EVALUATION OF STARTER FERTLIZERS FOR GRAIN SORGHUM (Sorghum bicolor) PRODUCTION IN OKLAHOMA

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Abstract: Starter fertilizer use in grain sorghum production has not been extensively researched. This study was conducted to evaluate starter fertilizers placed in the seed furrow, dribbled over the closed seed furrow, and broadcast after planting. Plant stand and yield was measured from plots planted over two years at nine locations in north central Oklahoma and the panhandle. Pre-plant soil test indicated deficient phosphorus (P) values at all locations. The sites spread across a large are also allowed for a wide range of soil pH; values ranged from slightly acidic to slightly alkaline for grain sorghum production. At only one location, OPREC dryland, was a significant stand impact documented, and this location had the lowest P values in the experiment. Four treatments had a significantly reduced stand, and two of the four treatments contained high rates of salt in furrow. The other two treatments with reduced stand contained no P in furrow. However, no treatment significantly impacted yield for any site year, including the untreated check treatment.

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CHAPTER I

INTRODUCTION

Introduction

Grain sorghum (*Sorghum bicolor*) is an important crop utilized around the world. Many countries depend upon the United States' grain sorghum supply, as the US is the number one producer of the grain in the World. The majority of the grain sorghum produced in the United States is grown in what is known as the Grain Sorghum Belt. This is a region that begins in South Dakota, and stretches to the southern portions of Texas. This region is dominated by a climate where rainfall and temperatures would limit the production of corn (Zia maize) without the use of irrigation. Kansas is consistently the top producer of grain sorghum in the country with just over 1 million hectares planted in 2017, while Oklahoma ranks in the top five producing states with nearly 127,500 hectares being planted in 2017 (Sorghum Check-Off 2018). Most grain sorghum produced in Oklahoma is grown in the panhandle and north central regions of the state (Sorghum Check-Off 2018). Grain sorghum is a drought tolerant crop and produces well in the arid environments of north western Oklahoma and the panhandle where annual rainfall averages from 300-760 mm.

Traditionally, most grain sorghum produced in the United States is exported or used for livestock feed. Poultry, cattle, and hog rations all utilize grain sorghum, which is nearly equal in nutritional value as corn, as well as containing a higher protein content than corn

(Oklahoma 4H, 2012). However, in recent years, utilization of grain sorghum has grown to be for more than just livestock feed in the US. Grain sorghum is naturally gluten-free and human consumption of the grain is increasing. Grain sorghum can be ground and used much like wheat flour. Grain sorghum can also be used to produce ethanol. Grain sorghum can produce an equal amount of ethanol as corn per volume of grain while using up to 33% less water to produce (Sorghum Check-Off 2015).

Commodity prices can influence the amount of acres of a crop produced. In recent years grain sorghum prices have had a premium over corn prices and could create increased interest in sorghum production.

Literature Review

Grain sorghum is a well-suited crop for Oklahoma as it grows well in a wide variety of climates. Grain sorghum is produced across the state from the arid regions of the panhandle to central and eastern portions of the state that receive considerably higher amounts of rainfall.

Planting dates for sorghum can vary. Early planted grain sorghum is planted when the soil temperatures are at least 15.5° C (Carter et al., 1989). There are key advantages and disadvantages of planting at different dates during the planting season. An early planting date allows the plant to bloom and pollinate before the most intense summer heat. However, planting too early inhibits plant growth due to the cool soils, as it slows germination. Late planted sorghum does not allow slow germination due to cool soil temperatures, and should be planted late enough to avoid blooming during the highest summer heat. Yield loss can be expected if the sorghum is blooming and pollinating during intense summer heat.

Soil pH can greatly influence crop productivity. Nutrient availability increases and decreases as soil pH changes. Grain sorghum grows best in soils with a pH of 5.5 to 7.0 (Zhang, 2006). As pH fall below 5.5, mineral toxicities can occur, especially with aluminum (Al) and manganese (Mn). When soil pH is above 5.5, aluminum remains with other nutrients and therefore cannot cause toxicity issues. As the pH drops, aluminum containing compounds dissolve and allows the Al to become available. Slight decreases in pH results in very large amounts of Al to become available. Al can cause root pruning and can slow plant growth and adversely affect crop yield (Zhang, 2006). Toxicities caused by manganese are similar to that of Al, but are usually less severe, due to Mn availability not increasing as great as Al as pH values drop. In acidic soils, pH 5.5 and lower, phosphorus (P) forms bonds with aluminum and manganese, and as a result, Al, Mn, and P become less plant available. In alkaline soils, pH 7.2 and above, phosphorus can be tied with calcium and become unavailable for plant uptake (Zhang, 2006).

Similar to corn, grain sorghum is often planted early in the spring growing season into cooler soils. This can result in delayed or slow emergence and can stress small plants (Alley et al., 2010; Hergert et al., 2012). As the seed germinates and begins to grow roots, the roots have limited access to only the nutrients in close proximity to the seed. Cultural practices such as no-till or minimum tillage practices can cause issues related to those with early planting, as the soil will often be wetter and cooler than conventionally tilled fields due to the shade from residue, and can therefore further reduce seedling vigor (Edwards et al., 2013).

The use of starter fertilizer at planting can provide the necessary nutrients early in the growing season (Touchton, 1986). Fertilizer placed in close proximity to the seed is referred to as a starter or pop-up fertilizer. Applying starter fertilizer in grain sorghum production does not always indicate a higher grain yield (Hergert et al., 2012). Grain sorghum research has shown that the application of starter fertilizers can have more of an impact on plant stand and uniformity rather than consistently resulting in a higher yielding crop (Hergert et al., 2012). A uniform plant stand as a result of using starter fertilizer can be very advantageous.

The use of a starter fertilizer has been shown to reduce the days to mid bloom, which will lead to an earlier plant maturity and harvest. Earlier plant maturity and harvest will allow the decrease of chance of yield loss caused by weather events, bird damage, etc. (Hergert et al., 2012).

Nutrient requirements for grain sorghum is similar to that of corn as well. Nitrogen (N) must be added to the soil for high producing grain sorghum crops (Carter et al, 1989). Soil nitrogen is controlled by organic matter. As nitrogen becomes mineralized from organic matter it becomes available for plant uptake.

Nitrogen can become unavailable or be lost in several ways. When N is absorbed by plants and microorganisms, immobilization occurs and limits the amount of N readily available for plant uptake. Nitrate (NO3-), a form of N readily available for plant uptake is negatively charged and prone to leaching. Rainfall and irrigation can both leach nitrate out of the crop root zone (Zhang, 2006).

Phosphorus is needed in large amounts for grain sorghum production. Phosphorus is considered an immobile nutrient therefore not generally prone to leaching. Most phosphorus in the soil is in forms unavailable for plant uptake. Factors that influence plant availability of soil P are soil pH, organic matter, temperature and soil moisture. In acidic soils, P can be tied up with iron (Fe), aluminum, and manganese. As soil pH increases above 7.2, P can be chemically bound with calcium and be left unavailable for plant uptake (Zhang, 2006). Previously it was mentioned that cool soil temperatures and wet soils impact P availability, however the plants ability to reach available P can also be limited in dry soil conditions (Diaz et al., 2011).

Phosphorus fertilizers are produced as orthophosphate, polyphosphate, or a combination of both forms. Before manufacturing phosphorus fertilizers, ground rock phosphate was the primary fertilizer for correcting P deficiencies. Rock phosphate is used very little around the world today as a primary fertilizer but is utilized for manufacturing P containing fertilizers (Rehm et al., 2002). Phosphoric acid, a key component of P containing fertilizer, is derived by either a wet or dry process. Most fertilizers are produced utilizing a wet process. Phosphoric acid produced in the dry process is a more pure product, however, costs more to produce, and is usually reserved for the food industry (Rehm et al., 2002). In the wet process, acid and water is introduced to finely ground rock phosphate. Orthophosphoric acid is produced in the reaction. As water is evaporated from the acid, the concentration of P205 is increased. The orthophosphoric acid can be blended with other nutrient containing fertilizers. If the acid is heated further, water will continue to evaporate and the molecules will begin to link together and form polyphorsphoric acid (Jensen, 2008).

Plant uptake is predominately in the orthophosphate form (Lohry, 2001). When P containing fertilizer is introduced into the soil, polyphosphates begin converting into the orthophosphate form. This transition into the orthophosphate form is controlled by factors such as soil moisture, temperature, and soil pH. This typically occurs within two to three days following application given proper conditions (Bly, 2003; Rehm et al., 2002). University research conducted by Kansas State University has shown that there is no difference in grain yield when using orthophosphates compared to fertilizers containing phosphates in the poly form (Kissel et al., 1988). Fertilizers containing polyphosphates usually contain higher concentrations of phosphorus, which makes these sources preferred for large scale agricultural uses. Higher concentrations equate to lower use rates and can make for easier handling.

Most soils in Oklahoma, especially western Oklahoma, have adequate levels of potassium (K). Potassium is relatively immobile in the soil so leaching is usually not a concern.

Exceptions occur in sandy soils, areas that receive high amounts of rainfall, and sandy soils that are irrigated. Much like P, K exists in the soil in forms not readily available for plant uptake. Plant available potassium exists as exchangeable K on the soil particles and solution K which is suspended in the soil solutions. In a typical soil, nearly 90% of the plant available K is in the exchangeable portion. Potassium, due to its positive charge ion K^+, can become fixed to the negatively charged clay particles found in the soil profile, and therefore, unavailable for plant uptake (Zhang, 2006).

Secondary and micronutrients have been used minimally in grain sorghum production. However, sulfur (S) deficiencies are becoming more common across the United States (Camberato, 2017). This is in part due to the more strict environmental regulations that have reduced the amount of sulfur being deposited from the atmosphere with rain and snowfall. Much like nitrogen, sulfur is mineralized from soil organic matter. Unless a soil has very low levels of organic matter, much of the crops sulfur needs can be met as the sulfur mineralizes. However, crops could experience temporary sulfur deficiencies if the organic matter isn't mineralizing at a fast enough rate. The process slows during cool temperatures and has the greatest chance of effecting early planted crops such as corn and grain sorghum which are commonly planted into cool soils (Zhang, 2006). Larger amounts of sulfur are also being removed as the average grain and forage yields continue to increase in many crops (Camberato, 2017). Sulfate (SO42-), the sulfur form readily used by plants, is negatively charged and is prone to leaching and can cause plant deficiencies (Zhang, 2006).

Zinc (Zn) deficiencies in grain sorghum are not commonly documented in Oklahoma. Corn is much more susceptible to Zn deficiencies and can be seen when soil test values fall below 0.8 ppm (Zhang, 2016). Wheat is one of the least likely crops to show symptoms of zinc deficiencies and can tolerate soil values down to 0.15 ppm. Critical values for grain sorghum will be closer to corn than wheat. Normally grain sorghum will have a more fibrous root system than corn. Since Zn is immobile in the soil the more fibrous root system can allow to the sorghum plant to uptake Zn more efficiently (Zhang, 2006; Hopkins et al., 1998). When grain sorghum is planted early into cool soils, organic matter mineralization is slower and could result in zinc deficiencies (Hopkins et al., 1998). Iron deficiencies are rare in Oklahoma crop production but can be seen in sorghum production. Most incidents occur in the western areas of the state where soils pH is generally near neutral to alkaline. As soil pH increases, iron becomes unavailable for plant uptake. Soil applied fertilizers should be limited to chelated products. If the iron is not chelated it will rapidly convert to an unavailable form. However, the price of chelated iron could make the application price-prohibited (Zhang, 2006).

There is an inherent risk with the application of fertilizer with the seed. Salt index (SI) should be carefully considered before using any starter fertilizer in direct contact with the seed. SI is the measure of the salt concentration of a fertilizer (Mortvedt, 2001). As higher amounts of soluble salt enters the soil solution the osmotic pressure increases. The increase in osmotic pressure in close proximity to the seed caused by salt in the starter fertilizer solution can adversely affect germination (Rader et al., 1943). Little research has been done looking at the maximum rate of salt in furrow for grain sorghum. In corn production salt index ($N+K_20$) should not exceed 7.85 kg ha^{-1} when applied in close proximity to seed (Raun et al, 1986). The same recommendation should be considered for grain sorghum. High rates of salt in direct contact with the seed can cause delayed emergence, and in some cases, seedling death. Broadcasting rather than banding fertilizer reduces nearly all concerns for germination problems caused by a change in osmotic pressure (Rader et al., 1943). Consideration should also be given to the form of N in the fertilizer because of the risk of ammonia toxicity (Diaz, 2012).

Objective

The objective of this research project is to evaluate the impact of rate of source of starter fertilizers on grain sorghum plant stand and grain yield.

CHAPTER II

MATERIALS AND METHODS

Materials and Methods

Locations for the study utilized Oklahoma State University research facilities as well as producer's fields. In both years, 2014 and 2015, an irrigated trial was planted at the Oklahoma Panhandle Research and Extension Center (OPREC), {lat 36.353201°, long 101.362231°}. A dryland plot was also planted at OPREC in 2015 {lat 36.352381°, long 101.355408°}, Billings {lat 36.3226°, long 97.313646°}, Enid {lat 36.27126°, long 97.515908°}, and Red Rock {lat 36.303172°, long 97.94018°}. Research plots were spread out approximately 426 km, from the panhandle to north central Oklahoma, and utilized various tillage practices. The distance provided a wide range of soil pH, growing conditions, and soil types. The irrigated OPREC plots were planted into a Gruver Clay Loam (very deep, well drained, moderately slowly permeable soils that formed in calcareous eolian sediments of Pleistocene age). OPREC dryland is located on a Sherman Clay Loam (very deep, well drained, slowly permeable soils that formed in loamy and clayey eolian sediments of Pleistocene age). Both Red Rock and Billings locations were on a Kirkland Silt Loam (very deep, well drained soils that formed in material weathered from clayey sediments over shale of Permian age). The Enid site was a Waynoka Loam (very deep, moderately well drained, slowly permeable soils that formed in old alluvium that is over soils formed from clayey Permian red beds).

Grain sorghum hybrids used in the study were selected based upon information obtained from the regional hybrid performance trials conducted by Oklahoma State University to obtain optimum yield at each location. Composite soil samples were collected to a depth of 0-15cm prior to planting and analyzed by the Oklahoma State Universities Soil, Water, and Forage Analytical Laboratory. See soil analysis results in Table 1. Nitrogen was applied either pre plant or during the growing season. Nitrogen rates were based on pre-plant soil test results and expected yields to maximize yield. The OPREC irrigated plots were strip tilled both site years. Both N and P were applied via strip till prior to planting the research plot in the 2014 growing season at a rate of 22.68 kg ha^{-1} P with ammonium polyphosphate (10-34-0) as the source and 90.5 kg N ha^{-1} utilizing liquid urea ammonium nitrate (32-0-0). In 2014 the application of APP was unintended, therefore only nitrogen was applied via strip till before planting in the 2015 growing season.

All locations were planted with a John Deere Max Emerge two row planter on 75 cm row spacing's. While two separate John Deere Max Emerge planters were used to plant the trials, both were equipped with a CO2 driven starter fertilizer system. The only difference between the planters used was the seed firmer, in which delivers the fertilizer into the seed furrow. One planter was equipped with a Schaffert brand seed firmer and the other planter, which was used exclusively for the OPREC locations, was equipped with a Keaton brand seed firmer. Both seed firmers functioned in the same way, delivering liquid fertilizer solution around the seed in the furrow. After planting each treatment, the liquid starter fertilizer system was blown out with compressed air before being recharged with the next fertilizer solution. Proper liquid flow was confirmed before and after each treatment was applied as a quality control measure. The dry fertilizer treatment was broadcast by hand after planting the plot.

Research plots were planted in a randomized complete block design (RCBD). The irrigated and dry land plots planted at OPREC had four replications, while the plots planted in the central regions of the state had three replications. Plots consisted of 4 rows with 75 cm row spacing by 6 meters in length. The OPREC dryland plot was extended to 9 meters in length to compensate for lower expected yield. A 6 meter alley separated each replication. Stand counts were taken after emergence in each plot. For yield data, a Massey Ferguson 8XP plot combine was used to harvest the middle two rows of each plot. The combine was equipped with a Harvest Master yield monitor to collect and determine plot yield and moisture content. Statistics were calculated using a mixed model analysis utilizing SAS 9.3 Proc Glimmix. Statistical differences were determined using an alpha=0.05.

The experiment consisted of 14 treatments including an untreated check (Table 2). The check was used the baseline to evaluate each treatment against and had the same amount of base nitrogen applied as the rest of the treatments, but did not receive a starter fertilizer. Treatments were chosen based on current Oklahoma State University recommendations or based upon the requests/interest of Oklahoma grain sorghum producers.

In this study, the starter fertilizer was placed either in the seed furrow or dribbled over the closed seed furrow. Treatment 1 was a fully fertilized check but did not include a starter fertilizer, and was used to check for a response of starter fertilizer. Ammonium polyphosphate, APP (10-34-0), is a commonly used liquid starter fertilizer for many crops. APP was evaluated in increasing amounts for treatments 2 (APP 2.5), 3 (APP 5), 4 (APP 10), and 5 (APP20). The amount of P applied in furrow was 4.84, 9.69, 19.38, and 38.75 kg ha^{-1} respectively. Treatment 3, APP5, is the tradition recommend for sorghum produced on 76cm row spacing while treatment 5 was include in hopes to show negative impacts of utilizing a high volume of a high salt containing fertilizer. Treatments 6-9 were included to evaluate the addition of nutrients APP that extension commonly receives questions about. Both Fe and Zn could be valuable in high pH soils, S is becoming deficient in Kansas and is expected to be deficient in sandy soil in

Oklahoma, and the addition of K have been thought to improve the standablity of sorghum. Treatment 6 evaluated Ultra-Fe (Agri-Solutions- Winfield Solutions, St. Paul, MN) in furrow at 0.63 kg ha^{-1} Fe. Treatment 7 (APP 2.5+S) evaluated APP plus Thio-Sul (Terrsenderlo-Kerley-Phoenix, AZ) in furrow at 4.75 kg ha^{-1} N, 4.84 kg ha^{-1} P, 3.2 g ha^{-1} S. Treatment 8 (APP 2.5+K) evaluated APP plus K-Leaf (ENC-Helena-Collierville, TN) in furrow at 3.25 kg ha^{-1} N, 4.84 kg ha^{-1} P, and 3.7 kg ha^{-1} K. Treatment 9 (APP 2.5+Zn) evaluated APP plus Micro Bolt Zn (Nachurs-Marion, OH) in furrow at 3.25 kg ha^{-1} N, 4.84 kg ha^{-1} P, and 2.5 kg ha^{-1} Zn. Treatment 10 evaluated dry broadcast DAP in central Oklahoma plots and MAP in the panhandle plots. This treatment is essential as not all producers have planting equipment capable of applying starter. Therefore this treatment would help determine if the added expense is necessary. Both products were broadcast at a rate of 10.91 kg ha^{-1} P. Treatment 11 evaluated 9-18-9-1 (Nachurs-Marion, OH), a low salt, 100% orthophosphate blend in furrow at 2.78 kg ha^{-1}N, 2.42 kg ha^{-1} P, 2.78 kg ha^{-1} K, and 0.309 kg ha^{-1} Zn. This is the only treatment to contain 100% orthophosphate. Treatment 12 evaluated 9-24-3-1, Pro-Germ (Agro-Culture-St. Johns, MI) in furrow at 2.8 kg ha^{-1}N, 3.26 kg ha^{-1} P, 0.932 kg ha^{-1} K, 0.311 kg ha^{-1} Fe. Pro-Germ is marketed as a low salt, balanced fertilizer. Some producers choose simply run a tube that puts fertilizer over the closed seed furrow. This choice reduces the amount of equipment, and cost, on each planter unit. Treatment 13 (APP 5 dribble) evaluated APP dribbled over the closed seed furrow at 6.5 kg ha^{-1} N, and 9.69 kg ha^{-1} P. Treatment 14 (APP 2.5+Accomplish) evaluated APP plus Accomplish (Loveland-Greeley, CO) in furrow at 6.5 kg ha^{-1} N, and 4.84 kg ha^{-1} P. Accomplish is a fertilizer catalyst and contains microorganisms <1*% Bacillus Licheniformis, Bacillus Megatrerium*, and *Bacillus Pumilus*.

CHAPTER III

RESULTS

LOCATIONS

Nine locations were planted over two growing seasons with six site years surviving until maturity and being harvested. The OPREC dryland plot was not harvested in 2014 because of stand loss caused by herbicide injury. Plots planted at Marland and Ponca City were not harvested in 2015 due to drought and excessive weed pressure. The treatment structure was designed to preform multiple comparisons (Table 2). All fertilizer sources are evaluated against the fertilized check. If a treatment is not significantly greater than the check it would suggest there is no response. Other comparisons of interest at each location was the evaluation of APP rate in treatments 2, 3, 4 and 5; the addition of S, K, and Zn to APP in treatment 2 versus 7, 8, and 9; the evaluation of starter source in treatments 2 vs 11 and 12 at equivalent rates of P; in-furrow against surface dribble with treatments 3 and 13; in-furrow compared to surface broadcast with treatments 3 and 10; and the addition of a microbial to APP, treatment 2 vs 14. Table 4 and 5 show treatment averages for stand and grain yield at each location, respectively. Figures 2 and 3 visually demonstrate the stand and yield response to the treatment relative to the un-treated check.

Billings

Soil test indicated pH was slightly acidic for below the critical threshold for grain sorghum production at 5.3. Phosphorus and potassium levels were both more than 80% sufficient and zinc and iron levels were sufficient (Table 1). ANOVA analysis and LSD t-test did not find any significant impact on stand. Treatment averages can be seen in Table 4. Average grain yield was 2897.7 kg ha^{-1} with a range of 1526.1 kg ha^{-1}. ANOVA analysis did not find any significant impact on yield either. However, LSD t-test did show several significant yield differences Table 5. The check yielded significantly higher than APP 2.5, Ultra-Fe, Pro-Germ, and APP 2.5+Accomplish, indicating that while no treatment increased yield, some did significantly decrease yield. Figure 2 shows the average treatment grain yield for the Billings location.

Enid

Field conditions at the time of planting were poor. The soil held little moisture and was very compacted. Soil test results indicated soil pH slightly higher than optimum range, P values under 80% sufficient, and K values near 95% sufficient (Table 1). ANOVA analysis did not show any statistical treatment impact on stand, Table 4. LSD t-test, Table 4 documented significant stand impacts with broadcasting DAP significantly better than APP 20 and APP 2.5+S. The yield range was 3328.9 kg ha^{-1} with an average yield of 3257.5 kg ha^{-1}. ANOVA analysis did not document any statistical treatment impact on yield. When looking at LSD t-test for grain yield (Table 5), DAP broadcast out yielded APP 2.5+S, APP 2.5+K, and APP 2.5+Zn. Also, Ultra-Fe and APP 2.5 yielded significantly higher than APP 2.5+S and APP 2.5+K; the addition of S and K in treatments 7 and 8 showed a negative response compared to treatment APP 2.5 with the same amount of P. Figure 3 shows the average treatment grain yield for the Enid location.

Red Rock

Soil test values indicate soil pH is in the optimal range for grain sorghum, P values 60 % sufficient, and K values near 80% sufficient (Table 1). ANOVA analysis did not document significant treatment impact on stand. Several significant stand differences were found with LSD t-test, Table 4. When looking at impact on stand, APP 2.5, APP 5, APP 2.5+S, and APP 2.5+Zn had a statistically better stand than APP 20 and Ultra-Fe, indicating the high rate of APP in treatment APP 20 hurt stand compared to the lower rates in APP 2.5 and APP 5. Plot yield average for Red Rock was 2897.1 kg ha^{-1} and yield range was 3674.4 kg ha^{-1}. ANOVA analysis did not document any statistical treatment impact on yield, but LSD t-test did document one difference, Table 5. The broadcast DAP treatment also yielded significantly higher than treatment APP 20. Figure 4 shows the average treatment grain yield for the Red Rock location.

OPREC Irrigated

During the 2014 growing season the plot was under the north lateral irrigation system at OPREC. Because of crop rotations the plot was moved to the south lateral irrigation system for the 2015 crop season. Soil pH both site years was at an optimal level or slightly above. Both years had P values over 60% sufficient. There was a drastic change in K levels between the two site years. The 2014 plot had very high K values while the 2015 plot had K values slightly above 80% sufficient (Table 1). As previously mentioned the 2014 trial was strip–tilled prior to planting with 22.68 kg ha^{-1} P and 90.5 kg ha^{-1} N being applied with a blend of APP and 32-0-0. No significant stand differences were found in ANOVA analysis for either site year. LSD t-test did find significant impacts between treatments on stand in 2014 but no differences in 2015, Table 4. Stand for APP 2.5 was significantly better than APP 10, Ultra-Fe, APP 2.5+K, Pro-Germ, and APP 2.5+Accomplish; this documents the higher rate of APP in APP 10 impacted stand compared to the lower rate in APP 2.5.When looking at source, APP 2.5 had a significantly higher stand count than Pro-Germ. Also, APP 2.5 had a significantly better stand than the same rate of P with APP+Accomplish. The 2014 growing season produced an average grain yield of 9205.4 kg ha^{-1} while the 2015 produced slightly less with an average yield of 7791.6 kg ha^{-1}. Yield ranges for 2014 and 2015 were 643.4 kg ha^{-1} and 2238.3 kg ha^{-1} respectively. ANOVA analysis did not document any statistical treatment impact on yield. LSD t-test documented several significant yield differences in 2014, Table 5. MAP broadcast yielded significantly higher than the check, APP 5, APP 10, APP 2.5+Zn, 9-18-9, Pro-Germ, APP 5 dribble, and APP 2.5+Accomplish; MAP broadcast after planting increased yield compared to an equal amount of P in furrow with APP 5. APP 2.5+K also yielded significantly higher than the untreated check, APP 20, and APP 2.5+Zn. The addition of K in treatment 8 showed a positive response compared to the check even with sufficient soil test values of K. No statistical difference was detected for yield in 2015. Figures 5 and 6 shows the average treatment grain yields for the OPREC irrigated locations in 2014 and 2015 respectively.

OPREC Dryland

Pre plant soil test results showed a slightly alkaline pH. This location had the lowest P values of any site at slightly under 60% sufficient. K values were sufficient at this location (Table 1). ANOVA analysis indicated significant treatment impact on stand. APP 10, APP 20, Ultra-Fe, and APP 5 dribble all had significantly reduced stands Table 4. Reduced stands for treatments APP 10 and APP 20 would suggest the high rates of APP affected emergence. Ultra-Fe was the only starter treatment that did not contain P. Although APP 5 dribble had a P starter fertilizer, it was dribbled on the soil surface and documented a stand reduction in the low P soil. Average grain yield was 6581 kg ha^{-1}and range of 2419 kg ha^{-1}. ANOVA analysis did not find any significant treatment impact on yield, but LSD t-test did find significant treatment differences Table 5. APP 10 yielded significantly higher than APP 20, APP 5 dribble, and Pro-Germ, documenting the lower rate of APP was more effective than the high rate in APP 20. Also, APP

5, Ultra-Fe, MAP broadcast, and 9-18-9 yielded significantly higher than Pro-Germ and APP 20; the lower rate of APP in APP 5 yielded higher than APP 20 even in low P soils. The source comparison documents 9-18-9 yielding significantly higher than Pro-Germ. Figure 7 shows the average treatment grain yield for the OPREC dryland 2015 location.

Discussion

Consistently the use of starter fertilizers resulted in stand counts which were numerically lower than the un-treated check (Figure 8). ANOVA analysis only found significant treatment impact on stand for one site year, OPREC dryland. The dry soils and high rate of salt in APP 10 and APP 20 was damaging to germination. LSD t-test documented numerous stand differences. Plant stand was significantly reduced in Enid, Red Rock, and OPREC irrigated 2014 with high rates of APP in either APP 10 or APP 20. While the addition of S, K, and Zn to APP did not improve stand compared an equal of P in APP 2.5, at only one location was the addition of K damaging to plant stand. Potassium containing fertilizers generally have higher salt index than Zn containing fertilizers so a response to APP+ S and APP+K would be expected.

Treatments containing high amounts of salt in furrow did not consistently have reduced stand or yield like expected. In some locations the high rate of APP in APP 20 had a positive impact while reducing stand or yield in other locations. Timely rain fall events shortly after planting most likely dispersed salt concentrations in the seed furrow and reduced negative impact. A significant reduction in stand did not always indicate a reduction in grain yield because of the ability of grain sorghum to tiller. Tillering will often occurs when resources such as water, nutrients and light are in excess of what thin and poor stands can utilize. This ability to compensate allows crops like grain sorghum to reach near maximum potential even when stands are heterogeneous.

A stand response to source was seen in the OPREC irrigated 2014 trail. APP 2.5 had a significantly better stand than the treatment with Pro-Germ. A negative stand response was also seen at this location when adding a microbial in-furrow with APP+ Accomplish compared to an equal amount of P in-furrow with APP 2.5.

ANOVA analysis found no significant treatment impacts on yield, but LSD t-test found treatment differences. The Billings location had the highest P values of any site year, and APP 2.5, Ultra Fe, Pro-Germ, and APP+Accomplish all yielded significantly lower than the check. A reduced yield caused by high salt rate was only seen in the OPREC dryland trial with APP 10 yielding significantly higher than APP 20. LSD t-test also documented reduced yield when comparing APP 2.5 to APP 2.5+ S and APP 2.5+K at the Enid location.

Previous research has shown that because the conversion of polyphosphate to orthophosphate occurs within two to three days no difference in grain yield is seen (Diaz, 2012). Grain yields from this experiment were consistent with that research, in no site year did the treatments with high ortho-P concentrations out yield the poly-P sources.

Specialty starters and balanced starter blends did not consistently produce higher yields than APP. The addition of a microbial in-furrow never yielded significantly higher than the check and does not seem conducive to increasing grain yield in grain sorghum. It also does not seem cost effective to set up a planter with a liquid starter fertilizer system for grain sorghum if it does not already have one. Broadcasting dry fertilizer after planting showed to be just as effective and even out yielded in furrow fertilizer in several locations. These results indicate that the additional cost of adding a starter system may not improve the yields enough to offset these cost. While the price per kg of P for the dry products, such as DAP, is typically lower than liquid sources such as APP, there is an added application cost of approximately \$12.35 ha^{-1} (Sahs 2018) if dry fertilizer was not already in the production plan. This means the cost of P in APP can be as much as $0.55 kg^{-1} P_2O_5 higher than that of DAP and still be equal in total cost.

Knowing pH and soil nutrient values would allow a producer to make a well-educated hypothesis on whether a stand or yield increase would be expected when using a starter fertilizer. The size of the research plots allowed for a near homogenous soil. On a large field pH and nutrient levels would be expected to vary. Arnall et al (2017) compiled soil test results from fields grid sampled across Oklahoma and Kansas. This project documented that the average soil pH of fields across north western Oklahoma and through the panhandle to be 6.0 yet the average range of pH within each field was 2.0 units. This compilation also shows an average field Mechlich 3 and Bray 1 P value of 28ppm with a range of 53 while the average field K value was 185ppm with a range of 192ppm. Therefore a field with a composite soil sample pH of 6.0 and Mechlich 3 P of 33ppm there is a high probability that 33% of the field will respond to a starter with P due to low pH and 50% of the field will respond due to low P. This field variance shows the importance of either documenting or managing the variability, or adopting a strategy that can effectively account for it.

Oklahoma State University has traditionally recommended 47 L ha^{-1} of APP as a starter fertilizer. In this study the APP 10 treatment yielded equal to or greater than the check (Figure 9). Oklahoma State University also recommends that soil test be taken prior to planting to determine if soil pH is within the crops optimum range and if nutrients are needed to reach maximum yield potential. Results from this experiment indicate that response to starter fertilizer was influenced by soil pH and nutrient levels. While a response to the starter commonly associated to the soil pH or P levels, this project showed that getting fertilizer on the field is as important as placement.

References

Alley, Mark, S. Reiter, W. Thomason, M. Reiter. 2010. Pop-up and/or starter fertilizers for corn. Dept of crop and soil environmental sciences, Virginia Tech. 3002-1438.

Arnall, D. B., J. Abit, E. B. Rutter and P. Alderman 2017. Summary of Grid Soil Sample Results from the Southern Great Plains. In Agronomy Abstracts. ASA, Madison, WI

Edwards, J., R. Boman, J. Bushong, R. Kochenower, S. Osborne. 2013. No-Till Crops. In: J. Malone, editor, No-Till Cropping Systems in Oklahoma. Oklahoma State University, Stillwater, Ok. P. 59-70.

Bly, A., J. Gerwing, R. Gelderman. 2003. Poly and ortho phosphate starter fertilizer influence on early corn plant growth and grain yield at Brookings SD in 2003. South Dakota State University. Soil RP 03-32.

Camberato, Jim, S. Casteel. 2017. Sulfur deficiency. Purdue University Department of Agronomy. July 2017.

Carter, P.R., D.R. Hicks, E.S. Oplinger, J.D. Doll, L.G. Bundy, R.T. Schuler, B.J. Holmes. 1989. Grain Sorghum (Milo). Alternative Field Crops Manual. University of Wisconsin. Madison, WI.

Diaz, Dorivar R., D. Mengel. 2012. Starter Fertilizer rates and placement for corn. Kansas State University. Feb. 2012.

Diaz, Dorivar R., K.L. Martin, D.B. Mengel. 2011. Diagnosing nutrient deficiencies in the field. Kansas State University. August 2011.

Hergert, W.G., C. Wortmann, R.B. Ferguson, C.A. Shapiro, T.M. Shaver. 2012. Using Starter Fertilizers for Corn, Grain Sorghum, and Soybeans. University of Nebraska-Lincoln. doi: G361

Hopkins, B.G, D.A.Whitney, R.E. Lamond, V.D. Jolley. 1998. Phytosiderophore release by sorghum, wheat, and corn under zinc deficiency. Journal PN. 21(12). 1998. 2636-2637.

Jensen, Thomas. 2008. Is promotion of orthophosphates as more plant available compared to polyphosphates justified. Plant Nutrition Today. No. 2.

Kissel, D., R. Lamond, L. Murphy. 1988. Phosphorus Facts. Soil, plant and fertilizer. Kansas State University. October 1988.

Lohry, R. Ortho vs. poly. 2001. Fluid J. 35:17-1

Mortvedt, John J. Calculating Salt Index. 2001. Fluid J. 9(2):8-11.

Oklahoma 4H. Sorghum Facts. 2012. Oklahoma State University. September 5, 2012 http://oklahoma4h.okstate.edu/aitc/lessons/extras/facts/milo.html

Rader, L.F., M. White, C.W. Whittaker. 1943. The salt index-a measure of the effect of fertilizers on the concentration of the soil solution. Soil Sci 55. No. 4. 1943. 201-218.

Raun, W.R., D.H. Sander, R.A. Olson. 1986. Emergence of corn as affected by source and rate of solution fertilizers applied with the seed. Journal of Fertilizer Issues 3.1. 1986: 18-24. NUE.OKSTATE.EDU. Web.

Rehm, G., M. Schmitt, J. Lamb, G. Randall, L. Busman. 2002. Understanding phosphorus fertilizers. University of Minnesota.

Sahs, R. 2018. Oklahoma Ranch and Farm Custom Rates 2017-2018.CR-205. http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-6752/CR-205%202017-2018web.pdf

Sorghum Check-Off. 2018. Accessed April 28 2018. All about sorghum. http://www.sorghumcheckoff.com/ all-about-sorghum.

Sorghum Check-Off. 2018. Accessed March 8 2015. Sorghum 101. http://sorhgumcheckoff.com/about-sorghum-checkoff/sorghum-101/.

Touchton, J.T., D.H. Rickerl. 1986. Soybean growth and yield response to starter fertilizer. Soil Sci. Soc. Sm. J. 50:234-237.

Zhang, K., B. Raun. 2006. Oklahoma Soil Fertility Handbook. Sixth Edition. Oklahoma State

University Plant and Soil Scienes. Print. p. 12-36.

Tables

Table 1. Composite soil samples (0-15 cm) collected prior to planting from all locations utilized for the grain sorghum response to starter fertilizer study. Soil samples analyzed by the Oklahoma State University Soil, Water, and Forage Analytical Laboratory.

Year	Site	pH	BI	NO_3	Mehlich 3 P	K	S	Ca	Mg	Fe	Zn	B	Cu
				----------------------------------ppm---									
2014	Billings	5.3	6.6	5	29	193	7	4,844	122	53	0.72	0.31	1.19
	Enid	7.8		9	16	192	na	2,870	655	24	0.30	0.50	1.10
	Red Rock	5.8	6.7	6	10	139	7	958	187	54	0.73	0.38	1.15
	OPREC Irrigated	7.3		35	12	527	na	Na	Na	na	na	na	na
2015	OPREC Irrigated	7		16	11	182	7	3,500	156	9	3.56	0.67	0.39
	OPREC Dryland	7.8		3	9	419	na	na	Na	na	na	na	na

Table 2. Grain sorghum response to starter fertilizer trial treatment structure. Each treatment includes the rate of each fertilizer product applied and resulting amount of each nutrient applied.

		Rate		Rate	Total amount applied in-furrow (kg ha^{-1})					
TRT	Product	L ha^{-1} *kg ha^{-1}	Additive	L ha^{-1}	N	P	K	S	Fe	Zn
1	Check				0		0	0	0	0
2	10-34-0[!]	23			3.25	4.8	0	0	0	0
3	10-34-0	47			6.5	9.7	0	0	0	0
4	10-34-0	94			13	19.4	0	0	0	0
5	10-34-0	187			26	38.8	0	0	0	0
6	Ultra-Fe[$]	23			0.63	0	0	0	14.2	0
7	10-34-0	23	Thio-Sul[@]	9.4	4.75	4.8	0	3.2	0	0
8	10-34-0	23	K-Leaf[#]	9.4	3.25	4.8	3.1	0	0	0
9	10-34-0	23	MicroBolt Zn[%]	23.4	3.25	4.8	0	0	0	2.5
10	18-46-0	*56			10	10.9	0	0	0	0
11	9-18-9-1[%]	23			2.78	2.4	2.3	0.31	0	0
12	9-24-3-1[^]	23			2.8	3.3	0.8	0	0.31	0
13	APP Dribble	47			6.5	9.7	0	0	0	0
14	10-34-0	23	Accomplish[$$]	4.7	3.25	4.8	0	0	0	0

*kg ha^{-1}

! Ammonium polyphosphate (APP), 10-34-0

$Agri-Solutions-Winfield Solutions (St. Paul, MN)

%Nachurs (Marion, OH)

^Agro-Culture (St. Johns, MI) Pro-Germ

@Terrsenderlo-Kerley (Phoenix, AZ)

#ENC-Helena (Collierville, TN)

$$Loveland (Greeley, CO) microorganisms <1%: Bacillus Licheniformis, Bacillus Megatrerium, and Bacillus Pumilus

Table 3. Treatment structure so that multiple comparisons could be made. This table lists the treatments to be evaluated and the reasoning for the analysis.

Treatments evaluated	Reasoning
1 v 2,3,4,5,6,7,8,9,10,11,12,13,14	Response to check
2 v 3 v 4 v 5	Response to rate
2 v 7,8,9	Response to S, K, and Zn + APP
2 v 11,12	Compare source
3 v 13	Compare in-furrow v dribble
3 v 10	Compare in-furrow v broadcast
2 v 14	Compare microbial + APP

Table 4. Grain sorghum average plant stand counts (plants per m2) for each location by treatment. Within each location, treatments with the same letters were not significantly different, Tukeys LSD Alpha = 0.05.

Treatment	Location					
	Billings	Enid	Red Rock	OPREC irrigated 2014	OPREC irrigated 2015	OPREC dryland 2015
(1) Check	8.29	4.74 ab	11.27 ab	15.53 abc	6.27	7.50 a
(2) APP 2.5	7.79	4.45 ab	12.38 a	15.93 a	6.46	7.32 ab
(3) APP 5	9.47	3.44 ab	13.02 a	15.31 abc	6.00	7.36 ab
(4) APP 10	9.26	4.02 ab	11.30 ab	13.80 bc	6.46	7.01 bc
(5) APP 20	9.22	2.94 b	8.00 c	14.72 abc	7.00	6.06 d
(6) Fe	8.79	4.84 ab	8.97 bc	13.72 c	5.68	6.75 c
(7) APP S	9.15	3.05 b	9.83 a	14.91 abc	5.81	7.27 ab
(8) APP K	9.08	4.74 ab	11.66 ab	14.05 bc	5.87	7.28 ab
(9) APP Zn	8.93	2.69 ab	12.52 a	14.15 abc	5.57	7.38 ab
(10) DRY BC	8.43	5.38 a	8.97 ab	14.42 abc	5.81	7.28 ab
(11) 9-18-9	9.04	4.66 ab	11.45 ab	15.61 ab	6.86	7.30 ab
(12) ProGerm	7.46	3.80 ab	11.37 ab	13.72 c	5.51	7.39 ab
(13) APP Drib	8.65	3.16 ab	10.94 abc	15.26 abc	5.87	7.03 abc
(14) APP + Accomplish	8.90	na	11.70 ab	13.99 bc	5.97	7.48 ab

Table 5. Grain sorghum average yield (Mg ha^{-1}) for each location by treatment. Within each location, treatments with the same letters were not significantly different, Tukeys LSD Alpha = 0.05.

Treatment	Location					
	Billings	Enid	Red Rock	OPREC irrigated 2014	OPREC irrigated 2015	OPREC dryland 2015
(1) Check	3.90 a	3.82 abc	6.51 ab	5.97 c	6.84	7.48 abcd
(2) APP 2.5	2.58 b	4.79 ab	7.50 ab	6.25 abc	6.08	8.87 abcd
(3) APP 5	3.21 ab	4.03 abc	7.88 ab	5.98 bc	7.56	7.96 ab
(4) APP 10	2.96 ab	4.00 abc	7.89 ab	5.97 c	7.63	6.63 a
(5) APP 20	3.87 a	3.45 abc	4.98 b	6.27 abc	5.21	7.85 d
(6) Fe	2.38 b	4.14 ab	6.38 ab	6.26 abc	7.40	8.04 ab
(7) APP S	2.89 ab	2.15 c	7.35 ab	6.29 abc	6.33	7.92 abcd
(8) APP K	3.50 ab	2.27 c	6.80 ab	6.39 ab	6.84	7.60 abcd
(9) APP Zn	3.26 ab	1.74 bc	7.51 ab	5.96 c	6.50	7.56 abcd
(10) DRY BC	2.89 ab	5.07 a	8.66 a	6.61 a	6.94	6.92 acb
(11) 9-18-9	3.18 ab	2.07 abc	6.93 ab	5.98 bc	6.96	7.75 ab
(12) ProGerm	2.47 b	4.21 abc	7.21 ab	6.10 bc	5.26	7.80 cd
(13) APP Drib	2.72 ab	3.74 abc	7.83 ab	6.17 bc	5.91	8.65 bcd
(14) APP + Accomplish	2.47 b	na	7.20 ab	5.98 bc	6.65	8.06 abcd

Figure 1. John Deere Max Emerge Planter on 75-cm row spacing with CO2 in-furrow and dribble fertilizer applicator. Rates controlled by changing orifice plate size and speed of the tractor. Turning on and off starter was controlled by electronic solenoids with a toggle switch located in the cab of the tractor.

Figure 2. Grain sorghum grain yield (Mg ha^{-1}) for the starter fertilizer study established near Billings, OK.

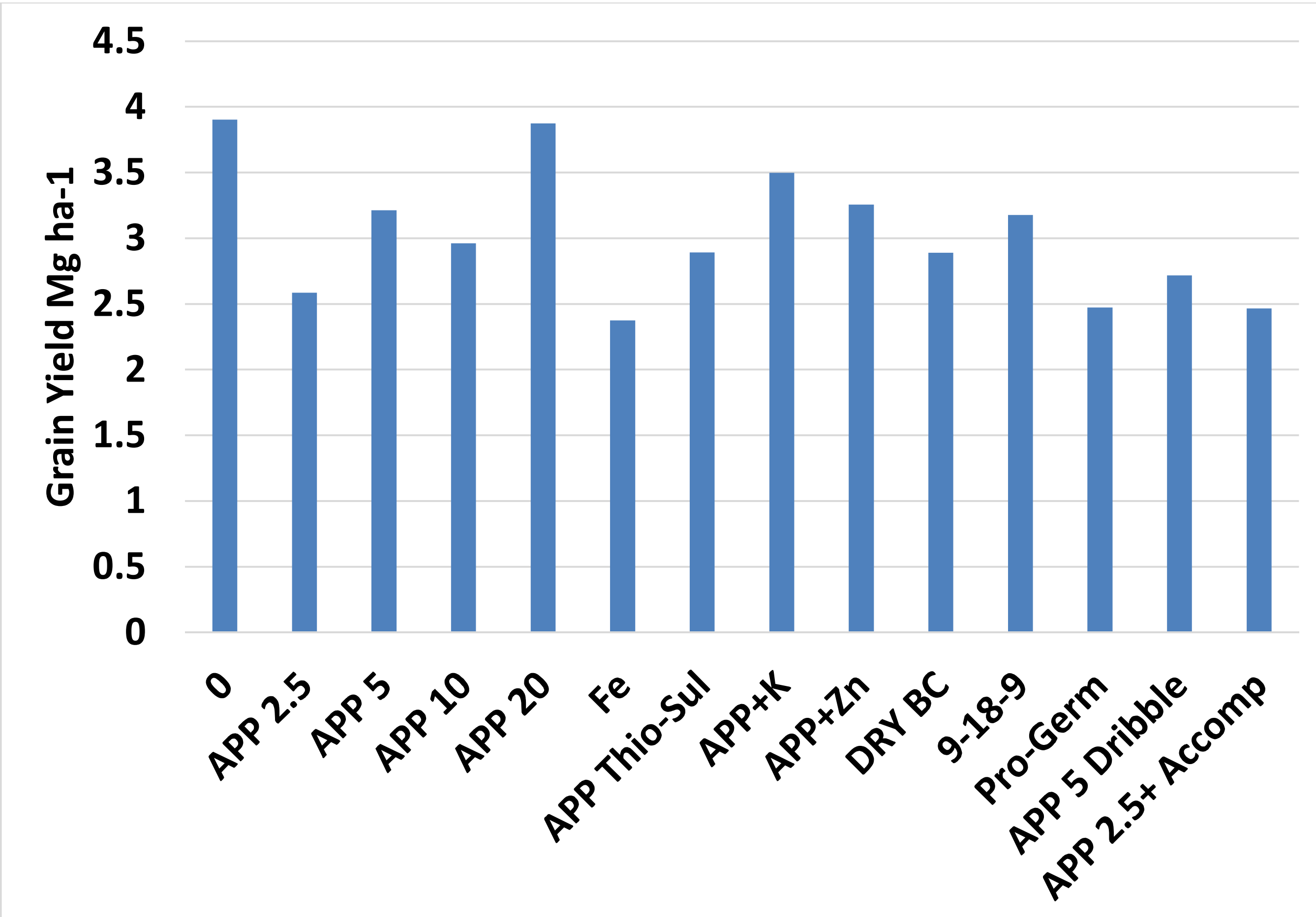


Figure 3. Grain sorghum grain yield (Mg ha^{-1}) for the starter fertilizer study established near Enid, OK.

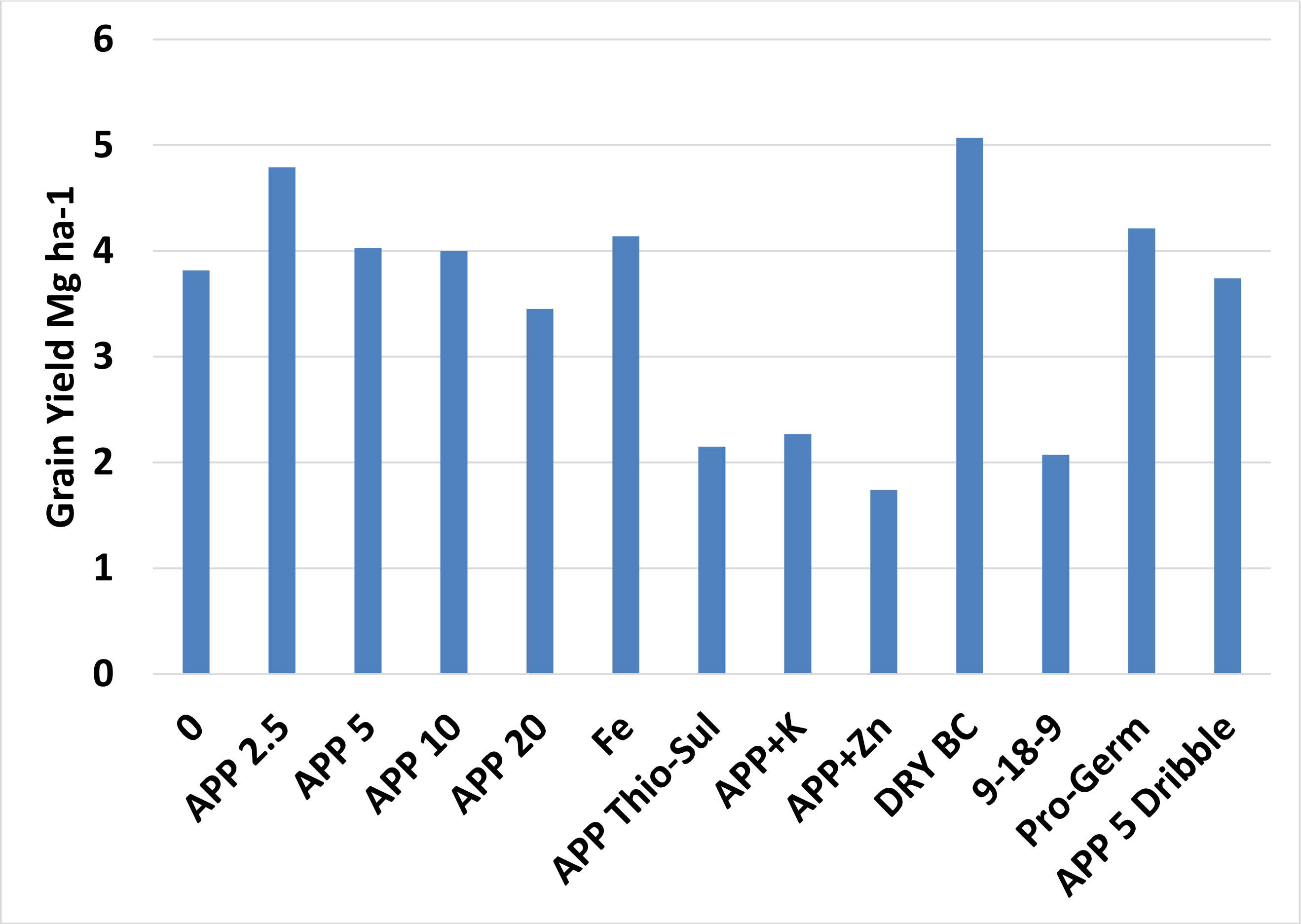


Figure 4. Grain sorghum grain yield (Mg ha^{-1}) for the starter fertilizer study established near Red Rock, OK.

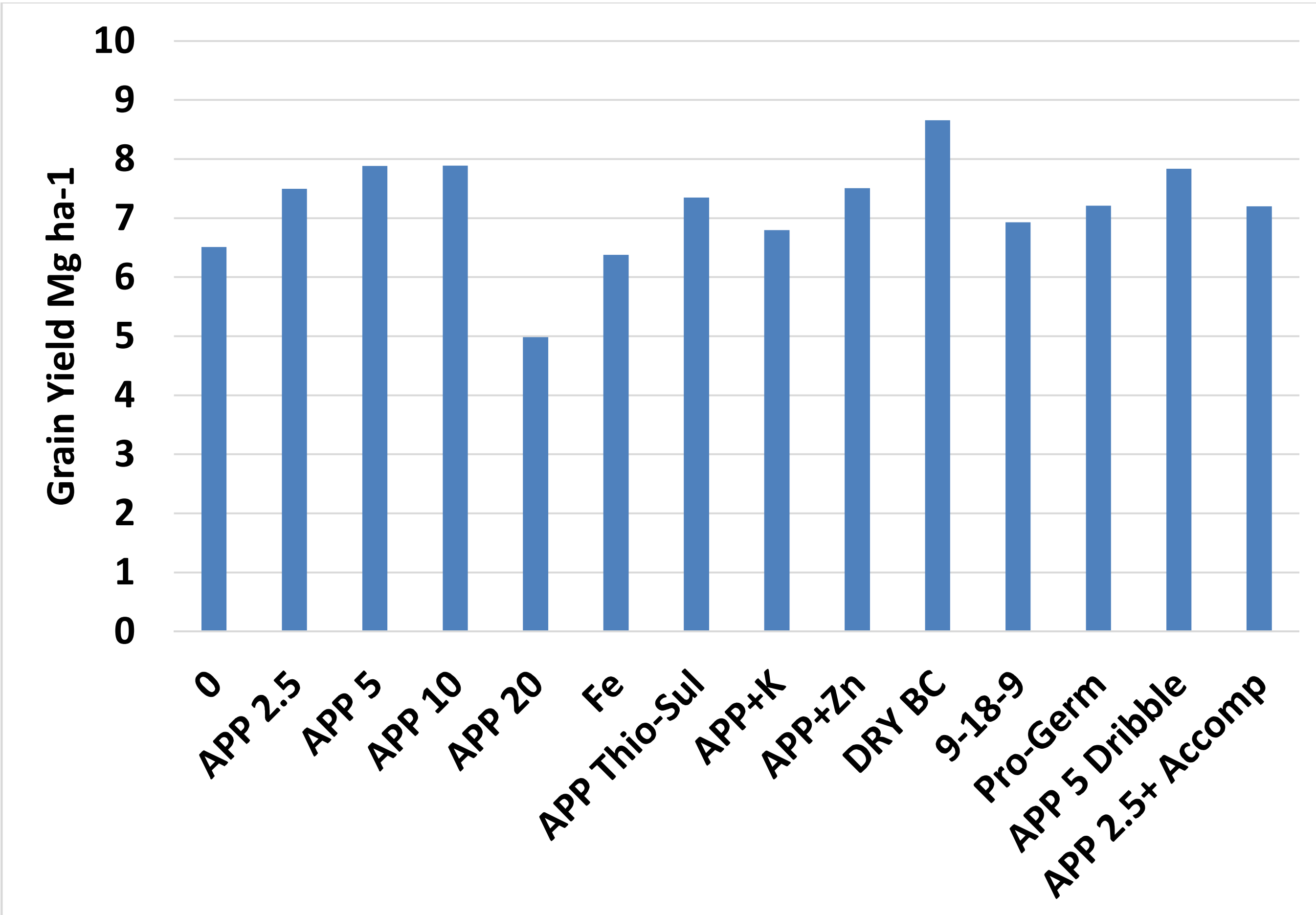


Figure 5. Grain sorghum grain yield (Mg ha^{-1}) for the 2014 irrigated starter fertilizer study established at OPREC near Goodwell,OK.

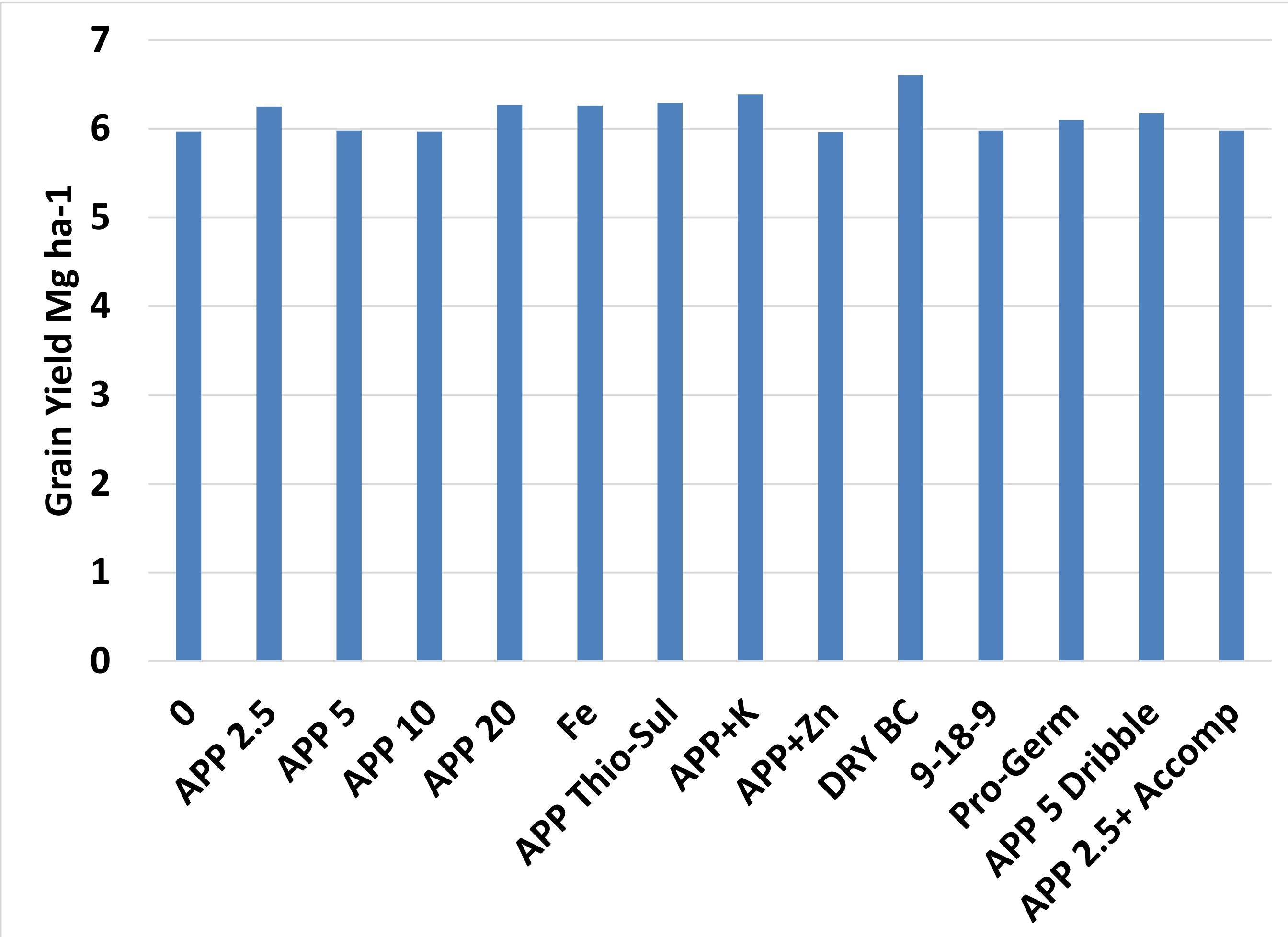


Figure 6. Grain sorghum grain yield (Mg ha^{-1}) for the 2015 irrigated starter study established at OPREC near Goodwell,OK.

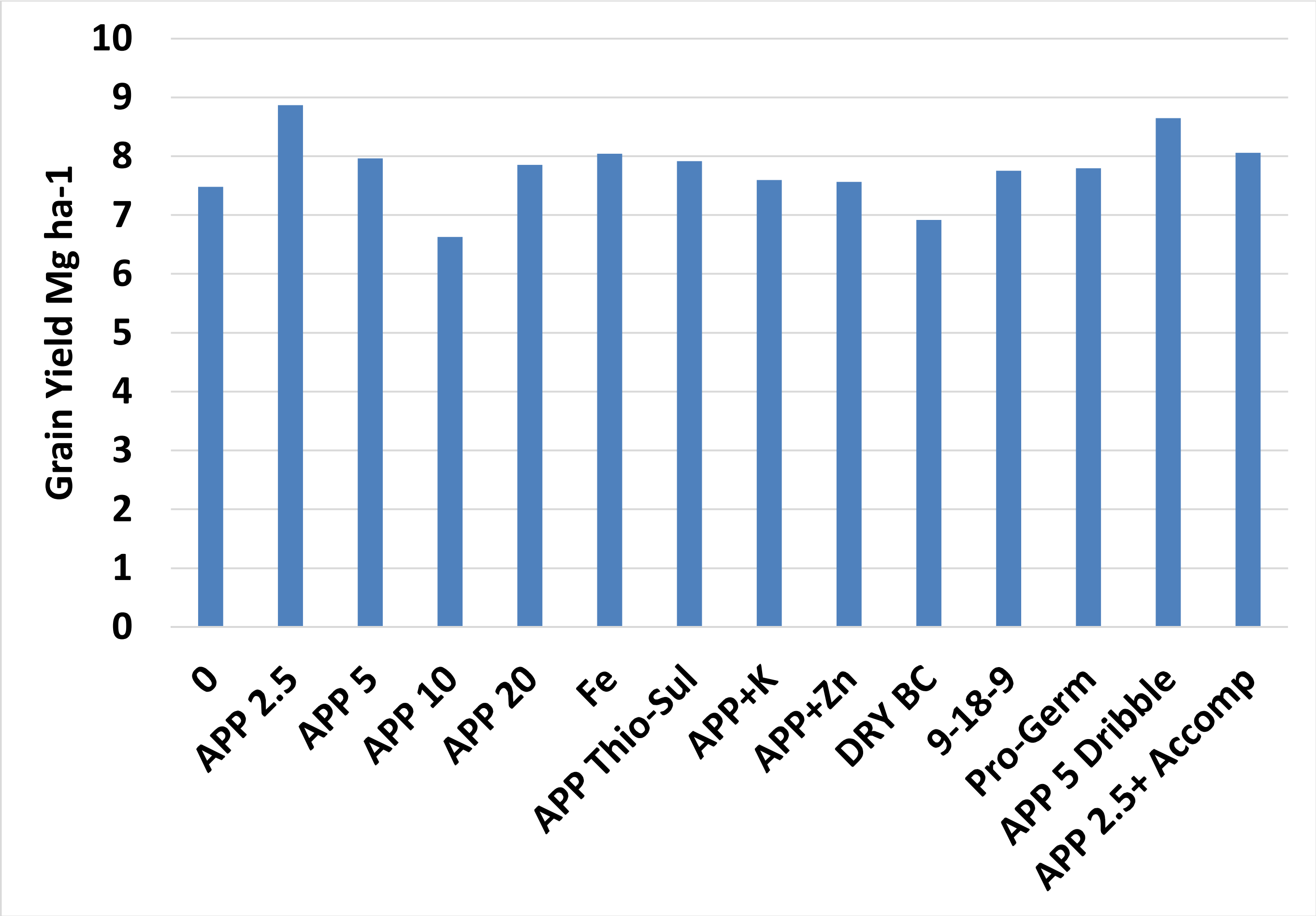


Figure 7. Grain sorghum grain yield (Mg ha^{-1}) for the 2015 dryland starter study established at OPREC near Goodwell,OK.

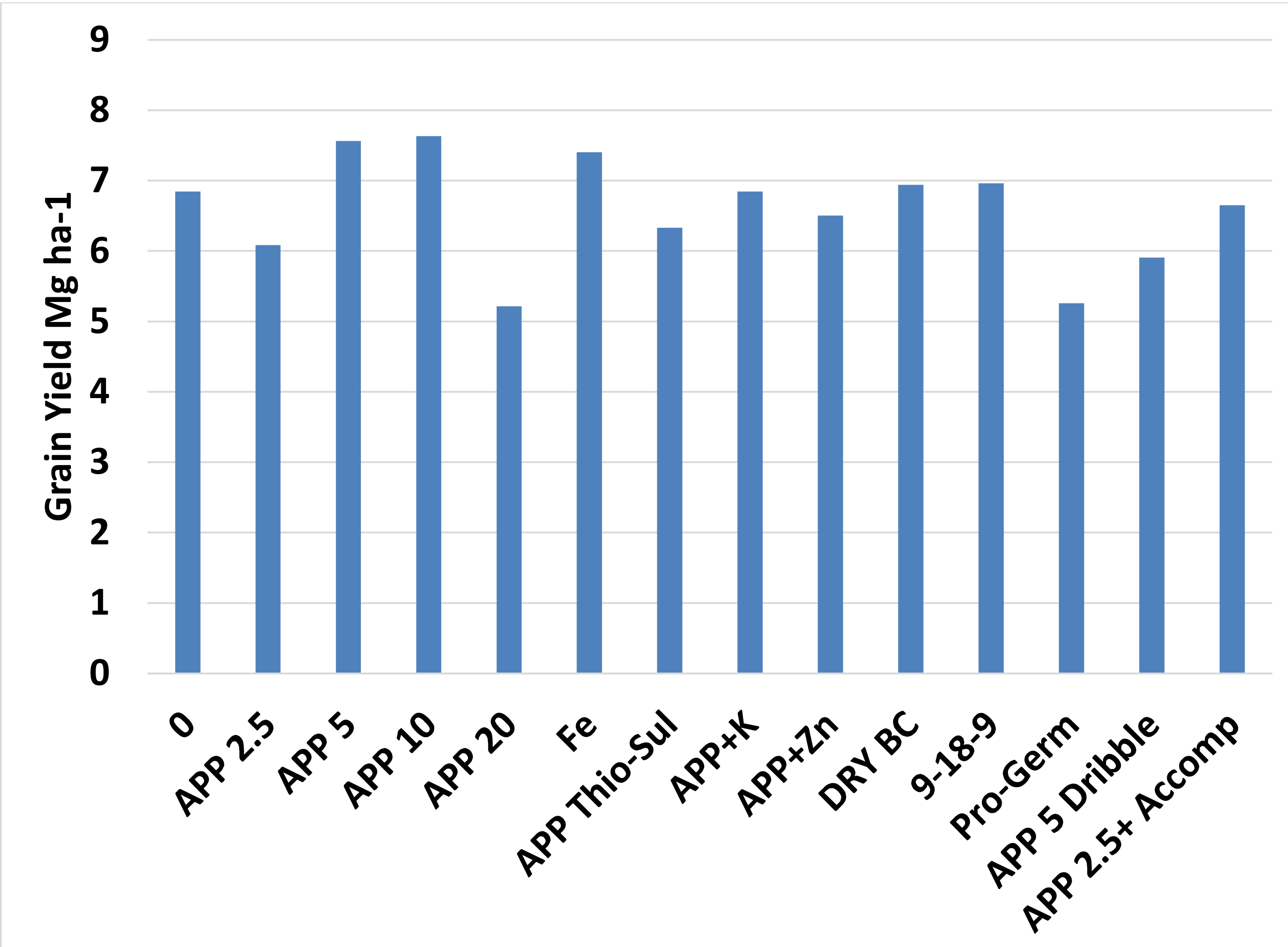


Figure 8. Grain sorghum plant stand of each treatment for the starter fertilizer study for all site years relative to the check

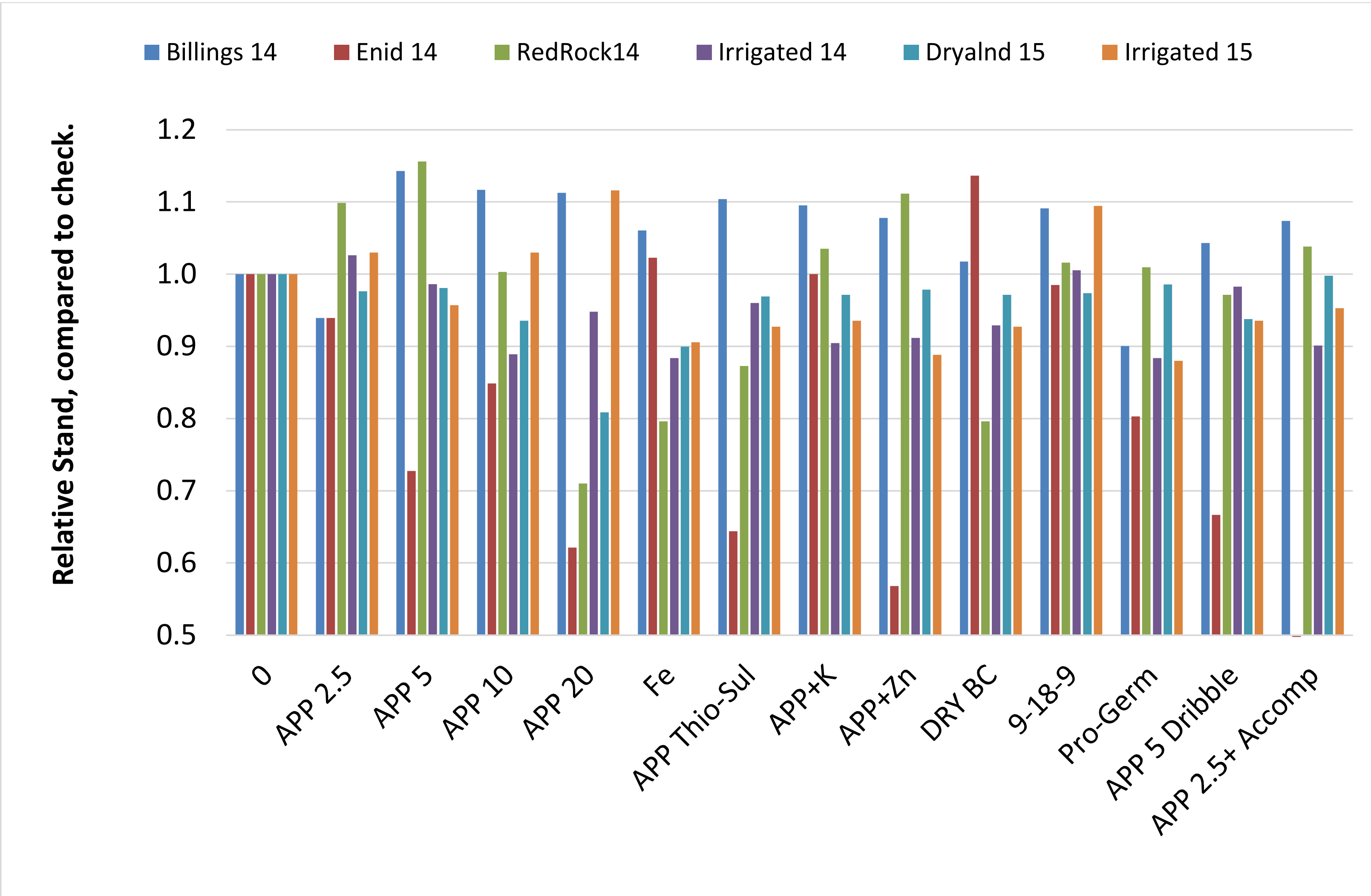
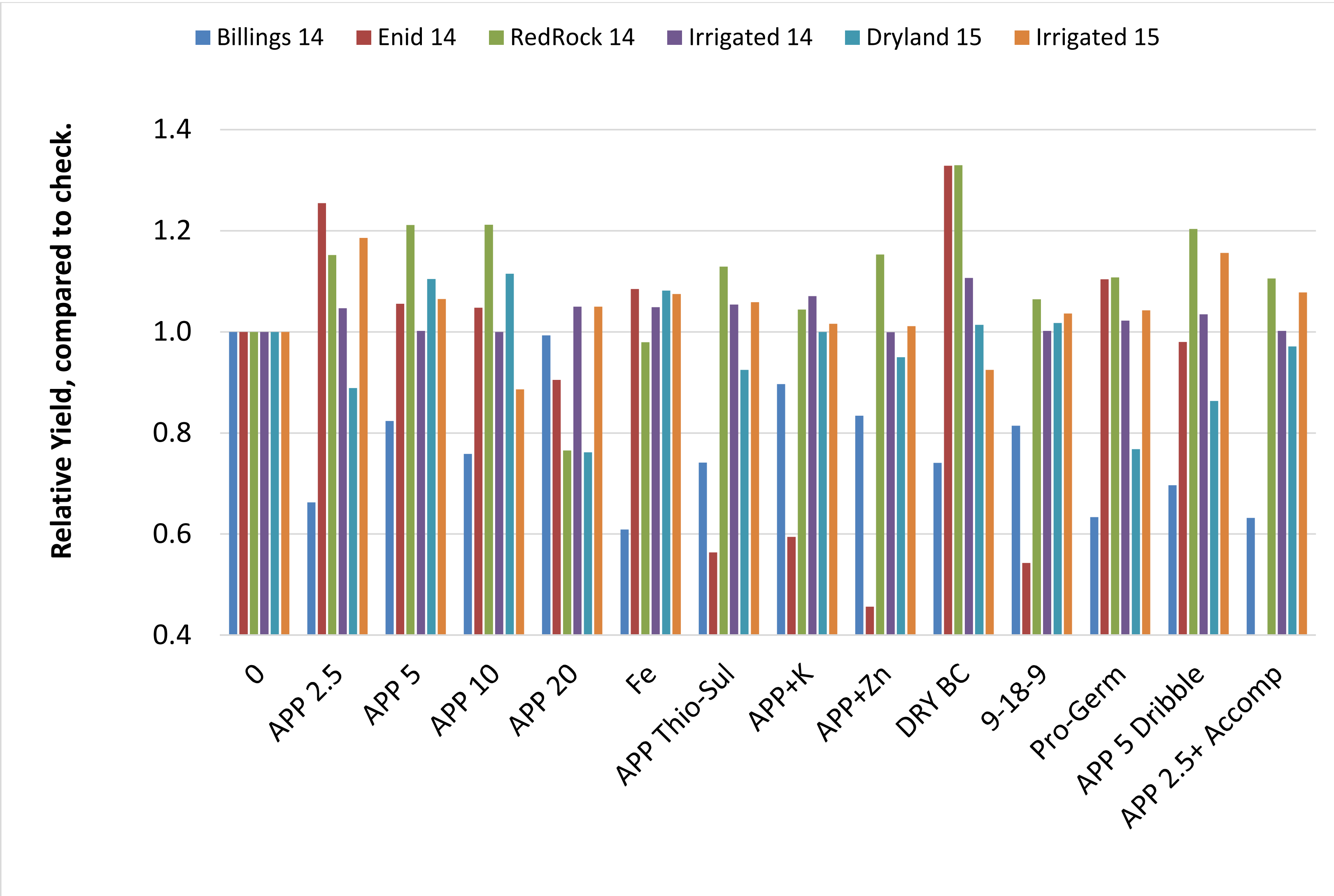


Figure 9. Grain sorghum grain yield of each treatment for the starter fertilizer study for all site years relative to the check



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