665	0.922	0.407	0.226	0.015	378.959	42.874	9.795	72.441	12.047
104	6.00	0.0060	1	11	4.360	0.246	0.618	0.987	0.337	0.219	0.016	605.108	39.561	9.173	75.133	11.719
105	18.50	0.0185	1	3	4.219	0.239	0.519	0.968	0.312	0.202	0.014	280.432	33.432	8.401	62.382	10.520
106	10.80	0.0108	1	2	4.028	0.222	0.533	1.172	0.333	0.201	0.014	189.710	35.072	8.631	50.802	10.328
107	18.10	0.0181	1	1	4.312	0.336	0.649	1.354	0.342	0.228	0.013	188.515	33.682	10.488	68.312	17.785
108	15.30	0.0153	1	8	4.196	0.288	0.654	1.142	0.397	0.239	0.017	293.355	42.996	10.073	59.818	17.535
109	15.30	0.0153	1	4	4.254	0.332	0.681	1.162	0.416	0.268	0.016	391.927	40.369	10.658	73.238	18.346
110	7.20	0.0072	1	12	4.238	0.294	0.714	1.417	0.412	0.264	0.019	496.264	48.697	12.174	75.302	18.367
111	15.20	0.0152	1	7	4.383	0.353	0.695	1.249	0.429	0.249	0.016	388.834	43.405	10.899	81.275	18.341
112	8.50	0.0085	1	0	3.867	0.376	0.825	1.196	0.585	0.274	0.020	464.433	52.932	11.495	76.014	17.538
113	12.30	0.0123	1	5	4.499	0.335	0.620	1.077	0.374	0.254	0.015	277.080	36.074	10.273	56.561	17.132
201	12.50	0.0125	2	7	4.387	0.302	0.669	1.116	0.416	0.259	0.016	389.329	40.372	10.475	89.331	17.211
202	12.50	0.0125	2	8	4.223	0.312	0.748	1.138	0.481	0.259	0.017	818.530	45.301	11.458	95.312	16.966
203	14.10	0.0141	2	6	4.311	0.253	0.494	0.885	0.309	0.214	0.013	552.102	30.946	8.626	62.384	15.594
204	9.00	0.0090	2	0	4.315	0.280	0.693	1.418	0.415	0.271	0.016	673.447	52.423	13.148	83.634	16.914
205	11.80	0.0118	2	3	4.388	0.291	0.626	1.177	0.369	0.241	0.015	443.724	43.662	10.861	72.353	16.288
206	6.90	0.0069	2	12	3.998	0.345	0.761	1.292	0.585	0.291	0.020	588.819	53.738	12.411	77.307	16.629
207	12.40	0.0124	2	5	4.391	0.344	0.661	1.337	0.385	0.276	0.015	358.279	37.021	10.615	68.652	17.030
208	8.40	0.0084	2	2	4.252	0.263	0.552	1.480	0.315	0.239	0.017	350.427	40.572	10.652	58.038	15.771
209	7.80	0.0078	2	9	4.181	0.286	0.679	1.369	0.364	0.268	0.016	303.651	42.024	11.591	85.299	16.671
210	11.10	0.0111	2	10	4.392	0.293	0.662	1.123	0.413	0.266	0.015	464.623	42.069	11.428	80.833	16.389
211	26.30	0.0263	2	1	4.349	0.330	0.616	1.334	0.380	0.230	0.014	351.109	35.283	9.891	67.944	16.685
212	16.60	0.0166	2	4	4.261	0.297	0.605	1.123	0.356	0.231	0.013	417.757	32.444	9.950	67.939	16.568
213	13.00	0.0130	2	11	4.317	0.276	0.615	1.218	0.381	0.268	0.019	367.299	42.990	11.651	76.552	16.904
301	9.60	0.0096	3	2	4.150	0.286	0.673	1.537	0.443	0.263	0.018	568.848	52.353	11.913	93.830	16.581
302	8.60	0.0086	3	10	4.491	0.283	0.629	0.987	0.384	0.246	0.015	685.248	40.235	10.298	92.598	16.537
303	10.10	0.0101	3	8	4.315	0.265	0.648	1.088	0.383	0.249	0.015	693.015	39.296	10.127	82.136	16.503

304	7.80	0.0078	3	12	4.058	0.243	0.627	1.318	0.384	0.252	0.017	711.372	46.973	11.089	82.475	16.194
305	13.00	0.0130	3	3	4.424	0.293	0.541	1.292	0.315	0.242	0.016	541.048	36.594	10.174	81.864	16.476
306	13.80	0.0138	3	5	4.481	0.339	0.615	1.262	0.353	0.266	0.014	401.001	32.255	9.683	74.791	16.364
307	7.50	0.0075	3	11	4.337	0.279	0.695	1.309	0.374	0.274	0.017	653.540	43.593	11.214	74.917	16.075
308	8.00	0.0080	3	0	3.777	0.317	0.651	1.461	0.480	0.251	0.015	586.271	45.247	11.250	80.339	15.703
309	10.60	0.0106	3	9	4.107	0.231	0.573	1.106	0.370	0.227	0.017	407.693	41.510	10.115	72.173	16.111
310	16.00	0.0160	3	1	4.271	0.307	0.609	0.961	0.383	0.226	0.013	549.735	34.692	9.205	77.877	16.231
311	15.00	0.0150	3	6	4.508	0.306	0.522	1.280	0.299	0.239	0.013	453.737	32.565	9.894	65.765	16.241
312	24.40	0.0244	3	4	4.160	0.324	0.637	1.261	0.398	0.225	0.015	326.322	37.292	9.669	74.845	17.164
313	20.00	0.0200	3	7	4.350	0.310	0.620	1.200	0.405	0.248	0.017	379.760	41.051	11.063	76.701	17.689
401	6.20	0.0062	4	12	4.177	0.288	0.674	1.363	0.432	0.260	0.018	542.450	44.467	11.961	92.949	17.710
402	7.90	0.0079	4	9	4.263	0.281	0.616	1.224	0.363	0.252	0.017	407.388	39.454	10.977	90.463	19.243
403	8.10	0.0081	4	4	4.439	0.363	0.672	1.277	0.366	0.257	0.020	355.280	35.658	10.686	85.951	18.911
404	16.10	0.0161	4	2	4.238	0.356	0.623	1.157	0.366	0.237	0.019	646.330	34.056	10.104	89.622	19.330
405	14.00	0.0140	4	6	4.490	0.341	0.656	1.101	0.403	0.278	0.020	644.585	38.326	11.354	91.603	19.722
406	8.40	0.0084	4	10	4.363	0.317	0.592	1.625	0.303	0.260	0.020	392.300	42.480	11.653	85.496	19.557
407	15.50	0.0155	4	1	4.291	0.336	0.635	1.453	0.364	0.249	0.019	368.414	37.350	11.220	81.228	19.016
408	6.00	0.0060	4	0	3.784	0.328	0.775	1.431	0.564	0.282	0.022	421.814	48.054	11.870	92.424	18.229
409	13.10	0.0131	4	7	4.112	0.309	0.545	1.507	0.301	0.247	0.020	296.920	34.260	10.001	96.777	18.323
410	13.00	0.0130	4	3	4.419	0.313	0.513	1.394	0.273	0.234	0.016	392.534	33.761	10.678	75.973	18.555
411	17.50	0.0175	4	8	4.066	0.331	0.618	1.575	0.348	0.262	0.019	373.826	41.251	11.912	76.919	19.009
412	16.40	0.0164	4	5	4.416	0.343	0.615	1.334	0.332	0.269	0.016	337.941	35.074	11.573	73.086	18.302
413	16.80	0.0168	4	11	4.618	0.270	0.599	1.303	0.309	0.277	0.014	436.376	39.679	10.383	79.939	18.166

Appendix D. Nutrient concentration for V4 corn at Covington, OK in 2012.

Plot	Dry Weight (g)	Rep	Trt	Adj. Weight (kg)	N Conc. (%)	P Conc. (%)	Ca Conc. (%)	K Conc. (%)	Mg Conc. (%)	S Conc. (%)	Na Conc. (%)	Fe Conc. (ppm)	Zn Conc. (ppm)	Cu Conc. (ppm)	Mn Conc. (ppm)	B Conc. (ppm)
101	47.70	1	0	0.048	3.377	0.468	0.641	1.286	0.499	0.225	0.019	367.878	59.448	10.945	94.272	18.611
102	84.70	1	1	0.085	3.473	0.369	0.738	1.310	0.505	0.204	0.018	276.733	54.827	10.645	103.177	18.391
103	61.20	1	2	0.061	3.750	0.395	0.571	1.147	0.443	0.199	0.015	237.467	48.147	10.288	88.124	16.984
104	62.40	1	3	0.062	3.961	0.390	0.598	1.235	0.444	0.200	0.017	304.182	46.937	11.453	97.061	18.575
105	63.20	1	4	0.063	3.796	0.389	0.631	1.211	0.440	0.204	0.016	283.083	45.719	11.498	104.865	17.898
106	58.60	1	5	0.059	3.870	0.527	0.873	1.796	0.568	0.290	0.018	357.719	52.738	15.398	139.059	22.684
107	57.90	1	6	0.058	3.913	0.492	0.775	1.522	0.482	0.261	0.018	415.320	48.602	14.045	133.316	21.516
108	51.50	1	7	0.052	4.058	0.455	0.629	1.400	0.436	0.233	0.016	269.456	47.008	11.875	119.581	19.522
109	48.80	1	8	0.049	4.225	0.565	0.723	1.929	0.442	0.278	0.019	311.433	52.449	14.461	138.480	22.529
110	37.90	1	9	0.038	4.515	0.496	0.621	1.599	0.350	0.245	0.016	376.055	43.258	11.582	126.688	19.832
111	31.70	1	10	0.032	4.194	0.411	0.565	1.322	0.324	0.215	0.016	290.098	42.209	11.631	115.019	18.588
112	50.00	1	11	0.050	4.151	0.555	0.690	1.806	0.442	0.281	0.017	276.527	46.636	15.048	134.699	22.315
113	35.20	1	12	0.035	3.730	0.457	0.767	1.520	0.493	0.242	0.017	343.467	43.307	14.590	137.890	22.029
114	37.80	1	13	0.038	4.213	0.420	0.597	1.589	0.340	0.223	0.016	341.833	43.415	12.478	120.066	19.870
201	35.50	2	7	0.036	3.958	0.446	0.690	1.382	0.463	0.231	0.019	286.110	55.515	11.531	103.528	16.892
202	36.10	2	2	0.036	4.118	0.468	0.768	1.508	0.468	0.261	0.018	341.676	53.030	14.126	122.564	18.119
203	38.30	2	5	0.038	4.031	0.425	0.683	1.416	0.405	0.239	0.016	351.861	47.170	14.165	128.722	18.728
204	46.60	2	11	0.047	4.135	0.478	0.789	1.528	0.468	0.260	0.019	377.290	53.447	14.351	121.821	18.827
205	38.90	2	8	0.039	4.373	0.439	0.594	1.301	0.343	0.211	0.017	271.413	45.395	11.074	99.471	16.947
206	35.30	2	4	0.035	4.137	0.453	0.678	1.624	0.380	0.229	0.017	308.114	51.878	13.810	123.158	18.803
207	36.70	2	12	0.037	3.831	0.476	0.734	1.466	0.427	0.236	0.018	353.642	52.381	13.809	126.083	18.512
208	39.90	2	1	0.040	4.086	0.427	0.661	1.489	0.351	0.228	0.017	314.900	48.384	12.921	126.304	18.132
209	33.50	2	6	0.034	4.094	0.409	0.629	1.816	0.291	0.260	0.016	281.224	39.909	13.494	138.236	21.680
210	21.80	2	3	0.022	4.280	0.447	0.622	1.716	0.288	0.238	0.017	286.828	42.667	15.101	134.149	19.202
211	44.10	2	10	0.044	4.314	0.583	0.779	1.788	0.399	0.307	0.019	451.814	53.436	17.633	173.089	23.602
212	46.10	2	9	0.046	4.188	0.526	0.650	1.856	0.353	0.256	0.018	321.050	51.876	13.789	147.784	19.947
213	52.80	2	13	0.053	4.004	0.539	0.782	1.924	0.450	0.286	0.020	353.566	56.742	16.076	159.134	23.448
214	27.20	2	0	0.027	3.505	0.505	0.686	1.470	0.469	0.261	0.018	362.581	52.081	13.076	152.201	17.379
301	51.20	3	7	0.051	4.086	0.465	0.758	1.393	0.420	0.243	0.020	339.540	58.727	11.165	111.924	18.886

302	47.50	3	5	0.048	3.831	0.517	0.760	1.815	0.476	0.291	0.020	226.007	54.084	13.252	112.688	17.892
303	52.00	3	13	0.052	4.209	0.503	0.681	1.887	0.352	0.261	0.020	310.905	56.882	12.177	115.096	20.165
304	55.50	3	11	0.056	4.047	0.513	0.755	1.558	0.477	0.256	0.019	226.979	48.092	13.227	114.576	17.810
305	68.60	3	12	0.069	3.700	0.395	0.601	1.340	0.376	0.200	0.015	293.447	46.920	12.249	95.647	16.498
306	47.60	3	9	0.048	4.321	0.514	0.775	1.564	0.402	0.276	0.018	293.815	49.324	12.927	122.804	19.783
307	55.30	3	4	0.055	3.830	0.352	0.617	1.264	0.347	0.197	0.015	203.379	43.133	10.803	104.190	15.493
308	55.50	3	8	0.056	3.973	0.491	0.667	1.712	0.361	0.253	0.017	264.534	41.847	11.877	124.122	18.998
309	36.60	3	3	0.037	4.055	0.376	0.589	1.508	0.329	0.211	0.015	245.214	49.685	12.209	123.724	15.672
310	56.70	3	10	0.057	3.958	0.361	0.566	1.276	0.329	0.204	0.016	232.623	44.741	10.718	108.560	17.197
311	57.10	3	1	0.057	3.897	0.378	0.671	1.482	0.392	0.229	0.016	242.621	44.836	12.559	121.137	18.152
312	37.10	3	0	0.037	3.292	0.426	0.565	1.517	0.410	0.220	0.018	275.905	51.184	10.445	100.879	15.201
313	51.60	3	2	0.052	3.787	0.378	0.606	1.546	0.341	0.209	0.016	219.728	46.305	12.228	113.329	16.729
314	37.40	3	6	0.037	3.984	0.344	0.690	1.421	0.330	0.242	0.017	335.422	46.068	12.450	150.130	19.523
401	53.00	4	11	0.053	4.014	0.410	0.601	1.400	0.350	0.213	0.016	203.851	41.904	10.780	93.071	14.774
402	51.50	4	9	0.052	4.020	0.424	0.638	1.421	0.330	0.221	0.017	336.912	44.780	10.729	99.269	16.834
403	60.90	4	7	0.061	3.920	0.416	0.570	1.352	0.320	0.203	0.016	239.534	43.987	10.141	101.946	15.655
404	51.90	4	10	0.052	3.994	0.400	0.619	1.210	0.325	0.209	0.017	271.110	44.529	12.093	100.702	16.279
405	41.10	4	4	0.041	3.738	0.380	0.543	1.271	0.358	0.200	0.013	166.070	40.279	10.854	90.312	14.677
406	56.60	4	13	0.057	4.094	0.399	0.611	1.332	0.335	0.214	0.017	265.269	47.034	10.132	107.044	16.671
407	61.70	4	2	0.062	3.791	0.356	0.653	1.214	0.423	0.200	0.017	243.019	49.214	11.221	103.466	15.329
408	50.40	4	1	0.050	3.612	0.329	0.621	1.167	0.424	0.197	0.017	237.575	49.688	10.760	90.040	14.633
409	28.80	4	0	0.029	3.382	0.373	0.596	1.168	0.456	0.219	0.016	168.794	46.240	10.026	89.183	15.706
410	51.00	4	8	0.051	4.028	0.362	0.603	1.175	0.383	0.192	0.015	164.552	41.357	9.723	88.216	16.493
411	22.90	4	3	0.023	4.227	0.361	0.612	1.166	0.391	0.200	0.014	185.061	38.972	10.974	102.056	15.789
412	54.30	4	5	0.054	3.819	0.317	0.545	1.196	0.371	0.193	0.015	140.076	37.734	9.074	87.822	14.128
413	38.20	4	12	0.038	3.854	0.346	0.598	1.090	0.429	0.189	0.017	197.288	48.395	10.395	87.531	14.913
414	52.20	4	6	0.052	3.815	0.300	0.600	1.114	0.354	0.198	0.014	210.344	35.983	10.234	99.775	16.604

Appendix E. Nutrient concentration for V4 corn at Miami, OK in 2012.

Plot	Dry Weight (g)	Rep	Trt	Adj. Weight (kg)	N Conc. (%)	P Conc. (%)	Ca Conc. (%)	K Conc. (%)	Mg Conc. (%)	S Conc. (%)	Na Conc. (%)	Fe Conc. (ppm)	Zn Conc. (ppm)	Cu Conc. (ppm)	Mn Conc. (ppm)	B Conc. (ppm)
101	17.50	1	0	0.0175	3.781	0.313	0.928	1.278	0.329	0.276	0.031	818.454	64.095	8.364	74.315	10.853
102	45.90	1	1	0.0459	3.585	0.309	0.901	0.962	0.309	0.247	0.019	605.612	57.403	7.569	68.255	9.776
103	29.30	1	2	0.0293	3.838	0.300	0.897	0.969	0.314	0.246	0.022	614.429	58.107	7.837	60.865	9.693
104	20.60	1	3	0.0206	3.911	0.324	1.026	1.012	0.344	0.283	0.024	632.786	66.912	8.921	72.055	11.007
105	42.60	1	4	0.0426	3.555	0.280	0.939	0.918	0.340	0.231	0.023	934.736	57.330	8.450	64.918	10.115
106	31.80	1	5	0.0318	3.671	0.307	1.005	0.899	0.343	0.267	0.022	917.544	59.921	9.800	75.582	14.110
107	36.50	1	6	0.0365	3.661	0.316	0.995	0.800	0.352	0.250	0.019	1160.910	59.404	9.348	87.074	11.787
108	21.20	1	7	0.0212	3.648	0.297	0.974	1.025	0.324	0.231	0.020	994.887	60.603	8.501	69.097	11.534
109	14.90	1	8	0.0149	3.428	0.273	1.015	1.081	0.282	0.238	0.021	1280.270	57.148	8.229	75.501	11.090
110	19.70	1	9	0.0197	3.325	0.241	1.071	0.925	0.305	0.211	0.021	1643.510	58.338	7.636	99.300	10.993
111	13.90	1	10	0.0139	3.686	0.265	1.105	1.244	0.263	0.230	0.020	1201.010	61.862	7.878	83.240	11.532
112	13.80	1	11	0.0138	3.831	0.277	1.066	1.176	0.276	0.249	0.021	869.142	57.233	8.256	72.531	11.053
113	21.50	1	12	0.0215	3.952	0.334	1.024	0.884	0.330	0.264	0.020	775.211	56.393	9.290	66.662	10.759
114	13.50	1	13	0.0135	3.458	0.238	0.922	1.385	0.219	0.218	0.021	1114.300	50.592	7.087	141.860	9.578
201	23.40	2	7	0.0234	4.044	0.355	0.880	1.373	0.292	0.282	0.028	610.140	55.125	8.282	65.547	10.926
202	32.10	2	2	0.0321	3.674	0.304	0.998	1.087	0.318	0.272	0.020	691.360	51.275	8.252	64.854	10.051
203	37.20	2	5	0.0372	3.766	0.323	0.921	1.046	0.312	0.279	0.017	645.901	52.474	9.031	66.738	9.950
204	24.00	2	11	0.024	4.029	0.305	0.902	1.305	0.293	0.264	0.019	416.101	54.847	8.059	56.070	10.008
205	22.50	2	8	0.0225	3.665	0.274	0.939	1.141	0.310	0.239	0.020	602.385	49.808	7.993	60.562	9.836
206	26.30	2	4	0.0263	3.426	0.304	0.953	0.854	0.337	0.265	0.018	649.631	48.957	8.928	68.248	9.696
207	21.60	2	12	0.0216	3.885	0.321	0.972	0.879	0.356	0.247	0.017	689.185	48.633	9.015	58.504	9.161
208	30.60	2	1	0.0306	3.823	0.320	0.922	0.759	0.330	0.245	0.016	878.017	45.666	9.061	63.620	9.328
209	24.00	2	6	0.024	3.797	0.292	1.050	0.785	0.363	0.256	0.017	719.098	44.830	8.560	62.836	9.384
210	15.80	2	3	0.0158	4.260	0.336	1.100	0.922	0.355	0.275	0.016	641.113	46.334	9.441	63.358	9.726
211	10.60	2	10	0.0106	3.882	0.275	1.018	1.314	0.271	0.252	0.022	821.814	52.910	7.930	82.781	11.163
212	9.20	2	9	0.0092	3.921	0.232	1.040	1.111	0.264	0.231	0.019	580.161	45.993	7.693	56.388	12.342
213	11.80	2	13	0.0118	3.861	0.222	0.998	1.558	0.219	0.220	0.021	702.069	43.906	6.391	54.501	10.784
214	16.80	2	0	0.0168	3.759	0.288	0.997	0.889	0.347	0.254	0.015	549.919	40.431	8.312	58.418	9.958
301	9.90	3	7	0.0099	3.618	0.227	1.068	1.173	0.265	0.249	0.027	644.104	46.367	6.730	59.181	9.922

302	25.40	3	5	0.0254	3.423	0.244	1.025	0.934	0.301	0.256	0.030	769.408	42.122	7.661	63.590	9.607
303	7.50	3	13	0.0075	3.818	0.201	0.989	1.437	0.207	0.229	0.025	841.581	43.494	6.570	109.802	11.005
304	10.00	3	11	0.01	3.665	0.220	0.993	1.096	0.276	0.209	0.017	942.472	44.545	7.190	64.135	9.903
305	23.60	3	12	0.0236	3.817	0.331	1.041	0.750	0.384	0.252	0.018	584.347	48.050	9.992	56.453	8.965
306	16.30	3	9	0.0163	3.811	0.263	0.958	1.046	0.284	0.219	0.018	801.755	52.653	8.368	77.776	9.802
307	22.70	3	4	0.0227	3.876	0.307	1.018	0.734	0.352	0.236	0.016	766.443	46.619	8.936	69.944	9.143
308	15.80	3	8	0.0158	3.895	0.242	0.914	0.999	0.262	0.216	0.017	884.298	47.055	8.046	80.976	9.864
309	17.50	3	3	0.0175	3.676	0.305	1.151	0.841	0.344	0.246	0.015	869.076	53.784	9.507	88.290	13.951
310	21.40	3	10	0.0214	3.789	0.294	0.974	1.084	0.295	0.239	0.016	903.474	54.858	9.171	82.794	12.272
311	30.60	3	1	0.0306	3.433	0.341	1.090	0.768	0.369	0.258	0.015	738.971	51.716	9.918	70.108	11.141
312	24.60	3	0	0.0246	3.642	0.299	0.943	0.684	0.349	0.210	0.014	1479.530	45.565	8.740	104.564	9.876
313	32.00	3	2	0.032	3.633	0.274	0.917	0.635	0.331	0.212	0.014	957.855	44.172	8.547	70.350	10.187
314	37.80	3	6	0.0378	3.527	0.272	0.989	0.776	0.312	0.231	0.014	812.841	49.563	8.427	64.092	10.212
401	10.10	4	11	0.0101	3.892	0.218	1.027	1.320	0.235	0.234	0.018	333.778	49.097	7.315	54.650	11.275
402	11.20	4	9	0.0112	3.696	0.211	1.059	1.247	0.252	0.217	0.018	788.176	54.552	6.914	72.758	11.469
403	15.70	4	7	0.0157	3.732	0.240	0.949	1.233	0.260	0.224	0.018	530.133	50.227	7.246	67.093	11.041
404	13.80	4	10	0.0138	3.838	0.235	0.990	1.366	0.254	0.217	0.015	609.842	49.833	7.013	68.872	10.920
405	45.30	4	4	0.0453	3.598	0.284	0.979	0.784	0.348	0.230	0.015	503.263	45.170	8.055	60.836	10.131
406	16.00	4	13	0.016	3.794	0.226	0.952	1.761	0.235	0.223	0.016	380.206	50.543	6.916	64.327	10.656
407	37.50	4	2	0.0375	3.574	0.244	0.972	0.751	0.327	0.217	0.013	673.841	39.582	6.461	72.793	9.925
408	31.10	4	1	0.0311	3.663	0.215	0.971	0.840	0.325	0.207	0.012	331.038	39.242	5.958	64.305	10.128
409	21.60	4	0	0.0216	3.501	0.270	0.917	0.788	0.343	0.211	0.014	860.076	41.684	7.236	64.118	9.497
410	9.90	4	8	0.0099	3.766	0.178	0.977	1.106	0.225	0.192	0.013	914.148	40.860	5.994	74.851	10.830
411	11.30	4	3	0.0113	3.852	0.262	1.105	0.752	0.338	0.232	0.012	691.329	37.368	7.758	72.546	9.758
412	28.40	4	5	0.0284	3.460	0.210	0.986	0.781	0.307	0.209	0.010	275.169	33.336	5.921	46.923	8.857
413	20.80	4	12	0.0208	3.869	0.296	0.984	0.840	0.288	0.224	0.016	927.388	43.842	9.158	63.797	12.427
414	27.70	4	6	0.0277	3.249	0.227	0.903	0.744	0.294	0.207	0.012	621.077	34.413	6.339	51.419	11.582

Appendix F. Nutrient uptake for V7 corn at Covington, OK in 2011.

Plot	Rep	Trt	Plant N Uptake (kg/ha)	Plant P Uptake (kg/ha)	Plant Ca Uptake (kg/ha)	Plant K Uptake (kg/ha)	Plant Mg Uptake (kg/ha)	Plant S Uptake (kg/ha)	Plant Na Uptake (mg/ha)	Plant Fe Uptake (mg/ha)	Plant Zn Uptake (mg/ha)	Plant Cu Uptake (mg/ha)	Plant Mn Uptake (mg/ha)	Plant B Uptake (mg/ha)
101	1	6	7.1008	0.5169	0.8198	3.3209	0.4970	0.4135	23578	65294	5178	1698	31167	2683
102	1	9	2.7411	0.1742	0.2731	1.0820	0.1417	0.1332	6028	12700	1672	439	12094	907
103	1	10	4.3581	0.2913	0.4194	1.6577	0.2242	0.2002	11011	38551	2533	623	19343	1472
104	1	11	2.1041	0.1480	0.2055	1.0596	0.1188	0.1188	6932	28784	1482	493	8496	718
105	1	3	7.3547	0.4987	0.6626	3.3881	0.4028	0.3941	26156	28740	4396	1709	23422	2736
106	1	2	6.4633	0.4412	0.5387	3.2145	0.3101	0.3469	15984	20517	3679	1479	21507	2411
107	1	1	4.0857	0.2620	0.4043	1.8957	0.2124	0.2211	9741	21021	2332	767	17560	1275
108	1	8	3.9732	0.2832	0.3697	1.6242	0.1934	0.1977	10269	24967	2242	624	20081	1149
109	1	4	5.9409	0.3962	0.5474	2.6130	0.3145	0.3132	19063	51395	4141	1132	29210	1780
110	1	12	4.6240	0.3038	0.4235	2.1786	0.2750	0.2483	14413	29003	2855	1136	18607	1410
111	1	7	5.1188	0.3633	0.4801	2.2939	0.3036	0.2820	12701	54593	2834	1171	24648	1678
112	1	5	8.3606	0.7933	1.2324	4.0998	0.9187	0.5868	28331	171529	8215	2357	39338	2763
201	2	7	3.1965	0.1551	0.2354	0.9568	0.1506	0.1223	6114	27512	1420	496	8073	829
202	2	8	3.3143	0.1946	0.3221	1.4903	0.1639	0.1711	7266	24993	1831	569	17481	941
203	2	6	5.1447	0.3539	0.5303	2.1882	0.2883	0.2871	13380	68311	3515	1057	22249	1536
204	2	3	4.9586	0.3325	0.4452	2.2227	0.2523	0.2662	11625	31543	2749	1023	19374	1413
205	2	12	2.5511	0.1528	0.2546	1.2743	0.1565	0.1374	7976	15746	1587	594	9225	1020
206	2	5	4.9777	0.3225	0.5045	2.0098	0.3041	0.2649	11517	39671	2726	977	16275	1792
207	2	2	3.2385	0.2156	0.3361	1.4366	0.1861	0.1774	7933	24547	1889	657	12575	1195
208	2	9	3.0135	0.2067	0.3023	1.0598	0.1569	0.1447	7104	27551	1658	454	12078	946
209	2	10	4.5257	0.3094	0.4282	1.7886	0.2424	0.2184	12454	50932	2265	798	17299	1515
210	2	1	8.7098	0.6253	0.9047	4.3682	0.5787	0.4590	22174	63513	5573	2003	31543	3252
211	2	4	4.9409	0.3259	0.4912	2.3527	0.2950	0.2593	13084	35884	3193	1098	17700	1753
212	2	11	2.7465	0.1970	0.2542	1.0819	0.1435	0.1338	6690	14282	1502	494	8975	860
301	3	2	3.1361	0.2132	0.3315	1.2244	0.2110	0.1643	9795	33999	2052	658	10047	1073
302	3	10	1.3400	0.0831	0.1346	0.4342	0.0715	0.0645	3197	10791	737	193	6167	404
303	3	8	3.9713	0.2989	0.4134	1.5949	0.2486	0.2002	9311	41180	2184	734	15241	1357
304	3	12	2.6504	0.1783	0.2792	1.2930	0.2025	0.1440	8073	31498	1908	640	7901	913
305	3	3	3.8379	0.2447	0.3738	1.7118	0.2383	0.2019	11824	36039	2457	837	14360	1276

306	3	5	8.1223	0.5303	0.7301	3.7505	0.4438	0.4112	19214	62744	4155	1648	27218	2734
307	3	11	1.7332	0.1185	0.1753	0.5749	0.0902	0.0824	3714	13176	998	253	7050	510
308	3	9	2.4746	0.1607	0.2436	1.0815	0.1296	0.1284	6910	24399	1633	487	10164	820
309	3	1	4.5969	0.3242	0.4412	2.1145	0.2640	0.2473	12255	53144	2890	913	18095	1582
310	3	6	4.8563	0.3142	0.4871	2.0231	0.2735	0.2543	13563	45129	3220	862	24058	1485
311	3	4	4.9284	0.3020	0.4501	2.1314	0.2453	0.2442	15043	35516	3325	856	19745	1457
312	3	7	6.7849	0.4050	0.5735	2.5531	0.3321	0.2965	14580	34778	3492	1085	21362	1924
401	4	12	2.1199	0.1291	0.2473	0.9155	0.1562	0.1356	9009	17697	1662	571	7760	1034
402	4	9	2.1150	0.1001	0.1483	0.4927	0.0777	0.0804	4914	9968	879	215	7876	489
403	4	4	6.9115	0.3825	0.6186	2.7457	0.3609	0.3393	14967	31785	4057	1405	24341	2225
404	4	2	4.5056	0.2765	0.4317	1.8256	0.2642	0.2303	11307	35971	2598	893	17125	1380
405	4	6	3.7339	0.2291	0.3488	1.5999	0.2093	0.1869	9472	29643	2345	695	13927	1027
406	4	10	3.4081	0.2285	0.3179	1.4620	0.1827	0.1811	7642	20102	2020	655	13168	986
407	4	1	5.4612	0.3283	0.5030	2.1379	0.3099	0.2600	11819	40738	2895	1020	18890	1568
408	4	7	5.3496	0.3567	0.5173	2.2487	0.2871	0.2567	13912	34392	2853	882	24707	2016
409	4	3	4.7807	0.3133	0.4457	2.0685	0.2361	0.2591	11517	30552	2708	981	19424	1939
410	4	8	5.3866	0.3807	0.5157	2.1407	0.3126	0.2457	17028	50537	3233	982	17872	1820
411	4	5	5.4012	0.3291	0.4918	2.1470	0.2588	0.2687	14790	34004	2829	946	18381	1752
412	4	11	4.8279	0.3052	0.4340	1.8739	0.2543	0.1978	10172	24170	2628	739	16191	1433

Appendix G. Nutrient uptake for V7 corn at Red Rock, OK in 2011.

Plot	Rep	Trt	Plant N Uptake (kg/ha)	Plant P Uptake (kg/ha)	Plant Ca Uptake (kg/ha)	Plant K Uptake (kg/ha)	Plant Mg Uptake (kg/ha)	Plant S Uptake (kg/ha)	Plant Na Uptake (mg/ha)	Plant Fe Uptake (mg/ha)	Plant Zn Uptake (mg/ha)	Plant Cu Uptake (mg/ha)	Plant Mn Uptake (mg/ha)	Plant B Uptake (mg/ha)
101	1	6	2.2134	0.1471	0.2773	0.6001	0.1525	0.1213	7922	19426	1653	444	3509	634
102	1	9	2.6980	0.1679	0.4114	0.6149	0.2397	0.1411	10613	16331	2756	620	5068	794
103	1	10	2.9259	0.1793	0.4366	0.6054	0.2672	0.1484	9849	24882	2815	643	4756	791
104	1	11	1.4078	0.0794	0.1996	0.3187	0.1088	0.0707	5167	19540	1277	296	2426	378
105	1	3	4.2009	0.2380	0.5167	0.9638	0.3106	0.2011	13939	27922	3329	836	6211	1047
106	1	2	2.3415	0.1290	0.3098	0.6812	0.1936	0.1168	8138	11027	2039	502	2953	600
107	1	1	4.2006	0.3273	0.6322	1.3190	0.3332	0.2221	12664	18364	3281	1022	6654	1732
108	1	8	3.4550	0.2372	0.5385	0.9404	0.3269	0.1968	13998	24156	3540	829	4926	1444
109	1	4	3.5032	0.2734	0.5608	0.9568	0.3426	0.2207	13175	32273	3324	878	6031	1511
110	1	12	1.6424	0.1139	0.2767	0.5491	0.1597	0.1023	7363	19230	1887	472	2918	712
111	1	7	3.5858	0.2888	0.5685	1.0218	0.3509	0.2037	13089	31809	3551	892	6649	1500
112	1	0	1.7688	0.1720	0.3774	0.5471	0.2676	0.1253	9149	21246	2421	526	3477	802
113	1	5	2.9780	0.2218	0.4104	0.7130	0.2476	0.1681	9930	18342	2388	680	3744	1134
201	2	7	2.9511	0.2032	0.4501	0.7508	0.2799	0.1742	10764	26192	2716	705	6010	1158
202	2	8	2.8412	0.2099	0.5032	0.7656	0.3236	0.1742	11437	55066	3048	771	6412	1141
203	2	6	3.2711	0.1920	0.3749	0.6716	0.2345	0.1624	9865	41897	2348	655	4734	1183
204	2	0	2.0899	0.1356	0.3357	0.6868	0.2010	0.1313	7750	32620	2539	637	4051	819
205	2	3	2.7864	0.1848	0.3976	0.7475	0.2343	0.1531	9526	28180	2773	690	4595	1034
206	2	12	1.4846	0.1281	0.2826	0.4798	0.2172	0.1081	7427	21866	1996	461	2871	618
207	2	5	2.9306	0.2296	0.4411	0.8923	0.2569	0.1842	10010	23910	2471	708	4582	1137
208	2	2	1.9224	0.1189	0.2496	0.6691	0.1424	0.1080	7685	15842	1834	482	2624	713
209	2	9	1.7553	0.1201	0.2850	0.5747	0.1528	0.1125	6717	12747	1764	487	3581	700
210	2	10	2.6239	0.1750	0.3955	0.6709	0.2467	0.1589	8961	27756	2513	683	4829	979
211	2	1	6.1555	0.4671	0.8719	1.8882	0.5379	0.3256	19816	49698	4994	1400	9617	2362
212	2	4	3.8068	0.2653	0.5405	1.0033	0.3181	0.2064	11614	37323	2899	889	6070	1480
213	2	11	3.0203	0.1931	0.4303	0.8522	0.2666	0.1875	13293	25698	3008	815	5356	1183
301	3	2	2.1442	0.1478	0.3477	0.7941	0.2289	0.1359	9300	29391	2705	616	4848	857
302	3	10	2.0788	0.1310	0.2911	0.4568	0.1777	0.1139	6943	31717	1862	477	4286	765
303	3	8	2.3457	0.1440	0.3522	0.5914	0.2082	0.1354	8154	37671	2136	550	4465	897

304	3	12	1.7034	0.1020	0.2632	0.5533	0.1612	0.1058	7136	29863	1972	466	3462	680
305	3	3	3.0954	0.2050	0.3785	0.9040	0.2204	0.1693	11194	37855	2560	712	5728	1153
306	3	5	3.3279	0.2518	0.4568	0.9373	0.2622	0.1976	10398	29783	2396	719	5555	1215
307	3	11	1.7505	0.1126	0.2805	0.5284	0.1510	0.1106	6862	26380	1760	453	3024	649
308	3	0	1.6261	0.1365	0.2803	0.6290	0.2067	0.1081	6458	25242	1948	484	3459	676
309	3	9	2.3428	0.1318	0.3269	0.6310	0.2111	0.1295	9698	23258	2368	577	4117	919
310	3	1	3.6777	0.2644	0.5244	0.8275	0.3298	0.1946	11194	47338	2987	793	6706	1398
311	3	6	3.6395	0.2470	0.4214	1.0333	0.2414	0.1929	10495	36630	2629	799	5309	1311
312	3	4	5.4627	0.4255	0.8365	1.6559	0.5227	0.2955	19698	42852	4897	1270	9829	2254
313	3	7	4.6827	0.3337	0.6674	1.2917	0.4359	0.2669	18299	40877	4419	1191	8256	1904
401	4	12	1.3938	0.0961	0.2249	0.4548	0.1442	0.0868	6006	18101	1484	399	3102	591
402	4	9	1.8126	0.1195	0.2619	0.5204	0.1543	0.1071	7228	17321	1677	467	3846	818
403	4	4	1.9351	0.1582	0.2930	0.5567	0.1596	0.1120	8719	15488	1554	466	3747	824
404	4	2	3.6725	0.3085	0.5398	1.0025	0.3171	0.2054	16463	56004	2951	876	7766	1675
405	4	6	3.3828	0.2569	0.4943	0.8296	0.3036	0.2095	15069	48568	2888	855	6902	1486
406	4	10	1.9725	0.1433	0.2676	0.7346	0.1370	0.1175	9042	17735	1920	527	3865	884
407	4	1	3.5792	0.2803	0.5297	1.2121	0.3036	0.2077	15850	30733	3116	936	6776	1586
408	4	0	1.2220	0.1059	0.2503	0.4621	0.1821	0.0911	7104	13621	1552	383	2985	589
409	4	7	2.8990	0.2179	0.3842	1.0625	0.2122	0.1741	14101	20934	2415	705	6823	1292
410	4	3	3.0916	0.2190	0.3589	0.9753	0.1910	0.1637	11194	27464	2362	747	5315	1298
411	4	8	3.8295	0.3117	0.5821	1.4834	0.3278	0.2468	17895	35208	3885	1122	7245	1790
412	4	5	3.8975	0.3027	0.5428	1.1774	0.2930	0.2374	14122	29828	3096	1021	6451	1615
413	4	11	4.1752	0.2441	0.5416	1.1781	0.2794	0.2505	12658	39456	3588	939	7228	1643

Appendix H. Nutrient uptake for V4 corn at Covington, OK in 2012.

Plot	Rep	Trt	Plant N Uptake (kg/ha)	Plant P Uptake (kg/ha)	Plant Ca Uptake (kg/ha)	Plant K Uptake (kg/ha)	Plant Mg Uptake (kg/ha)	Plant S Uptake (kg/ha)	Plant Na Uptake (mg/ha)	Plant Fe Uptake (mg/ha)	Plant Zn Uptake (mg/ha)	Plant Cu Uptake (mg/ha)	Plant Mn Uptake (mg/ha)	Plant B Uptake (mg/ha)
101	1	0	8.6691	1.2014	1.6456	3.3014	1.2810	0.5776	48777	94441	15261	2810	24201	4778
102	1	1	15.8331	1.6821	3.3642	5.9717	2.3020	0.9299	82053	126149	24993	4853	47033	8384
103	1	2	12.3503	1.3010	1.8807	3.7779	1.4591	0.6555	49406	78216	15858	3389	29026	5594
104	1	3	13.3007	1.3098	2.0083	4.1475	1.4911	0.6717	57092	102155	15763	3846	32596	6238
105	1	4	12.9130	1.3231	2.1463	4.1191	1.4966	0.6939	54422	96288	15551	3911	35669	6088
106	1	5	12.2066	1.6621	2.7533	5.6643	1.7914	0.9146	56769	112818	16633	4856	43857	7154
107	1	6	12.1929	1.5331	2.4150	4.7428	1.5020	0.8133	56091	129420	15145	4377	41543	6705
108	1	7	11.2487	1.2611	1.7434	3.8804	1.2085	0.6458	44347	74685	13029	3291	33144	5411
109	1	8	11.0962	1.4839	1.8989	5.0663	1.1609	0.7301	49901	81795	13775	3798	36370	5917
110	1	9	9.2087	1.0117	1.2667	3.2616	0.7139	0.4997	32636	76706	8824	2362	25841	4045
111	1	10	7.1551	0.7012	0.9639	2.2554	0.5528	0.3668	27297	49493	7201	1984	19623	3171
112	1	11	11.1694	1.4935	1.8568	4.8599	1.1894	0.7562	45747	74413	12550	4049	36247	6005
113	1	12	7.0657	0.8658	1.4530	2.8796	0.9340	0.4585	32206	65068	8204	2764	26123	4173
114	1	13	8.5716	0.8544	1.2145	3.2326	0.6917	0.4537	32550	69542	8832	2538	24426	4042
201	2	7	7.5627	0.8521	1.3183	2.6404	0.8846	0.4413	36301	54664	10607	2203	19780	3227
202	2	2	8.0000	0.9093	1.4921	2.9299	0.9093	0.5071	34972	66384	10303	2745	23813	3520
203	2	5	8.3080	0.8760	1.4079	2.9188	0.8348	0.4926	32981	72529	9723	2920	26533	3860
204	2	11	10.3698	1.1988	1.9788	3.8322	1.1737	0.6521	47652	94624	13404	3599	30553	4722
205	2	8	9.1554	0.9191	1.2436	2.7237	0.7181	0.4417	35591	56822	9504	2318	20825	3548
206	2	4	7.8602	0.8606	1.2881	3.0853	0.7219	0.4351	32297	58536	9856	2624	23398	3572
207	2	12	7.5673	0.9402	1.4498	2.8956	0.8434	0.4661	35553	69851	10346	2728	24904	3656
208	2	1	8.7736	0.9169	1.4194	3.1975	0.7537	0.4896	36506	67622	10390	2775	27122	3894
209	2	6	7.3804	0.7374	1.1341	3.2742	0.5247	0.4688	28847	50703	7195	2433	24923	3909
210	2	3	5.0211	0.5244	0.7298	2.0133	0.3379	0.2792	19946	33653	5006	1772	15739	2253
211	2	10	10.2378	1.3837	1.8489	4.2437	0.9470	0.7286	45095	107235	12683	4185	41082	5602
212	2	9	10.3918	1.3050	1.6127	4.6049	0.8758	0.6352	44659	79655	12871	3421	36666	4949
213	2	13	11.3792	1.5317	2.2222	5.4674	1.2788	0.8127	56833	100472	16124	4568	45221	6663
214	2	0	5.1314	0.7393	1.0042	2.1519	0.6866	0.3821	26350	53078	7624	1914	22281	2544
301	3	7	11.2584	1.2813	2.0887	3.8385	1.1573	0.6696	55111	93562	16183	3077	30841	5204

302	3	5	9.7926	1.3217	1.9429	4.6399	1.2169	0.7439	51129	57777	13826	3388	28808	4574
303	3	13	11.7791	1.4077	1.9059	5.2810	0.9851	0.7304	55972	87010	15919	3408	32211	5643
304	3	11	12.0883	1.5323	2.2552	4.6537	1.4248	0.7647	56753	67798	14365	3951	34224	5320
305	3	12	13.6608	1.4583	2.2189	4.9473	1.3882	0.7384	55380	108341	17323	4522	35313	6091
306	3	9	11.0703	1.3168	1.9854	4.0067	1.0298	0.7071	46113	75270	12636	3312	31460	5068
307	3	4	11.3977	1.0476	1.8363	3.7619	1.0327	0.5863	44643	60530	12837	3215	31009	4611
308	3	8	11.8658	1.4666	1.9923	5.1137	1.0783	0.7557	50779	79016	12500	3548	37075	5675
309	3	3	7.9867	0.7406	1.1602	2.9704	0.6481	0.4156	29547	48302	9787	2405	24371	3087
310	3	10	12.0793	1.1016	1.7272	3.8938	1.0040	0.6225	48825	70986	13653	3271	33128	5248
311	3	1	11.9762	1.1616	2.0620	4.5543	1.2047	0.7037	49169	74560	13779	3859	37227	5578
312	3	0	6.5725	0.8506	1.1281	3.0290	0.8186	0.4393	35941	55090	10220	2086	20143	3035
313	3	2	10.5157	1.0497	1.6829	4.2934	0.9470	0.5804	44433	61020	12859	3396	31472	4646
314	3	6	8.0196	0.6924	1.3889	2.8603	0.6642	0.4871	34218	67515	9273	2506	30219	3930
401	4	11	11.4497	1.1695	1.7143	3.9934	0.9984	0.6076	45639	58147	11953	3075	26548	4214
402	4	9	11.1414	1.1752	1.7683	3.9386	0.9147	0.6125	47119	93382	12412	2974	27514	4666
403	4	7	12.8466	1.3635	1.8682	4.4313	1.0488	0.6654	52442	78510	14417	3324	33414	5131
404	4	10	11.1559	1.1173	1.7290	3.3798	0.9078	0.5838	47485	75727	12438	3378	28128	4547
405	4	4	8.2682	0.8406	1.2011	2.8114	0.7919	0.4424	28756	36734	8910	2401	19977	3247
406	4	13	12.4699	1.2154	1.8612	4.0575	1.0205	0.6519	51785	80806	14327	3086	32608	5078
407	4	2	12.5870	1.1822	2.1684	4.0313	1.4046	0.6641	56451	80698	16342	3726	34358	5090
408	4	1	9.7970	0.8924	1.6845	3.1655	1.1501	0.5344	46113	64442	13478	2919	24423	3969
409	4	0	5.2416	0.5782	0.9238	1.8104	0.7068	0.3395	24800	26163	7167	1554	13823	2434
410	4	8	11.0569	0.9936	1.6551	3.2251	1.0513	0.5270	41172	45166	11352	2669	24213	4527
411	4	3	5.2093	0.4449	0.7543	1.4371	0.4819	0.2465	17255	22808	4803	1353	12578	1946
412	4	5	11.1618	0.9264	1.5927	3.4952	1.0842	0.5640	43836	40936	11027	2652	25665	4129
413	4	12	7.9235	0.7113	1.2294	2.2409	0.8820	0.3886	34950	40561	9950	2137	17996	3066
414	4	6	10.7189	0.8428	1.6856	3.1296	0.9945	0.5563	39331	59094	10109	2875	28031	4665

Appendix I. Nutrient uptake for V4 corn at Miami, OK in 2012.

Plot	Rep	Trt	Plant N Uptake (kg/ha)	Plant P Uptake (kg/ha)	Plant Ca Uptake (kg/ha)	Plant K Uptake (kg/ha)	Plant Mg Uptake (kg/ha)	Plant S Uptake (kg/ha)	Plant Na Uptake (mg/ha)	Plant Fe Uptake (mg/ha)	Plant Zn Uptake (mg/ha)	Plant Cu Uptake (mg/ha)	Plant Mn Uptake (mg/ha)	Plant B Uptake (mg/ha)
101	1	0	3.5615	0.2948	0.8740	1.2037	0.3099	0.2599	29197	77085	6037	788	6999	1022
102	1	1	8.8558	0.7633	2.2258	2.3764	0.7633	0.6102	46936	149605	14180	1870	16861	2415
103	1	2	6.0514	0.4731	1.4145	1.5280	0.4952	0.3879	34692	96890	9163	1236	9598	1529
104	1	3	4.3356	0.3592	1.1375	1.1220	0.3814	0.3138	26608	70156	7418	989	7989	1220
105	1	4	8.1506	0.6420	2.1529	2.1047	0.7795	0.5296	52732	214308	13144	1937	14884	2319
106	1	5	6.2826	0.5254	1.7200	1.5386	0.5870	0.4570	37652	157034	10255	1677	12936	2415
107	1	6	7.1915	0.6208	1.9546	1.5715	0.6915	0.4911	37324	228051	11669	1836	17105	2315
108	1	7	4.1625	0.3389	1.1113	1.1695	0.3697	0.2636	22819	113514	6915	970	7884	1316
109	1	8	2.7489	0.2189	0.8139	0.8669	0.2261	0.1909	16840	102666	4583	660	6055	889
110	1	9	3.5257	0.2555	1.1355	0.9807	0.3234	0.2237	22265	174252	6185	810	10528	1166
111	1	10	2.7571	0.1982	0.8266	0.9306	0.1967	0.1721	14962	89846	4628	589	6227	863
112	1	11	2.8453	0.2057	0.7917	0.8734	0.2050	0.1849	15597	64552	4251	613	5387	821
113	1	12	4.5727	0.3865	1.1849	1.0229	0.3818	0.3055	23142	89701	6525	1075	7714	1245
114	1	13	2.5125	0.1729	0.6699	1.0063	0.1591	0.1584	15258	80961	3676	515	10307	696
201	2	7	5.0930	0.4471	1.1083	1.7291	0.3677	0.3551	35263	76840	6942	1043	8255	1376
202	2	2	6.3476	0.5252	1.7242	1.8779	0.5494	0.4699	34552	119440	8858	1426	11204	1736
203	2	5	7.5403	0.6467	1.8439	2.0942	0.6247	0.5586	34035	129315	10506	1808	13362	1992
204	2	11	5.2036	0.3940	1.1651	1.6856	0.3785	0.3410	24542	53746	7084	1041	7242	1293
205	2	8	4.4378	0.3318	1.1371	1.3817	0.3754	0.2894	24219	72945	6031	968	7334	1191
206	2	4	4.8486	0.4303	1.3489	1.2088	0.4770	0.3751	25478	91952	6930	1264	9660	1372
207	2	12	4.5167	0.3732	1.1300	1.0218	0.4139	0.2871	19763	80118	5654	1048	6801	1065
208	2	1	6.2963	0.5270	1.5184	1.2500	0.5435	0.4035	26350	144599	7521	1492	10477	1536
209	2	6	4.9049	0.3772	1.3563	1.0140	0.4689	0.3307	21958	92884	5791	1106	8116	1212
210	2	3	3.6226	0.2857	0.9354	0.7840	0.3019	0.2338	13606	54517	3940	803	5388	827
211	2	10	2.2147	0.1569	0.5808	0.7496	0.1546	0.1438	12551	46883	3018	452	4723	637
212	2	9	1.9415	0.1149	0.5149	0.5501	0.1307	0.1144	9408	28726	2277	381	2792	611
213	2	13	2.4523	0.1410	0.6338	0.9894	0.1391	0.1397	13336	44586	2788	406	3461	685

214	2	0	3.3990	0.2604	0.9015	0.8038	0.3137	0.2297	13563	49722	3656	752	5282	900
301	3	7	1.9279	0.1209	0.5690	0.6250	0.1412	0.1327	14386	34319	2470	359	3153	529
302	3	5	4.6786	0.3336	1.4012	1.2768	0.4115	0.3500	41010	105179	5758	1047	8693	1313
303	3	13	1.5410	0.0811	0.3992	0.5800	0.0836	0.0924	10091	33970	1756	265	4432	444
304	3	11	1.9723	0.1184	0.5344	0.5899	0.1485	0.1125	9149	50723	2397	387	3452	533
305	3	12	4.8477	0.4204	1.3222	0.9526	0.4877	0.3201	22863	74220	6103	1269	7170	1139
306	3	9	3.3434	0.2307	0.8404	0.9176	0.2491	0.1921	15791	70335	4619	734	6823	860
307	3	4	4.7353	0.3751	1.2437	0.8967	0.4300	0.2883	19547	93637	5695	1092	8545	1117
308	3	8	3.3122	0.2058	0.7772	0.8495	0.2228	0.1837	14456	75196	4001	684	6886	839
309	3	3	3.4619	0.2873	1.0841	0.7921	0.3240	0.2317	14128	81853	5066	895	8316	1314
310	3	10	4.3644	0.3386	1.1218	1.2485	0.3398	0.2753	18428	104056	6318	1056	9536	1413
311	3	1	5.6531	0.5616	1.7951	1.2648	0.6077	0.4249	24703	121699	8517	1633	11546	1835
312	3	0	4.8219	0.3959	1.2485	0.9056	0.4621	0.2780	18535	195884	6033	1157	13844	1308
313	3	2	6.2570	0.4719	1.5793	1.0936	0.5701	0.3651	24111	164964	7607	1472	12116	1754
314	3	6	7.1761	0.5534	2.0120	1.5787	0.6347	0.4699	28481	165363	10083	1714	13039	2078
401	4	11	2.1154	0.1185	0.5583	0.7175	0.1277	0.1272	9784	18143	2669	398	2971	613
402	4	9	2.2280	0.1272	0.6383	0.7517	0.1519	0.1308	10850	47510	3288	417	4386	691
403	4	7	3.1530	0.2028	0.8019	1.0418	0.2197	0.1893	15209	44794	4244	612	5669	933
404	4	10	2.8503	0.1745	0.7353	1.0145	0.1886	0.1612	11141	45294	3701	521	5115	811
405	4	4	8.7725	0.6924	2.3868	1.9114	0.8484	0.5607	36570	122697	11013	1964	14832	2470
406	4	13	3.2669	0.1946	0.8198	1.5164	0.2024	0.1920	13778	32740	4352	596	5539	918
407	4	2	7.2136	0.4924	1.9617	1.5157	0.6600	0.4380	26237	135997	7989	1304	14691	2003
408	4	1	6.1302	0.3599	1.6252	1.4060	0.5440	0.3465	20085	55409	6568	997	10763	1695
409	4	0	4.0700	0.3139	1.0660	0.9161	0.3987	0.2453	16275	99984	4846	841	7454	1104
410	4	8	2.0064	0.0948	0.5206	0.5893	0.1199	0.1023	6927	48707	2177	319	3988	577
411	4	3	2.3427	0.1593	0.6720	0.4573	0.2056	0.1411	7298	42044	2273	472	4412	593
412	4	5	5.2888	0.3210	1.5071	1.1937	0.4692	0.3195	15285	42059	5095	905	7172	1354
413	4	12	4.3306	0.3314	1.1015	0.9403	0.3224	0.2508	17911	103816	4908	1025	7142	1391
414	4	6	4.8433	0.3384	1.3462	1.1092	0.4383	0.3086	17890	92590	5130	945	7666	1727

Appendix J. Nutrient concentration (N, P, K, S, Mg, and Ca) for corn starter fertilizer treatments at V7 in Covington, OK in 2011.

N-P-K-S-Zn	N		P		K		S		Mg		Ca	
kg ha^{-1}	--%--											
In-Furrow†												
11-22-0	4.10	d§	0.27	abc	1.86	a	0.21	ab	0.24	abc	0.40	ab
22-22-0	4.27	bcd	0.28	abc	1.85	a	0.23	a	0.25	abc	0.42	ab
45-22-0	4.21	bcd	0.28	abc	1.88	a	0.23	a	0.23	bc	0.39	ab
11-22-0-0-0.3‡	4.23	bcd	0.26	abc	1.85	ab	0.22	ab	0.23	bc	0.39	ab
11-22-0-11	4.27	bcd	0.30	a	1.87	a	0.24	a	0.29	a	0.46	a
11-22-0-11-0.3	4.19	cd	0.28	abc	1.82	ab	0.23	a	0.25	abc	0.43	a
2x2 placement												
101-22-0	4.16	cd	0.26	c	1.60	b	0.19	b	0.22	c	0.36	b
134-22-0	4.36	abc	0.30	ab	1.80	ab	0.22	ab	0.24	abc	0.42	ab
168-22-0	4.56	a	0.28	abc	1.60	b	0.21	ab	0.22	c	0.42	ab
2x4 placement												
134-22-0	4.54	a	0.30	ab	1.73	ab	0.22	a	0.24	abc	0.44	a
168-22-0	4.43	ab	0.30	a	1.78	ab	0.21	ab	0.24	abc	0.42	ab
Broadcast												
168-0-0	4.13	d	0.26	bc	1.95	a	0.23	a	0.28	ab	0.43	ab

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ (p>0.05)

Appendix K. Nutrient concentration (N, P, K, S, Mg, and Ca) for corn starter fertilizer treatments at V7 in Red Rock, OK in 2011.

N-P-K-S-Zn	N		P		K		S		Mg		Ca	
kg ha^{-1}						%						
0-0-0 (Check)	3.94	e[§]	0.33	abc	1.38	a	0.27	a	0.51	a	0.74	a
In-Furrow[†]												
11-22-0	4.31	abc	0.33	ab	1.28	ab	0.23	c	0.37	cd	0.63	bcd
22-22-0	4.17	cd	0.28	de	1.34	ab	0.24	c	0.36	cd	0.60	cde
45-22-0	4.36	ab	0.28	cde	1.21	ab	0.23	c	0.32	d	0.55	e
11-22-0-0-0.3[‡]	4.28	abcd	0.33	ab	1.21	ab	0.25	bc	0.38	bcd	0.65	bc
11-22-0-11	4.45	a	0.34	a	1.25	ab	0.27	ab	0.36	cd	0.63	bcd
11-22-0-11-0.3	4.44	a	0.30	abcde	1.12	b	0.24	bc	0.33	cd	0.56	de
2x2 placement												
101-22-0	4.31	abc	0.32	abcd	1.27	ab	0.25	abc	0.39	bcd	0.63	bcd
134-22-0	4.20	bcd	0.30	abcde	1.24	ab	0.25	abc	0.40	bc	0.67	abc
168-22-0	4.22	bcd	0.27	e	1.17	ab	0.24	bc	0.37	cd	0.63	bcd
2x4 placement												
134-22-0	4.43	a	0.29	bcde	1.16	ab	0.25	abc	0.38	cd	0.64	bc
168-22-0	4.41	a	0.27	e	1.20	ab	0.26	ab	0.35	cd	0.63	bcd
Broadcast												
168-0-0	4.12	d	0.29	bcde	1.35	ab	0.27	ab	0.45	ab	0.69	ab

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ ($p>0.05$)

Appendix L. Nutrient concentration (N, P, K, S, Mg, and Ca) for corn starter fertilizer treatments at V4 in Covington, OK in 2012.

N-P-K-S-Zn	N		P		K		S		Mg		Ca	
kg ha^{-1}						%						
0-0-0 (Check)	3.39	f§	0.44	abcd	1.36	bc	0.23	abcd	0.46	a	0.62	ab
In-Furrow†												
11-22-0	3.77	e	0.38	d	1.36	bc	0.21	cd	0.42	abc	0.67	ab
22-22-0	3.86	de	0.40	bcd	1.35	c	0.22	bcd	0.42	abc	0.65	ab
45-22-0	4.13	abc	0.39	cd	1.41	bc	0.21	d	0.36	bcd	0.61	b
11-22-0-0-0.3‡	3.88	de	0.39	cd	1.34	c	0.21	d	0.38	bcd	0.62	ab
11-22-0-11	3.89	de	0.45	abc	1.56	abc	0.25	a	0.46	a	0.72	a
11-22-0-11-0.3	3.95	cde	0.39	cd	1.47	abc	0.24	abcd	0.36	bcd	0.67	ab
2x2 placement												
101-22-0	4.01	bcd	0.45	abc	1.38	bc	0.23	abcd	0.41	abcd	0.66	ab
134-22-0	4.15	ab	0.46	ab	1.53	abc	0.23	abcd	0.38	bcd	0.65	ab
134-22-36	4.13	abc	0.47	ab	1.68	a	0.25	abc	0.37	bcd	0.67	ab
168-22-0	4.26	a	0.49	a	1.61	ab	0.25	ab	0.36	cd	0.67	ab
2x4 placement												
134-22-0	4.12	abc	0.44	abcd	1.40	bc	0.23	abcd	0.34	d	0.63	ab
168-22-0	4.09	abc	0.49	a	1.57	abc	0.25	a	0.43	ab	0.71	a
Broadcast												
168-0-0	3.78	e	0.42	bcd	1.35	c	0.22	bcd	0.43	ab	0.68	ab

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ (p>0.05)

Appendix M. Nutrient concentration (N, P, K, S, Mg, and Ca) for corn starter fertilizer treatments at V4 in Miami, OK in 2012.

N-P-K-S-Zn	N		P		K		S		Mg		Ca	
kg ha^{-1}			----------------------		----------------------		%		----------------------			
0-0-0 (Check)	3.67	bcde[§]	0.29	abc	0.91	cd	0.24	abc	0.34	a	0.95	c
In-Furrow[†]												
11-22-0	3.63	cde	0.30	abc	0.83	d	0.24	abc	0.33	a	0.97	bc
22-22-0	3.68	bcde	0.28	bcd	0.86	d	0.24	bc	0.32	a	0.95	c
45-22-0	3.92	a	0.31	ab	0.88	d	0.26	a	0.35	a	1.10	a
11-22-0-0-0.3[‡]	3.61	de	0.29	abc	0.82	d	0.24	abc	0.34	a	0.97	bc
11-22-0-11	3.58	de	0.27	bcdef	0.92	cd	0.25	ab	0.32	ab	0.98	bc
11-22-0-11-0.3	3.56	e	0.28	bcde	0.78	d	0.24	bc	0.33	a	0.98	bc
2x2 placement												
101-22-0	3.76	abcde	0.28	bcd	1.20	b	0.25	ab	0.29	bc	0.97	bc
134-22-0	3.69	bcde	0.24	efg	1.08	bc	0.22	c	0.27	c	0.96	bc
134-22-67	3.73	abcde	0.22	g	1.54	a	0.22	c	0.22	d	0.97	bc
168-22-0	3.69	bcde	0.24	fg	1.08	bc	0.22	c	0.28	c	1.03	ab
2x4 placement												
134-22-0	3.80	abcd	0.27	cdef	1.25	b	0.23	bc	0.27	c	1.02	abc
168-22-0	3.85	abc	0.26	defg	1.22	b	0.24	abc	0.27	c	1.00	bc
Broadcast												
168-0-0	3.88	ab	0.32	a	0.84	d	0.25	ab	0.34	a	1.01	bc

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ ($p>0.05$)

Appendix N. Nutrient uptake (N, P, K, S, Mg, and Ca) for corn starter fertilizer treatments at V7 in Covington, OK in 2011.

N-P-K-S-Zn	Plant dry weight		N		P		K		S		Mg		Ca	
kg ha^{-1}			----------kg ha^{-1}----------											
In-Furrow†														
11-22-0	140.47	ab§	5.71	ab	0.38	ab	2.63	ab	0.30	ab	0.34	ab	0.56	ab
22-22-0	102.53	bcd	4.34	bcd	0.29	bcde	1.93	bcde	0.23	bc	0.24	bcd	0.41	bcde
45-22-0	124.19	abc	5.23	abc	0.35	abcd	2.35	abc	0.28	ab	0.28	bcd	0.48	bcd
11-22-0-0-0.3‡	134.28	ab	5.68	ab	0.35	abc	2.46	ab	0.29	ab	0.30	bc	0.53	abc
11-22-0-11	158.23	a	6.72	a	0.49	a	3.00	a	0.38	a	0.48	a	0.74	a
11-22-0-11-0.3	125.53	ab	5.21	abc	0.35	abc	2.28	abcd	0.29	ab	0.32	abc	0.55	abc
2x2 placement														
101-22-0	122.98	abc	5.11	abc	0.32	bcd	2.01	bcde	0.24	bc	0.27	bcd	0.45	bcde
134-22-0	95.26	bcd	4.16	bcd	0.29	bcde	1.71	bcdef	0.20	bcd	0.23	bcd	0.41	bcde
168-22-0	56.78	d	2.59	d	0.16	e	0.93	f	0.12	d	0.13	d	0.24	e
2x4 placement														
134-22-0	75.35	cd	3.41	cd	0.23	cde	1.34	def	0.17	cd	0.18	bcd	0.33	cde
168-22-0	65.12	d	2.85	d	0.19	de	1.15	ef	0.13	cd	0.15	cd	0.27	de
Broadcast														
168-0-0	72.39	d	2.99	d	0.19	de	1.42	cdef	0.17	cd	0.20	bcd	0.30	de

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ ($p>0.05$)

Appendix O. Nutrient uptake (N, P, K, S, Mg, and Ca) for corn starter fertilizer treatments at V7 in Red Rock, OK in 2011.

N-P-K-S-Zn	Plant dry weight		N		P		K		S		Mg		Ca	
kg ha^{-1}			---kg ha^{-1}---											
0-0-0 (Check)	42.38	e[§]	1.68	e	0.14	de	0.58	cd	0.11	ef	0.21	cde	0.31	de
In-Furrow[†]														
11-22-0	102.12	a	4.40	a	0.33	a	1.31	a	0.24	a	0.38	a	0.64	a
22-22-0	60.41	bcde	2.52	bcde	0.18	cde	0.79	bcd	0.14	cdef	0.22	cde	0.36	cde
45-22-0	75.75	abcd	3.29	abcd	0.21	bcd	0.90	bc	0.17	abcde	0.24	bcde	0.41	bcde
11-22-0-0-0.3[‡]	86.65	ab	3.68	ab	0.28	ab	1.04	ab	0.21	ab	0.34	ab	0.56	ab
11-22-0-11	73.87	bcd	3.28	abcd	0.25	abc	0.93	bc	0.20	abcd	0.26	bcde	0.46	bcd
11-22-0-11-0.3	70.37	bcd	3.13	bcd	0.21	bcd	0.78	bcd	0.17	bcde	0.23	bcde	0.39	bcde
2x2 placement														
101-22-0	81.81	abc	3.53	abc	0.26	abc	1.03	ab	0.20	abc	0.32	abc	0.52	abc
134-22-0	74.54	abcd	3.12	bcd	0.23	bcd	0.95	abc	0.19	abcd	0.30	abcd	0.49	abc
168-22-0	50.99	de	2.15	de	0.13	de	0.59	cd	0.12	ef	0.19	de	0.32	de
2x4 placement														
134-22-0	54.22	cde	2.40	cde	0.16	de	0.62	cd	0.13	def	0.21	de	0.35	cde
168-22-0	58.26	cde	2.59	bcde	0.16	de	0.72	bcd	0.15	bcdef	0.20	de	0.36	cde
Broadcast														
168-0-0	37.81	e	1.56	e	0.11	e	0.51	d	0.10	f	0.17	e	0.26	e

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ ($p>0.05$)

Appendix P. Nutrient uptake (N, P, K, S, Mg, and Ca) for corn starter fertilizer treatments at V4 in Covington, OK in 2012.

N-P-K-S-Zn	Plant dry weight		N		P		K		S		Mg		Ca	
kg ha^{-1}			--kg ha^{-1}--											
0-0-0 (Check)	189.44	b§	6.40	c	0.84	cd	2.57	c	0.43	cb	0.87	bc	1.18	b
In-Furrow†														
11-22-0	312.29	a	11.60	a	1.16	abc	4.22	ab	0.66	a	1.35	a	2.13	a
22-22-0	283.36	a	10.86	a	1.11	abcd	3.76	abc	0.60	ab	1.18	ab	1.81	a
45-22-0	193.35	b	7.88	bc	0.75	d	2.64	c	0.40	c	0.74	c	1.16	b
11-22-0-0-0.3‡	262.24	ab	10.11	ab	1.02	abcd	3.44	abc	0.54	abc	1.01	abc	1.62	ab
11-22-0-11	267.35	ab	10.37	ab	1.20	abc	4.18	ab	0.68	a	1.23	ab	1.92	a
11-22-0-11-0.3	243.53	ab	9.58	ab	0.95	bcd	3.50	abc	0.58	abc	0.92	bc	1.66	ab
2x2 placement														
101-22-0	267.89	ab	10.73	ab	1.19	abc	3.70	abc	0.61	ab	1.07	abc	1.75	ab
134-22-0	261.29	ab	10.79	a	1.22	abc	4.03	ab	0.61	ab	1.00	abc	1.70	ab
134-22-36	268.02	ab	11.05	a	1.25	ab	4.51	a	0.66	a	0.99	abc	1.80	a
168-22-0	246.36	ab	10.45	ab	1.20	abc	3.95	ab	0.61	ab	0.88	bc	1.66	ab
2x4 placement														
134-22-0	248.11	ab	10.16	ab	1.08	abcd	3.44	abc	0.58	abc	0.85	bc	1.57	ab
168-22-0	275.96	a	11.27	a	1.35	a	4.33	ab	0.70	a	1.20	ab	1.95	a
Broadcast														
168-0-0	240.44	ab	9.05	abc	0.99	abcd	3.24	bc	0.51	abc	1.01	abc	1.59	ab

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ ($p>0.05$)

Appendix Q. Nutrient uptake (N, P, K, S, Mg, and Ca) for corn starter fertilizer treatments at V4 in Miami, OK in 2012.

N-P-K-S-Zn	Plant dry weight		N		P		K		S		Mg		Ca	
kg ha^{-1}	------------------------------kg ha^{-1}------------------------------													
0-0-0 (Check)	108.31	cb[§]	3.96	cd	0.32	cde	0.96	cd	0.25	cd	0.37	cd	1.02	bc
In-Furrow[†]														
11-22-0	185.95	a	6.73	a	0.55	a	1.57	a	0.45	a	0.61	a	1.79	a
22-22-0	176.12	a	6.47	a	0.49	ab	1.50	ab	0.42	a	0.57	a	1.67	a
45-22-0	87.73	bc	3.44	cd	0.27	def	0.79	d	0.23	cd	0.30	cde	0.96	bc
11-22-0-0-0.3[‡]	184.2	a	6.63	a	0.53	a	1.53	a	0.44	a	0.63	a	1.78	a
11-22-0-11	165.23	a	5.95	ab	0.46	abc	1.53	a	0.42	a	0.52	ab	1.62	a
11-22-0-11-0.3	169.53	a	6.03	ab	0.47	ab	1.32	abc	0.40	ab	0.56	a	1.67	a
2x2 placement														
101-22-0	94.45	bc	3.58	cd	0.28	def	1.14	abcd	0.24	cd	0.27	cdef	0.90	bc
134-22-0	84.9	bc	3.13	cd	0.21	ef	0.92	cd	0.19	cd	0.24	def	0.81	bc
134-22-67	65.66	c	2.44	d	0.15	f	1.02	bcd	0.15	d	0.15	f	0.63	c
168-22-0	75.89	bc	2.76	d	0.18	ef	0.80	d	0.17	d	0.21	ef	0.78	c
2x4 placement														
134-22-0	80.33	bc	3.05	cd	0.22	ef	0.99	cd	0.19	cd	0.22	ef	0.82	bc
168-22-0	77.9	bc	3.03	cd	0.21	ef	0.97	cd	0.19	cd	0.21	ef	0.76	c
Broadcast														
168-0-0	117.73	b	4.57	bc	0.38	bcd	0.98	cd	0.29	bc	0.40	bc	1.18	b

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ ($p>0.05$)

Appendix R. Nutrient concentration (Na, Fe, Zn, Cu, Mn, and B) for corn starter fertilizer treatments at V7 in Covington, OK in 2011.

N-P-K-S-Zn	Na		Fe		Zn		Cu		Mn		B	
kg ha^{-1}			-----------------------				ppm		-----------------------			
In-Furrow†												
11-22-0	100.0	b§	322.4	a	24.3	ab	8.2	bcde	157.2	abc	13.5	ab
22-22-0	112.5	b	317.5	a	25.4	ab	8.9	abc	152.2	bc	14.8	ab
45-22-0	120.0	ab	274.4	a	24.8	ab	9.1	ab	156.9	abc	14.7	ab
11-22-0-0-0.3‡	117.5	ab	294.3	a	27.6	a	8.3	bcde	170.1	abc	13.4	ab
11-22-0-11	115.0	ab	448.6	a	27.2	a	9.1	ab	156.6	abc	14.4	ab
11-22-0-11-0.3	117.5	ab	416.3	a	28.3	a	8.4	bcd	182.3	abc	13.1	b
2x2 placement												
101-22-0	95.0	b	319.1	a	21.3	b	7.3	de	156.7	abc	13.0	b
134-22-0	112.5	b	364.8	a	24.7	ab	7.6	cde	190.5	a	13.7	ab
168-22-0	110.0	b	321.0	a	25.4	ab	6.9	e	185.1	ab	13.7	ab
2x4 placement												
134-22-0	112.5	b	387.8	a	25.2	ab	7.4	de	189.6	a	14.3	ab
168-22-0	110.0	b	346.2	a	26.2	a	7.9	bcde	163.1	abc	13.8	ab
Broadcast												
168-0-0	140.0	a	335.0	a	28.3	a	10.2	a	147.7	c	15.9	a

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ ($p>0.05$)

Appendix S. Nutrient concentration (Na, Fe, Zn, Cu, Mn, and B) for corn starter fertilizer treatments at V7 in Red Rock, OK in 2011.

N-P-K-S-Zn	Na		Fe		Zn		Cu		Mn		B	
kg ha^{-1}			---ppm---									
0-0-0 (Check)	182.5	a[§]	536.5	ab	49.7	a	11.9	a	83.1	ab	17.1	ab
In-Furrow[†]												
11-22-0	147.5	b	364.4	cd	35.3	efg	10.2	bc	73.8	bc	17.4	ab
22-22-0	170.0	ab	438.8	abcd	40.5	bcde	10.3	bc	73.1	bc	15.5	ab
45-22-0	152.5	b	414.4	bcd	36.9	cdefg	10.0	bc	73.1	bc	15.5	b
11-22-0-0-0.3[‡]	160.0	ab	372.8	cd	36.4	defg	10.2	bc	75.5	abc	17.7	ab
11-22-0-11	150.0	b	343.6	d	35.1	fg	10.5	bc	68.3	c	17.2	ab
11-22-0-11-0.3	155.0	b	510.7	abc	33.8	g	9.7	c	72.7	bc	16.1	ab
2x2 placement												
101-22-0	172.5	ab	363.7	cd	39.8	bcdef	10.6	bc	86.0	a	17.9	a
134-22-0	170.0	ab	544.7	ab	42.2	b	10.9	ab	78.5	abc	17.5	ab
168-22-0	167.5	ab	345.1	d	41.8	bc	10.7	bc	82.3	ab	16.2	ab
2x4 placement												
134-22-0	162.5	ab	480.3	abcd	41.9	bc	10.8	abc	82.8	ab	16.1	ab
168-22-0	165.0	ab	515.6	abc	41.5	bcd	10.6	bc	76.6	abc	15.7	ab
Broadcast												
168-0-0	185.0	a	584.7	a	48.5	a	11.9	a	82.0	ab	17.2	ab

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ (p>0.05)

Appendix T. Nutrient concentration (Na, Fe, Zn, Cu, Mn, and B) for corn starter fertilizer treatments at V4 in Covington, OK in 2012.

N-P-K-S-Zn	Na		Fe		Zn		Cu		Mn		B	
kg ha^{-1}			------------------------------ppm------------------------------									
0-0-0 (Check)	177.5	ab[§]	293.8	abc	52.2	a	11.1	b	109.1	ab	16.7	e
In-Furrow[†]												
11-22-0	170.0	abcd	268.0	abc	49.4	abc	11.7	ab	110.2	ab	17.3	cde
22-22-0	165.0	abcd	260.5	bc	49.2	abcd	12.0	ab	106.9	b	16.8	de
45-22-0	157.5	cd	255.3	bc	44.6	cd	12.4	ab	114.3	ab	17.3	cde
11-22-0-0-0.3[‡]	152.5	d	240.2	c	45.3	bcd	11.7	ab	105.6	b	16.7	e
11-22-0-11	172.5	abc	268.9	abc	47.9	abcd	13.0	ab	117.1	ab	18.4	abcde
11-22-0-11-0.3	162.5	bcd	310.6	ab	42.6	d	12.6	ab	130.4	a	19.8	ab
2x2 placement												
101-22-0	177.5	ab	283.7	abc	51.3	ab	11.2	b	109.2	ab	17.7	bcde
134-22-0	170.0	abcd	253.0	bc	45.3	bcd	11.8	ab	112.6	ab	18.7	abcde
134-22-36	182.5	a	317.9	ab	51.0	abc	12.7	ab	125.3	ab	20.0	a
168-22-0	172.5	abc	332.0	a	47.3	abcd	12.3	ab	124.1	ab	19.1	abc
2x4 placement												
134-22-0	170.0	abcd	311.4	ab	46.2	abcd	13.0	ab	124.3	ab	18.9	abcd
168-22-0	177.5	ab	271.2	abc	47.5	abcd	13.4	a	116.0	ab	18.4	abcde
Broadcast												
168-0-0	167.5	abcd	297.0	abc	47.8	abcd	12.8	ab	111.8	ab	18.0	abcde

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ ($p>0.05$)

Appendix U. Nutrient concentration (Na, Fe, Zn, Cu, Mn, and B) for corn starter fertilizer treatments at V4 in Miami, OK in 2012.

N-P-K-S-Zn	Na		Fe		Zn		Cu		Mn		B	
kg ha^{-1}	---ppm---											
0-0-0 (Check)	185.0	abc§	927.0	ab	47.9	b	8.2	bc	75.4	ab	10.0	ab
In-Furrow†												
11-22-0	155.0	c	638.4	b	48.5	ab	8.1	bc	66.6	b	10.1	ab
22-22-0	172.5	bc	734.4	ab	48.3	ab	7.8	c	67.2	b	10.0	ab
45-22-0	167.5	bc	708.6	ab	51.1	ab	8.9	ab	74.1	ab	11.1	ab
11-22-0-0-0.3‡	180.0	bc	713.5	ab	49.5	ab	8.6	abc	66.0	b	9.8	b
11-22-0-11	197.5	abc	652.0	ab	47.0	b	8.1	bc	63.2	b	10.6	ab
11-22-0-11-0.3	155.0	c	828.5	ab	47.1	b	8.2	bc	66.4	b	10.7	ab
2x2 placement												
101-22-0	232.5	a	694.8	ab	53.1	ab	7.7	cd	65.2	b	10.9	ab
134-22-0	177.5	bc	920.3	ab	48.7	ab	7.6	cd	73.0	b	10.4	ab
134-22-67	207.5	ab	759.5	ab	47.1	b	6.7	d	92.6	a	10.5	ab
168-22-0	190.0	abc	953.4	a	52.9	ab	7.7	cd	76.6	ab	11.2	ab
2x4 placement												
134-22-0	182.5	abc	884.0	ab	54.9	a	8.0	bc	79.4	ab	11.5	a
168-22-0	187.5	abc	640.4	b	51.4	ab	7.7	cd	61.8	b	10.6	ab
Broadcast												
168-0-0	177.5	bc	744.0	ab	49.2	ab	9.4	a	61.4	b	10.3	ab

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ ($p>0.05$)

Appendix V. Nutrient uptake (Na, Fe, Zn, Cu, Mn, and B) for corn starter fertilizer treatments at V7 in Covington, OK in 2011.

N-P-K-S-Zn	Na		Fe		Zn		Cu		Mn		B	
kg ha^{-1}			------------------------------mg ha^{-1}------------------------------									
In-Furrow[†]												
11-22-0	13997	abc[§]	44604	bc	3423	abc	1176	ab	21522	abc	1919	ab
22-22-0	11255	bcd	28759	bc	2555	bcde	922	bc	15314	cde	1515	abcde
45-22-0	15281	ab	31719	bc	3078	abcd	1138	ab	19145	abcd	1841	abc
11-22-0-0-0.3[‡]	15539	ab	38645	bc	3679	ab	1123	ab	22749	abc	1804	abc
11-22-0-11	18463	a	76987	a	4481	a	1482	a	25303	a	2260	a
11-22-0-11-0.3	14998	ab	52094	ab	3565	ab	1078	ab	22850	ab	1683	abc
2x2 placement												
101-22-0	11827	bcd	37819	bc	2650	bcde	909	bc	19698	abcd	1612	abcd
134-22-0	10969	bcd	35419	bc	2373	bcde	727	bcd	17669	bcde	1317	bcde
168-22-0	6239	d	18655	c	1461	e	399	d	10553	e	791	e
2x4 placement												
134-22-0	8576	cd	30094	bc	1889	de	567	cd	13994	de	1094	cde
168-22-0	6877	d	20103	c	1653	de	495	cd	10178	e	880	de
Broadcast												
168-0-0	9868	bcd	23486		2003	cde	735	bcd	10873	e	1094	cde

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ (p>0.05)

Appendix W. Nutrient uptake (Na, Fe, Zn, Cu, Mn, and B) for corn starter fertilizer treatments at V7 in Red Rock, OK in 2011.

N-P-K-S-Zn	Na		Fe		Zn		Cu		Mn		B	
kg ha^{-1}	--mg ha^{-1}--											
0-0-0 (Check)	7615	ef[§]	23182	bcd	2115	cd	508	de	3493	ef	722	ef
In-Furrow[†]												
11-22-0	14881	a	36533	ab	3595	a	1038	a	7438	a	1770	a
22-22-0	10397	bcdef	28066	abcd	2382	bcd	619	bcde	4548	cdef	961	cdef
45-22-0	11463	abcde	30355	abcd	2756	abcd	746	bcd	5462	abcde	1133	bcdef
11-22-0-0-0.3[‡]	13302	abc	31984	abc	3169	abc	876	ab	6419	abc	1517	ab
11-22-0-11	11115	abcdef	25466	abcd	2588	abcd	782	abcd	5083	bcdef	1275	abcd
11-22-0-11-0.3	10838	abcdef	36630	ab	2380	bcd	688	bcde	5114	bcde	1154	bcde
2x2 placement												
101-22-0	14063	ab	29953	abcd	3275	ab	873	ab	6935	ab	1464	ab
134-22-0	12871	abcd	38025	a	3152	abc	818	abc	5762	abcd	1318	abc
168-22-0	8564	def	17414	d	2141	cd	538	cde	4153	def	808	def
2x4 placement												
134-22-0	8699	def	25523	abcd	2278	bcd	583	cde	4434	cdef	855	cdef
168-22-0	9495	cdef	27769	abcd	2408	bcd	626	bcde	4509	cdef	963	cdef
Broadcast												
168-0-0	6983	f	22265	cd	1835	d	450	e	3088	f	650	f

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ (p>0.05)

Appendix X. Nutrient uptake (Na, Fe, Zn, Cu, Mn, and B) for corn starter fertilizer treatments at V4 in Covington, OK in 2012.

N-P-K-S-Zn	Na		Fe		Zn		Cu		Mn		B	
kg ha^{-1}	--------------------						mg ha^{-1}	--------------------				
0-0-0 (Check)	33967	bc[§]	57193	ab	10068	bc	2091	c	20112	c	3198	c
In-Furrow[†]												
11-22-0	53460	a	83193	a	15660	a	3602	a	33951	a	5456	a
22-22-0	46316	ab	71580	ab	13841	ab	3314	ab	29667	abc	4713	abc
45-22-0	30960	c	51730	b	8840	c	2344	bc	21321	bc	3381	bc
11-22-0-0-0.3[‡]	40030	abc	63022	ab	11789	abc	3038	abc	27513	abc	4380	abc
11-22-0-11	46179	ab	71015	ab	12802	abc	3454	a	31216	a	4929	ab
11-22-0-11-0.3	39622	abc	76683	ab	10431	bc	3048	abc	31179	a	4802	ab
2x2 placement												
101-22-0	47050	ab	75355	ab	13559	ab	2974	abc	29295	abc	4743	abc
134-22-0	44361	abc	65700	ab	11783	abc	3083	abc	29621	abc	4917	ab
134-22-36	49285	a	84458	a	13801	ab	3400	a	33617	a	5357	a
168-22-0	42632	abc	81253	ab	11686	abc	3017	abc	30370	ab	4682	abc
2x4 placement												
134-22-0	42176	abc	75860	ab	11494	abc	3205	ab	30490	ab	4642	abc
168-22-0	48948	ab	73746	ab	13068	abc	3669	a	31893	a	5065	a
Broadcast												
168-0-0	39522	abc	70955	ab	11456	abc	3038	abc	26084	abc	4247	abc

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ ($p>0.05$)

Appendix Y. Nutrient uptake (Na, Fe, Zn, Cu, Mn, and B) for corn starter fertilizer treatments at V4 in Miami, OK in 2012.

N-P-K-S-Zn	Na		Fe		Zn		Cu		Mn		B	
kg ha^{-1}	-----	-----	-----	-----	-----	mg ha^{-1}	-----	-----	-----	-----	-----	-----
0-0-0 (Check)	19393	cd[§]	105669	abcd	5143	c	885	cd	8395	bcd	1084	bc
In-Furrow[†]												
11-22-0	29519	ab	117828	abc	9197	a	1498	ab	12412	a	1870	a
22-22-0	29898	ab	129323	ab	8404	ab	1360	ab	11902	ab	1756	a
45-22-0	15410	d	62143	de	4674	c	790	cde	6526	d	989	bc
11-22-0-0-0.3[‡]	33582	a	130649	ab	9196	a	1564	a	11980	ab	1820	a
11-22-0-11	31996	a	108397	abcd	7904	ab	1359	ab	10541	abc	1769	a
11-22-0-11-0.3	26413	abc	144722	a	8168	ab	1400	ab	11482	ab	1833	a
2x2 placement												
101-22-0	21919	bcd	67367	cde	5143	c	746	cde	6240	d	1039	bc
134-22-0	15611	d	74879	cde	4198	c	658	de	6066	d	874	bc
134-22-67	13116	d	48064	e	3143	c	446	e	5935	d	686	c
168-22-0	14579	d	80206	bcde	4092	c	586	de	6132	d	832	bc
2x4 placement												
134-22-0	14271	d	71520	cde	4416	c	655	de	6400	d	931	bc
168-22-0	14768	d	46791	e	4100	c	610	de	4763	d	815	bc
Broadcast												
168-0-0	20920	bcd	86964	bcde	5798	bc	1104	bc	7207	cd	1210	b

†N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡The 4th and 5th number represents sulfur and zinc

§Values followed by the same letter within the same column do not differ ($p>0.05$)

Appendix Z. Nutrient sufficiency according to the nutrient concentration for V7 corn starter fertilizer rates at Covington, OK in 2011.

N-P-K-S-Zn	N	P	K	S	Zn
kg ha^{-1}	----------------------------------%----------------------------------				--ppm--
In-Furrow†					
11-22-0	S§	D	D	S	S
22-22-0	S	D	D	S	S
45-22-0	S	D	D	S	S
11-22-0-0-0.3‡	S	D	D	S	S
11-22-0-11	S	S	D	S	S
11-22-0-11-0.3	S	D	D	S	S
2x2 placement					
101-22-0	S	D	D	D	S
135-22-0	S	S	D	S	S
168-22-0	S	D	D	S	S
2x4 placement					
135-22-0	S	S	D	S	S
168-22-0	S	S	D	S	S
Broadcast					
168-0-0	S	D	D	S	S

† N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡ The 4th and 5th number represents Sulfur and Zinc.

§ The letter S represents sufficient and D represents deficient.

Source: The University of Georgia, aesl.ces.uga.edu/publication/plant/cornwhole.htm

Appendix AA. Nutrient sufficiency according to the nutrient concentration for V7 corn starter fertilizer rates at Red Rock, OK in 2011.

N-P-K-S-Zn	N	P	K	S	Zn
kg ha^{-1}	----------------------------------%----------------------------------				--ppm--
0-0-0 (Check)	S[§]	S	D	S	S
In-Furrow[†]					
11-22-0	S	S	D	S	S
22-22-0	S	D	D	S	S
45-22-0	S	D	D	S	S
11-22-0-0-0.3[‡]	S	S	D	S	S
11-22-0-11	S	S	D	S	S
11-22-0-11-0.3	S	S	D	S	S
2x2 placement					
101-22-0	S	S	D	S	S
135-22-0	S	S	D	S	S
168-22-0	S	D	D	S	S
2x4 placement					
135-22-0	S	D	D	S	S
168-22-0	S	D	D	S	S
Broadcast					
168-0-0	S	D	D	S	S

† N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡ The 4th and 5th number represents Sulfur and Zinc.

§ The letter S represents sufficient and D represents deficient.

Source: The University of Georgia, aesl.ces.uga.edu/publication/plant/cornwhole.htm

Appendix BB. Nutrient sufficiency according to the nutrient concentration for V4 corn starter fertilizer rates at Covington, OK in 2012.

N-P-K-S-Zn	N	P	K	S	Zn
kg ha^{-1}	----------------------------------%----------------------------------				--ppm--
0-0-0 (Check)	S[§]	S	D	S	S
In-Furrow[†]					
11-22-0	S	S	D	S	S
22-22-0	S	S	D	S	S
45-22-0	S	S	D	S	S
11-22-0-0-0.3[‡]	S	S	D	S	S
11-22-0-11	S	S	D	S	S
11-22-0-11-0.3	S	S	D	S	S
2x2 placement					
101-22-0	S	S	D	S	S
135-22-0	S	S	D	S	S
135-22-36	S	S	D	S	S
168-22-0	S	S	D	S	S
2x4 placement					
135-22-0	S	S	D	S	S
168-22-0	S	S	D	S	S
Broadcast					
168-0-0	S	S	D	S	S

† N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡ The 4th and 5th number represents Sulfur and Zinc.

§ The letter S represents sufficient and D represents deficient.

Source: The University of Georgia, aesl.ces.uga.edu/publication/plant/cornwhole.htm

Appendix CC. Nutrient sufficiency according to the nutrient concentration for V4 corn starter fertilizer rates at Miami, OK in 2012.

N-P-K-S-Zn	N	P	K	S	Zn
kg ha^{-1}	--------	--------	%	--------	--ppm--
0-0-0 (Check)	S[§]	D	D	S	S
In-Furrow[†]					
11-22-0	S	S	D	S	S
22-22-0	S	D	D	S	S
45-22-0	S	S	D	S	S
11-22-0-0-0.3[‡]	S	D	D	S	S
11-22-0-11	S	D	D	S	S
11-22-0-11-0.3	S	D	D	S	S
2x2 placement					
101-22-0	S	D	D	S	S
135-22-0	S	D	D	S	S
135-22-67	S	D	D	S	S
168-22-0	S	D	D	S	S
2x4 placement					
135-22-0	S	D	D	S	S
168-22-0	S	D	D	S	S
Broadcast					
168-0-0	S	S	D	S	S

† N was balanced to 168 kg ha^{-1} on all in-furrow treatments.

‡ The 4th and 5th number represents Sulfur and Zinc.

§ The letter S represents sufficient and D represents deficient.

Source: The University of Georgia, aesl.ces.uga.edu/publication/plant/cornwhole.htm

Appendix DD. Soil characteristics for soybean sites.

			NO3-N		STP	STK	SO4-S		Ca	Mg	Zn	Fe	B	Cu	OM	Sand	Silt	Clay
Year	Location	pH	0-15†	15-30	0-15	0-15	0-15	15-30	0-15 cm	0-15 cm	0-15	0-15 cm	0-15 cm	0-15 cm	0-15	0-15	0-15	0-15
			---kg ha^{-1}---		---mg kg^{-1}---		----------------kg ha^{-1}----------------				----------------mg kg^{-1}----------------				----------------%----------------			
2011	Miami, OK	7.3	92	72	10	63	16	78	4547	334	2.2	28	0.10	0.50	1.45			
2012	Perkins, OK	6.0	15	18	55	113	37	58	2051	244	1.9	72	0.10	0.50	0.98	76.2	13.8	10.0
2012	Stillwater, OK	6.0	21	85	90	164	18	34	3354	1005	1.4	31	0.40	1.10	0.92	37.5	40.0	22.5

† Soil sampling depth units are in centimeters

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