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Evaluating Starter Fertilizer Applications in Grain Sorghum Production

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Core Ideas

- The application of in-furrow starter fertilizers did not consistently improve yields over the non-treated control.
- Applying high rates of starter fertilizer close to the seed resulted in decreased emergence, which can potentially result in diminished yields.
- The use of fertilizer additives did not improve yields over non-treated ammonium polyphosate in-furrow starter applications.

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ABSTRACT

Starter fertilizers have been documented as a successful practice for several crops. However, information on these fertilizer applications on grain sorghum [*Sorghum bicolor* (L.) Moench] is very limited. This research was conducted to evaluate the impact of in-furrow starter fertilizers on grain sorghum establishment and yields in the southern Great Plains. Studies were conducted at four sites across Oklahoma in 2014 and two sites in 2015. Trials evaluated eight in-furrow starter fertilizer treatments as well as a non-treated check. Stand counts were collected 1 mo following planting to evaluate impact on stand establishment. At maturity, plot grain weights were used to estimate grain yield. Starter fertilizer applied at high rates (187 L ha^{-1}) reduced stands in four of six site locations by an average of 2.0 plants m^{-2}. This resulted in nearly a 21% decrease in yields. Positive yield effects from in-furrow starter fertilizers were not consistent, with only one location having significantly greater yields compared with the non-treated check. The addition of fertilizer additives did not have a significant effect on sorghum yields. However, with the lack of positive yield results from in-furrow starter fertilizer, it was unexpected that these additives would provide additional yield. These results suggest little yield advantage of in-furrow starter fertilizers in grain sorghum production. Furthermore, if in-furrow starter fertilizers are used in sorghum production, higher application rates could result in decreased stand establishment, potentially resulting in lower yields.

Abbreviations: APP, ammonium polyphosphate; DAP, diammonium phosphate; OPREC, Oklahoma Panhandle Research and Extension Center; UAN, urea–ammonium nitrate.

Grain sorghum [*Sorghum bicolor* (L.) Moench] is a critical crop for the central and southern Great Plains region. Sorghum is primarily grown in the Grain Sorghum Belt, which stretches from southern South Dakota through southern Texas (NASS, 2017). This region's climate has historically been dominated by rainfall and temperature patterns that would limit the productivity of corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], and cotton (*Gossypium hirsutum* L.). Furthermore, sorghum has begun replacing other grain crops within the food, feed, and biofuel industry as a more viable option with a smaller environmental footprint. This has resulted in a consistent amount of planted sorghum hectares in the last decade, with levels being maintained at nearly 3.2 million ha across the United States (NASS, 2018).

Timely emergence and rapid early season growth are critical for optimizing grain sorghum production (Gerik et al., 2003). Non-uniform stands and uneven early season growth have been shown to significantly reduce grain sorghum yields (Conley et al., 2005). In sorghum production, reduced stands can be a result of sorghum being planted into suboptimal conditions, including cool, wet soils. These cool, wet soils not only have negative influence on sorghum germination and emergence, but also result in decreased availability of many soil nutrients, including N, P, and micronutrients (Hunsigi, 1975; Greenwood et al., 2001). Hunsigi (1975) noted that lower soil temperatures did not directly influence soil availability of nutrients but limited the root growth, and thereby limited the accessible volume of the developing plants. Decreasing uptake of these nutrients can greatly reduce early season growth, which further limited nutrient and water uptake later in the production season, potentially leading to decreased productivity.

To overcome these issues, an increased number of grain sorghum fields are being planted in conjunction with starter fertilizers. Starter fertilizer application involved the placement of fertilizer in close proximity to the seed at or near planting. These applications have been shown to increase root growth and, in turn, early season plant growth (Touchton and Karim, 1986; Randall and Hoeft, 1988; Reeves et al., 1990; Wortmann and Mamo, 2006). Reeves et al. (1990) highlighted this fact, indicating that grain sorghum biomass accumulation at 5 to 6 wk following planting was significantly higher with the use of starter fertilizer compared with when starter fertilizer applications were omitted. By increasing early season growth, starter application has also been associated with better established and more rapid crop development (Wortmann and Mamo, 2006). However, yield response to starter fertilizer application has been inconsistent (Reeves et al., 1990; Wortmann and Mamo, 2006). Yield response of sorghum to starter fertilizer applications has been associated with higher yielding environments (Reeves et al., 1990) or problematic soil (Hergert et al., 2012), such as in soils with high or low pH, low soil nutrient availability, or low organic matter soils.

While the primary starter fertilizer used for most crop production systems has historically been ammonium polyphosphate (APP) (10–34–0), other products are available that could potentially provide additional K, S, Fe, and Zn (Jokela, 1992). Furthermore, the rate at which starter fertilizers are applied has been shown to impact germination and growth of crops when placed in-furrow with the seed (Niehues et al., 2004); however, limited information has been documented on the impact of starter fertilizer products and their rate of application on grain sorghum production. The current lack of recommended management practices for starter applications in sorghum highlights the limited information available. Therefore, the objectives of this study were to (i) determine the impact of in-furrow starter fertilizer application and rates on sorghum stands and yields, and (ii) evaluate the influence of in-furrow fertilizer additives on sorghum yields.

METHODS

Field experiments were established in 2014 near Billings, Enid, Red Rock, and at the Oklahoma Panhandle Research And Extension Center (OPREC) in Goodwell, OK. All locations were dryland production systems, with the exception of Goodwell, which was irrigated using overhead sprinkler irrigation. In 2015, additional field trials were established in Goodwell, OK, under both sprinkler irrigation and dryland production systems. Specific locations and soils for each location are detailed in Table 1. All locations were no-till production systems, with the exception of the irrigated locations in 2014 and 2015, which was strip-tilled immediately prior to planting.

Eight starter fertilizer treatments were evaluated as well as an untreated check. Detailed treatment descriptions are provided on Table 2. Four in-furrow starter fertilizer rates as well as four in-furrow starter fertilizer additives were evaluated. The four in-furrow fertilizer rates were 23, 47, 94, and 187 L ha^{-1}. Ammonium polyphosate (APP; 10–34–0) was the in-furrow nutrient source utilized. Higher rates of in-furrow nutrients were applied by increasing the orifice size. Fertilizer additives evaluated included Thio-Sul, K-Leaf, MicroBolt Zn, and Accomplish (Table 2). All fertilizer additives were blended with the APP in-furrow treatment at the rate of 23 L ha^{-1} rate. Details regarding these additives, including fertilizer concentrations, are available in Table 2. All treatments were arranged in a randomized complete block design. Locations at OPREC in 2014 and 2015 had four replications, whereas all other locations had three replications.

Table 1. Coordinates and soil classifications for the site locations utilized in 2014 and 2015 evaluation.

Location	Year	Coordinates	Soil	Soil classification
Billings	2014	36.3226 N; 97.3136 W	Kirkland silt loam	fine, mixed, superactive, thermic Udertic Paleustolls
Enid	2014	36.2712 N; 97.5159 W	Waynoka loam	fine-loamy, mixed, superactive, thermic Udic Argiustolls
Red Rock	2014	36.3032 N; 97.9402 W	Kirkland silt loam	fine, mixed, superactive, thermic Udertic Paleustolls
OPREC- irrigated	2014	36.3532 N; 101.3622 W	Gruver clay loam	fine, mixed, superactive, mesic Aridic Paleustolls
OPREC- irrigated	2015	36.3532 N; 101.3622 W	Gruver clay loam	fine, mixed, superactive, mesic Aridic Paleustolls
OPREC- dryland	2015	36.3523 W; 101.3622 W	Sherm clay loam	fine, mixed, superactive, mesic Torrertic Paleustolls

Table 2. Descriptions, rates, fertilizer additives, application rates, and nutrient analysis of the starter fertilizer treatments utilized in the starter fertilizer analysis in 2014 and 2015. All treatments were consistent across years.

					Total amount of applied in-furrow nutrient				
Treatment	Product	Rate	Additive	Rate	N	P	K	S	Zn
		L ha^{-1}		L ha^{-1}	kg ha^{-1}				
1	Control	–	–	–	0	0	0	0	0
2	10–34–0	23	–	–	3.3	4.8	0	0	0
3	10–34–0	47	–	–	6.5	9.7	0	0	0
4	10–34–0	94	–	–	13	19.4	0	0	0
5	10–34–0	187	–	–	26	38.8	0	0	0
6	10–34–0	23	Thio-Sul†	9.4	4.8	4.8	0	3.2	0
7	10–34–0	23	K-Leaf‡	9.4	3.3	4.8	3.1	0	0
8	10–34–0	23	MicroBolt Zn§	23.4	3.3	4.8	0	0	2.5
9	10–34–0	23	Accomplish¶	4.7	3.3	4.8	0	0	0

† Terrsenderlo-Kerley (Phoenix, AZ).

‡ ENC-Helena (Collierville, TN).

§ Nachurs (Marion, OH).

¶ Loveland (Greeley, CO) microorganisms <1%; *Bacillus licheniformis*, *Bacillus megatrerium*, and *Bacillus*.

The research plots were 3.3 m wide and 6 m long. Each plot consisted of four crop rows planted at 75 cm spacing.

Hybrids utilized varied by locations and were based on optimum hybrid selection for the region. At the OPREC location, due to the later planting dates and shorter season, an early–medium hybrid was used (DKS 37-07), whereas the longer growing season in the remainder of the locations allowed for the use of a medium–late hybrid (KS 585). All plots were planted using modified John Deere MaxEmerge Planter (John Deere Manufacturing Company, Moline, IL).The planter was equipped with a custom-built CO_2 driven fertilizer system that allowed for variable-rate placement of starter fertilizer with the seed at planting. Fertilizer was applied in-furrow following a Keeton seed firmer. Furrows were immediately closed using a paired spiked closing wheel. After the planting of each treatment, all the lines used to deliver the liquid fertilizer to the furrow were blown out with air, rinsed with water, and then recharged prior to the application of the next treatment. Before planting, 15 soil cores were taken and mixed to produce a composite sample across the trial area to the depth of 15 cm. The soils were homogenized, dried at 76°C for 72 h, and ground to pass a 2-mm sieve. These samples were then submitted to the Oklahoma State University Soil, Water, and Forage Analytical Laboratory for nutrient analysis. Results for these analyses were used to guide all non-starter nutrient applications (Table 3). Higher N and seeding rates were applied at the OPREC-irrigated location in 2014 and 2015 due to recommended higher application rates for irrigated production systems. Nitrogen fertilizer applications were made using urea–ammonium nitrate (UAN; 32–0–0) and applied as a blanket applications before establishment of the research plots. All agronomic and pest management practices were performed based on Oklahoma Extension Service current recommendations for grain sorghum production (Table 4).

Early season stand counts were taken 1 mo following planting to evaluate the impact of starter fertilizer application on crop emergence. Stands were determined by counting the number of individual plants in 5.3 m of row for both the middle two rows and averaging the value for each plot. Once all treatments reached physiological maturity, all plots were chemically terminated by applying 2.4 L ha^{-1} of glyphosate (*N*-(phosphonomethyl)glycine) once the crop had reached 30% moisture. Ten days after application, the middle two rows of the four-row plots were mechanically harvested using a Massey Ferguson 8XP (Massey Ferguson Agricultural Company, Duluth, GA) small plot combine. Plot weights and harvest moistures were used to determine crop grain yields on a per-hectare basis.

All statistical analyses was performed using SAS 9.4 (SAS Institute, Cary, NC). Residuals were tested to ensure normality as well as homogeneity of the data set prior to further analysis. The impact of in-furrow starter fertilizer rates and in-furrow starter products were evaluated independently. Both analyses were done with a one-factor analysis of variance using Procedure GLIMMIX. Within the analysis, in-furrow starter application rates and products were considered fixed effects, whereas year, location, and replication were considered random effects. Significant treatment × year and treatment × location interactions were present; therefore, dependent variables were evaluated independently of year and location. In-furrow starter fertilizer rates were analyzed using a Dunnett's *D* test, comparing starter fertilizer rates to the untreated check. Starter fertilizer products were analyzed using LSD with a Tukey adjustment, comparing starter fertilizer products as well as the starter fertilizer applied at the 23 L ha^{-1} rate. Both analyses were conducted at an $\alpha = 0.05$.

RESULTS AND DISCUSSION

Environmental Conditions

Weather data from both 2014 and 2015 are presented in Fig. 1 and 2. Averages were collected from Oklahoma Mesonet Weather Stations (www.mesonet.org). These stations are located in particular areas around the state and may not be located adjacent to the plots. Climate data for the Enid plots were collected from the station located near Breckinridge, OK, 17 km from the plots. The Red Rock mesonet station was being utilized as a weather location for both the Red Rock and Billings locations (the weather station was 37 km from Billings). Both OPREC and Red Rock are within

Table 3. Soil analysis for the pre-plant samples collected from the evaluation sites in 2014 and 2015. Samples were analyzed at the Oklahoma State University Soil Testing Laboratory in Stillwater, OK.

			Nutrient analysis									
Year	Location	pH	NO_3	P	K	S	Ca	Mg	Fe	Zn	B	Cu
			ppm									
2014	Billings	5.3	5	29	193	7	4844	122	53	0.7	0.3	1.2
	Enid	7.8	9	16	192	na†	2870	655	24	0.3	0.5	1.1
	Red Rock	5.8	6	10	139	7	958	187	54	0.7	0.4	1.2
	OPREC-irrigated	7.3	35	12	527	na	na	na	na	na	na	na
2015	OPREC-dryland	7	16	11	182	8	3500	156	9	3.6	0.7	0.4
	OPREC-irrigated	7.8	3	9	419	na	na	na	na	na	na	na

† Indicates that analysis was not conducted for the individual analysis at the individual location.

Table 4. Agronomic practices carried out in 2014 and 2015.

Year	Location	Hybrid	Planting date	Planting rate	N fertilization	Harvest date
				seed ha^{-1}	kg ha^{-1}	
2014	Billings	KS 585	20 Apr. 2014	125,000	99	2 Sept. 2014
	Red Rock	KS 585	20 Apr. 2014	125,000	99	3 Sept. 2014
	Enid	KS 585	21 Apr. 2014	125,000	99	4 Sept. 2014
	OPREC-irrigated	DKS 37-07	11 June 2014	175,000	132	15 Oct. 2014
2015	OPREC-dryland	DKS 37-07	7 June 2015	125,000	99	17 Oct. 2015
	OPREC-irrigated	DKS 37-07	7 June 2015	175,000	132	22 Oct. 2015

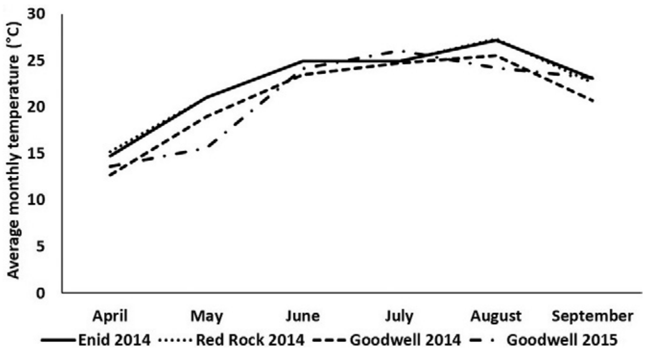

Fig. 1. Average monthly temperature collected from Mesonet (www.mesonet.org) weather centers near Enid, Red Rock, and Goodwell (OPREC) locations in 2014 and 2015.

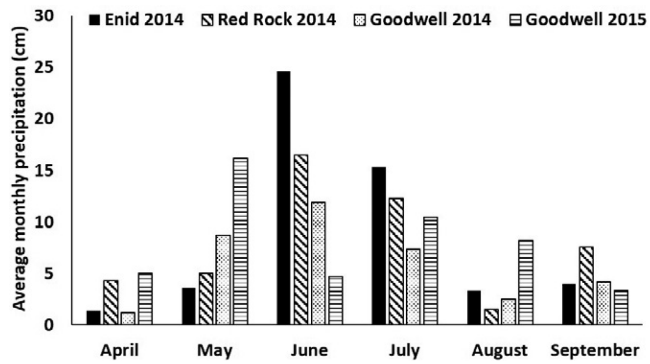

Fig. 2. Average monthly precipitation collected from Mesonet (www.mesonet.org) weather centers near Enid, Red Rock, and Goodwell (OPREC) locations in 2014 and 2015.

5 km of the plot locations. Air temperatures for the OPREC was lower than all other locations in 2014. However, the OPREC locations were not planted until much later in the season (Table 4). By June, ambient temperatures were consistent between all locations with only minor differences. Precipitation patterns were fairly consistent between locations (Fig. 2). The only major variability was seen in June between Enid in 2014, which received nearly 30 cm of precipitation, and OPREC in 2015, which received just under 5 cm of precipitation. This would have little impact on the OPREC-irrigated location in 2015 because of the ability to provide supplemental irrigation when needed, but may limit overall yield potential at the OPREC-dryland location.

Early-Season Stands

Starter fertilizers can have a positive impact on early season growth, but its impact on stand establishment can be negative. This is primarily due to the salt concentration associated with various starter fertilizers. High concentrations of salt applied in-furrow, either through high salt concentration fertilizers or through high application rates, can reduce crop stands (Niehues et al., 2004). Excessive rates of fertilizer rates can result in salt-related injury to the seedlings, resulting in decreased emergence and lower early season crop stands (Gerwing et al., 1994).

Overall, stand counts across trial locations were highly variable. Highest stands were found at the OPREC-irrigated trials but these trials were planted at a higher rate than the other locations, at just over 17 seeds m^{-2} compared with 11 seeds m^{-2} at the other locations (Tables 5 and 6). Highest emergence rates occurred at the Red Rock location, which averaged nearly 90% of the target population (Tables 4, 5, and 6). Poor stands, indifferent of treatment applied, were found at the Enid location in 2014. These conditions arose from lower soil moisture at planting and a significant rainfall event that occurred just after planting that resulted in highly crusted conditions. Although this did decrease stands compared with all the other tested locations, it did not substantially influence the variability associated with the location, and therefore it was considered a location that viable data could be collected.

Table 5. Influence the rate of in-furrow starter fertilizers on sorghum stands collected at site locations in 2014 and 2015.

	Stand counts					
	2014				2015	
In-furrow rate	Billing	Enid	Red Rock	OPREC-irrigated	OPREC-dryland	OPREC-irrigated
L ha^{-1}	plants m^{-2}					
0	8.3	4.7	11.3	15.5	7.5	7.5
23	7.8	4.7	12.4	15.9	7.3	7.3
47	9.5	3.3	13.0	15.3	7.4	7.4
94	9.3	3.5	11.3	13.8	7.0	7.1
187	9.2	3.0*	8.0*	14.7	6.1*	6.0*

* Indicates a significant difference compared to the check treatment at the α = 0.05 level. As a Dunnett *D* test was conducted, no other comparisons were made.

Table 6. Influence of in-furrow starter fertilizer products on grain sorghum stands collected at site locations in 2014 and 2015.

	Stand counts					
	2014				2015	
Starter additive	Billing	Enid	Red Rock	OPREC-irrigated	OPREC-dryland	OPREC-irrigated
	plants m^{-2}					
–	7.8a†	4.7a	12.4a	15.9a	7.3a	7.3a
Thio-Sul	9.1a	3.2a	9.8b	14.9a	7.3a	7.3a
K-Leaf	9.1a	4.7a	11.7ab	14.0a	7.3a	7.3a
MicroBolt Zn	8.9a	3.2a	12.5a	14.2a	7.3a	7.4a
Accomplish	8.9a	–‡	11.7ab	14.0a	7.5a	7.3a

† Different letters within the same column indicate significant differences in stand counts.

‡ Indicates that the treatment was not evaluated at the specific location.

The application of in-furrow starter furrow, at any application rate, did not positively influence stand counts. However, in four of the six site-years, the application of 187 L ha^{-1} in-furrow starter rate significantly decreased stands compared with the nontreated check (Table 5). These applications resulted in a 20 to 40% decline in stands between the highest application rate and the nontreated plots. These results were not unexpected as Raun et al. (1986) noted that germination was delayed and emergence was uneven when higher rates of in-furrow starter fertilizers were applied in corn. They indicated that a subsequent precipitation event was needed following planting when using higher rates of in-furrow fertilizer rates to achieve acceptable stands. Prolonged periods without a precipitation event could have resulted in the decreased stands at these higher application rates, but rainfall following the application of the treatments was not directly measured. However, it must be noted, adequate moisture was present at planting.

The in-furrow starter products had a very minimal impact on stand counts (Table 6). The only significant effect occurred at the Red Rock location, where the in-furrow starter Thio-Sul product significantly decreased stands compared with the untreated check and the starter with MicroBolt Zn product, but no other differences existed. It could be expected that starter fertilizers placed with the seed with higher rates of N and S would reduce stands due to their contribution to the fertilizer salt index (Hergert et al., 2012); however, this effect was not consistently found across all site-years.

Crop Yield

Sorghum grain yields were highly variable across site-years (Tables 7 and 8). For 2014, yields ranged from 2.2 to 8.7 Mg ha^{-1} at Enid and Red Rock, respectively. Yields were greater in 2015 compared with 2014, with yields ranging from 5.2 to 8.9 Mg ha^{-1} for OPREC- dryland and OPREC-irrigated locations, respectively. The higher yields in 2015 could be contributed to more favorable environmental conditions experienced in 2015. This can be seen by the increased yields at the OPREC-irrigated location in 2015 compared with the same location in 2014. The lowest yields were found at Billings and Enid in 2014. At least for the Enid location, the lower yields could be attributed to the significant precipitation event following planting, which resulted in lower stands and a lower yield potential.

The response of sorghum grain yields were variable but generally unaffected by starter fertilizer applications, at lower application rates (Table 7). The only site-year that starter fertilizers positively influenced grain yields was with APP applied at 23 L ha^{-1} at the OPREC-irrigated location in 2015. At this location at this rate of in-furrow starter fertilizer, yields were increased by 1.4 Mg ha^{-1} compared with the untreated check. It is interesting to note that five of the six site-years tested were considered P-deficient (20 mg kg^{-1}; Zhang et al., 2017). This indicated that, as opposed to previous literature, low soil test P levels paired with higher yielding environments must be present to find a significant benefit of starter fertilizers (Reeves et al., 1990).

In this same comparison, the application of starter fertilizer at the 23 L ha^{-1} rate did not significantly influence stand counts, indicating that the yield improvement was not associated with stands but potentially increased due to early season growth or improved nutrition (Rideout and Gooden, 2000; Osborne and Riedell, 2006). The three other site-years in which starter fertilizer influenced yields was at the 187 L ha^{-1} application rate at Red Rock in 2014, OPREC-dryland in 2015, and OPREC-irrigated in 2015. At these locations, the highest application of APP resulted in a significant decrease in yields compared with the untreated check. When comparing yields with stand counts (Table 7), these locations also had significantly lower stands compared with the check. Our results are in agreement with those of Walker et al. (1984) and Rehm and Lamb (2009), who reported reduction in yields due to early season stand losses.

Table 7. Influence the rate of in-furrow starter fertilizers on sorghum grain yields at site locations in 2014 and 2015.

	Sorghum grain yield					
	2014				2015	
In-furrow rate	Billing	Enid	Red Rock	OPREC-irrigated	OPREC-dryland	OPREC-irrigated
L ha^{-1}	Mg ha^{-1}					
0	3.9	3.8	6.5	6.0	6.8	7.5
23	2.6	4.8	7.5	6.2	6.1	8.9*
47	3.2	3.8	7.9	6.0	7.6	8.0
94	3.0	3.9	7.9	6.0	7.6	7.9
187	3.9	3.1	5.0*	6.3	5.2*	5.8*

* Indicates a significant difference compared to the check treatment at α = 0.05 level. As a Dunnett *D* test was conducted, no other comparisons were made.

Table 8. Influence of in-furrow starter fertilizer products on grain sorghum yields collected at site locations in 2014 and 2015.

	Sorghum grain yield					
	2014				2015	
Starter additive	Billing	Enid	Red Rock	OPREC-irrigated	OPREC-dryland	OPREC-irrigated
	Mg ha^{-1}					
–	2.6a†	4.8a	7.5a	6.2a	6.1a	8.9a
Thio-Sul	2.9a	4.4a	7.3a	6.3a	6.3a	7.9a
K-Leaf	3.5a	4.2a	6.8a	6.4a	6.8a	7.7a
MicroBolt Zn	3.3a	3.8a	7.5a	6.0a	6.5a	7.7a
Accomplish	2.5a	–‡	7.2a	6.0a	6.6a	8.1a

† Different letters within the same column indicate significant differences in stand counts.

‡ Indicates that the treatment was not evaluated at the specific location.

The use of additives with the starter fertilizer did not positively influence sorghum grain yields at any site-location evaluated (Table 8). Even at the Red Rock location, where stands were decreased with the application of Thio-Sul in-furrow with the APP, yields did not have any significant differences. The lack of positive effects of starter fertilizer applications in the absence of additives could have influenced these results and be indicative of an environment that is non-responsive to additional fertility.

CONCLUSIONS

The results of this study highlight the variable and complex nature of starter fertilizers in cropping production systems. Generally, the use of in-furrow starter fertilizers did not have a consistent influence on grain sorghum yields, with only the OPREC-irrigated trial resulting in significant increases in yields compared with the untreated check. The response at this location could be attributed to the higher yield potential and low soil test *P* values. This would suggest that several factors play a role in determining the value of starter fertilizer applications to the sorghum crop.

The results also indicate that sorghum was able to withstand in-furrow starter applications as high as 94 L ha^{-1} without any negative effects on stands or yield. However, higher fertilizer applications, 187 L ha^{-1}, did result in significant declines in stands, with two of the four locations that were found to have significant stand declines also had significant yield declines.

Overall, based on the results of this study, grain sorghum production systems did not greatly benefit from the use of starter fertilizer applications. Even in deficient soil conditions, starter fertilizers did not consistently increase sorghum yields, and traditional fertilizer applications should be used to help alleviate these deficiencies. These starter applications could be used to improve other aspects of sorghum productions; however, specific soil, agronomic, and environmental conditions have to be present to find consistent yield benefits.

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