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Evaluation of Sorghum Emergence and Grain Yield Response to Seeding Density and Plant Spacing Attained Using the OSU Hand Planter

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ABSTRACT
Plant spacing and density are important metrics in crop production because they impact the plant's ability to utilize resources and attain full yield potential. Planting sorghum (*Sorghum bicolor* (L.) Moench) in a more narrow spacing brings about phytochrome-mediated responses, where plants develop narrow leaves, long stems, fewer roots, and this is linked to competition that plants develop for nutrients like nitrogen (N). The Oklahoma State University hand planter (OSU-HP) can improve plant homogeneity and mid-season placement of N. However, this crop production tool alongside other agronomic practices have not been adequately evaluated for improving sorghum grain yields. The objective of this work was to evaluate the response of sorghum to planting methods, the number of seeds per hole, within row spacing, and N rate. A randomized complete block design with 13 treatments replicated 3 times was used in this study. The treatments included different combinations of 3 planting methods (John Deere [JD], OSU-HP, and stick planter [check]), 3 within-row spacings (10, 30, and 60 cm), 3 different number of seeds per hole (1, 3, and 6) and 3 N rates (0, 30 and 60 kg ha^{-1}). Average grain yield with 3 seeds per hole was at least 18% higher than the yield range of 0.7 to 4.6 Mg ha^{-1} achieved with 1 or 6 seeds per hole. This study demonstrated that the production of sorghum using sound agronomic practices could improve yield.

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Sorghum; nitrogen; urea incorporation; hand planter; plant spacing; seeding density; sorghum grain yield; agronomic practices

Introduction

Sorghum (*Sorghum bicolor* L. Moench) also called 'milo' in some English-speaking countries is a cereal grain originating in Africa and grown in tropical, subtropical, and arid regions (Dykes, Rooney, and Rooney 2013). Today, sorghum is grown all over the world because it is a drought-tolerant crop with better water use efficiency compared to cereals maize and rice (Moges et al. 2007). It is the fifth most important cereal crop in the world cultivated on at least 44 million hectares of land (Aula et al. 2019; Chala, Tronsmo, and Brurberg 2011; Dhillon et al. 2019; Dicko et al. 2006).

It is also reported that more than 35% of sorghum grown is used for human consumption while the rest is used for animal feed, alcohol production, building material, fencing, or for brooms and industrial products (Dahlberg et al. 2011; Dicko et al. 2006; Rooney 2004). Seventy-eight percent of the harvested area lies within Africa and Asia (Berenji and Dahlberg 2004).

World sorghum production was estimated at 68 million tons in 2014 with 59.8% coming from the developed world including Europe and the United States (FAOSTAT,2014). In the USA and other developed countries, sorghum is planted using mechanized planters which are calibrated to

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drop exact quantities of seed at a required spacing, and that results in uniform and homogenous plant stands. This may explain why much of the grain yields come from these developed nations.

Plant spacing and density are important practices when it comes to crop production because they influence the plant's ability to utilize resources and attain full yield potential. Planting sorghum at a closer spacing has been found to bring about phytochrome-mediated responses, the plants develop narrow leaves, long stems, fewer roots, and this is linked to the competition that plants develop for nutrients like nitrogen (N) (Fernandez, Fromme, and Grichar 2012). These two factors have also been found to impact grain yield of sorghum through improved water use efficiency, weed control, reduced number of tillers, and increased N use efficiency (Bayu, Rethman, and Hammes 2005; Conley, Stevens, and Dunn 2005; Fernandez, Fromme, and Grichar 2012; Godsey et al. 2012; Heslehurst 1983; Steiner 1986).

According to work by Bandaru et al. (2006), yields were found to increase when sorghum was planted in clumps compared to where plants were uniformly spaced. They went ahead to report that clumping seeds reduced the number of tillers to about one per plant compared to about three for uniformly spaced plants and vegetative growth which resulted in increased water available during the grain filling stage.

A study by Conley, Stevens, and Dunn (2005) indicated that crop development and the harvest was delayed at lower plant densities, and they also found that yields increased with increasing plant density. According to work done by Chim et al. (2014) on the effect of seed distribution and population on maize, grain yields were increased by an average of 1.15 Mg ha^{-1} (range: 0.33 to 2.46 Mg ha^{-1}) when planting 1 seed, every 0.16 m, compared to the farmer practice of placing 2 to 3 seeds per hill, every 0.48 m.

Bayu, Rethman, and Hammes (2005) in a separate study found that higher plant populations increased leaf area and this was due to the increased number of plants per unit area. Steiner (1986) reported that higher plant populations increased evapotranspiration (ET) and this shifted the partitioning of ET to the vegetative period. He also continued to report that high plant populations increased dry matter and resulted in low grain production. Planting sorghum at high plant populations may also result in excessive lodging and overall yield loss (Godsey et al. 2012). Heslehurst (1983) also reported that grain yield response to increasing plant population also may depend on each genotype in its environment.

At low plant densities, grain sorghum head number per plant and seed number per head increased as compared to the recommended plant density (Conley, Stevens, and Dunn 2005; Fernandez, Fromme, and Grichar 2012). Conley, Stevens, and Dunn (2005) reported that crop row spacing of less than 76 cm may lead to increased grain yields and was attributed to decreased soil water depletion or increased evapotranspiration (ET) efficiency. Fernandez, Fromme, and Grichar (2012) showed that weed-grain sorghum competition increases with open canopy structures compared to narrow row spacing. Fernandez, Fromme, and Grichar (2012) reported that a 76 cm row spacing increased grain yield in areas with high yield potential and with less risk in comparison to areas with lower yield potential. In a separate study, Staggenborg et al. (1999) found yields to exceed 6.3 Mg ha^{-1} and were estimated to be 10% higher when sorghum was grown in 25 cm and 51 cm rows versus 76 cm. They also found that reducing row spacing or plant populations reduced panicles per plant.

Steiner (1986) reported that narrow row spacing in sorghum produces higher dry matter and grain yields at a certain level of ET under irrigated conditions. He continued to report that the risk of grain yield reduction would be greater in narrow spacing than wide rows in semi-arid conditions. A study on fodder sorghum by Malik, Hussain, and Awan (2007) showed that high seeding rates with narrow row spacing tend to produce higher fodder yield while yields decreased with decreasing seed rate and increasing row spacing.

Most of the sorghum in the developing world is planted by hand where one person leads and makes a hole while the other follows from behind to drop seed and cover. It is, therefore, difficult to determine the number of seeds planted per hole and the distance between each plant. Added to this difficulty, fertilizer application is a problem where most farmers choose to broadcast urea on the surface, which results in losses due to ammonia (NH_3) volatilization and uneven distribution. To improve plant populations and density, the method of planting and fertilizing has to be improved. Therefore, this research is designed to bridge this gap in production for producers in developing countries.

The OSU-HP has the potential to drop the exact amount of seed depending on the internal drum size, and vital to establishing optimum plant populations and spacing. The OSU-HP also is capable of placing the fertilizer below the surface close to the plant at the right stage of growth which reduces losses due to volatilization. Furthermore, the plant will be able to utilize applied nutrients at the stage when it is most required. The OSU-HP, therefore, could be used to improve crop yield while at the same time optimizing N utilization particularly for farmers in the developing world. While the selected agronomic practices (seeding density, spacing, N rate, and planting methods) have previously been studied, the evaluation did not include OSU-HP as one of the planting methods for sorghum. This provides an opportunity to evaluate how sorghum grain yield will respond to agronomic practices when OSU-HP was included as a planting method.

The objective of this study was to evaluate the effect of planting methods, seeding rate (number of seeds per hill), and N rate on sorghum grain yield.

Materials and methods

Five sorghum trials were established at two locations in the summer of 2016, 2017, and 2019 (Table 1). One of the locations was the EFAW experiment station in Stillwater, OK and the other was Lake Carl Blackwell (LCB), situated 14 miles west of Stillwater on Highway 51.

Soil classification at the Efaw research station is Ash port silty clay loam (fine-silty, mixed, superactive, thermic Fluventic Haplustolls) and at LCB the soil classification is Pulaski fine-sandy loam (coarse/loamy, mixed nonacid, thermic, Typic, Ustifluvent) (USDA/NRCS soil taxonomy). Seed density, spacing, and estimated plant population for all sites in 2016, 2017, and 2019 are reported in Table 1.

A randomized complete block design with 3 replications and 13 treatments was used at the two experimental sites. The incomplete factorial treatment structure was comprised of three planting methods including John Deere (JD), OSU-HP, and conventional stick or wooden pole planters common in developing countries (Table 1). As part of the treatment structure, each of the planting methods was accompanied by one or more N rates (0, 30, and 60 kg N ha^{-1}), three seeding rates (1, 3, and 6 seeds per hill), and three within row spacings (10, 30 and 60 cm).

Table 1. Treatment structure for all three years 2016, 2017, and 2019.

Treatment	Planting method	Within row spacing, cm	Seed number	N, kg ha^{-1}	seed size kgha^{-1}
1	JD	10	1	0	29778
2	JD	10	1	0	28889
3	JD	10	1	60	29778
4	JD	10	1	60	28889
5	OSU-HP$_A$	60	6	30	29778
6	OSU-HP$_A$	60	6	30	28889
7	OSU-HP$_A$	60	6	60	29778
8	OSU-HP$_A$	60	6	60	28889
9	OSU-HP$_B$	30	3	30	29778
10	OSU-HP$_B$	30	3	30	28889
11	OSU-HP$_B$	30	3	60	29778
12	OSU-HP$_B$	30	3	60	28889
13	Check	30	3	60	28889

Treatments 1 to 4 were planted using a JD planter at a spacing of 10 cm, 1 seed per hill, and received either 0 or 60 kg N ha^{-1}. Treatments 5 to 12 were planted using OSU-HP at two seeding rates (3 or 6 seeds per hill), a within row spacing of 30 or 60 cm, and two N rates (30 or 60 kg N ha^{-1}). The OSU-HP planting method was further subdivided into two drum types with treatments 5 to 8 using drum A (figure 1) (0.35 cm^3) (OSU-HP$_A$) with sorghum planted at 60 cm spacing, 6 seeds per hill, and 30 or 60 kg N ha^{-1} Treatments 9 to 12 used drum B (figure 2) (0.40 cm^3) (OSU-HP$_B$) and was planted at a 30 cm spacing, 3 seeds per hill and 30 or 60 kg N ha^{-1}. The conventional stick planter was used in treatment 13 where sorghum was planted at a spacing of 30 cm with 3 seeds per hill and 60 kg N ha^{-1}. For all treatments, N was applied at the V7 growth stage as urea (46-0-0) (N-*P*-K). For all treatments, sorghum was planted at a row spacing of 76 cm. The two outer rows of treatments planted using OSU-HP and stick planter were planted using the JD planter while the two middle rows were planted using the OSU-HP, stick planter, and JD as shown in Table 3.

The different drums were identified by carrying out several lab tests in which the different seed types were used to determine the number of seeds that are dropped by each drum. Drum A was chosen based on a range of 5 to 9 seeds per strike while drum B was chosen based on a range of 2 to 5 seeds per strike. Two different ropes marked at a distance of 30 cm and 60 cm were used using OSU-HP and the stick planter where 3 seeds and 6 seeds were dropped per hole as shown in Table 1. Plot management dates and activities for all sites and years are reported in Table 2.

At physiological maturity, the two center rows were harvested from each four-row plot using Massey Ferguson 8XP experimental plot combine (AGCO Corp., Duluth, GA) equipped with a HarvestMaster weighing system (Juniper Systems Inc., Logan, UT) to obtain total plot weight and

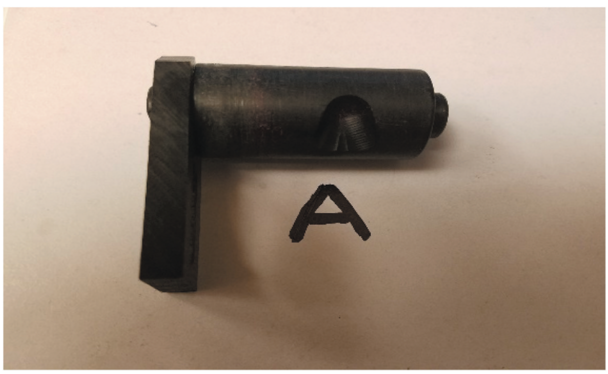

Figure 1. Drum A.

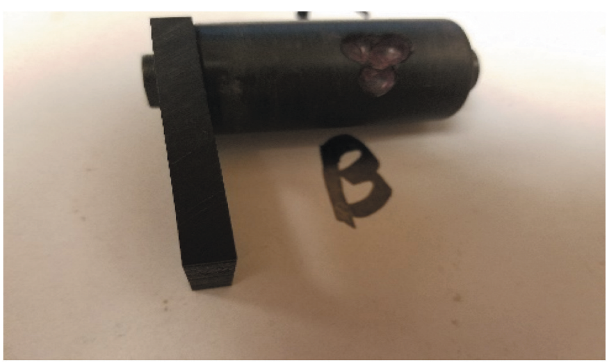

Figure 2. Drum B.

Table 2. Field activities for 2016, 2017 and 2019 seasons for locations EFAW and LCB.

Year	2016		2017		2019
Location	EFAW	LCB	EFAW	LCB	LCB
Planting date	04/4/2016	04/6/2016	05/12/2017	05/2/2017	04/29/2019
Sidedress	06/17/2016	06/16/2016	07/24/2017	07/24/2017	06/28/2019
Harvest date	08/16/2016	08/17/2016	08/30/2017	08/31/2017	09/5/2019

grain percent moisture. Grain moisture was adjusted to 10% of total grain weight. Statistical analysis was accomplished using SAS version 9.4 (SAS Institute, 2012). In SAS, procedure GLM was used to analyze the response of sorghum grain yield to independent variables. Mean separation was achieved using the Least Significant Difference procedure at the 0.05 probability level. Single-degree-of-freedom -contrasts were also used to partition differences among treatments.

Results

EFAW (2016)

The highest emergence was achieved with seed size 28889 seeds kg^{-1} and OSU-HP_B, which was calibrated to drop three seeds per hole at a plant spacing of 0.3 m between plants. When carrying out non-orthogonal single-degree-of-freedom-contrasts, it was observed that OSU-HP_A and OSU-HP_B were significantly different, $p < .0001$(Table 3).

According to single-degree-of-freedom-contrasts, it was observed that there was no significant difference in emergence with the different seed sizes (Table 3). Nonetheless, it was difficult to achieve the exact amount of seed required (3 seeds and 6 seeds) with the two different drums.

Grain yield collected at harvest ranged from 0.84 to 3.77 Mg ha^{-1} with an average of 2.42 Mg ha^{-1} (Table 3). However, treatment 12 (seed size 28889 seeds kg^{-1} and 60 kg N ha^{-1}) had higher yields compared to all the other treatments with three seeds per hole followed by treatment 4 with one seed per hole. Treatment 4 was planted at a 10 cm plant-to-plant spacing with one seed per hole and 60 kg N ha^{-1}. Treatments 1 to 4 were different from each other (Table 3). However, treatments 3 and 4 (60 kg N ha^{-1}) stood out from the group. Single degree of freedom analysis showed that treatments 1 and 2 were significantly different from treatments 3 and 4, $p < .0001$ (Table 4). According to single-degree-of-freedom-contrasts, JD planted treatments yielded significantly lower than that of Drum A (OSU-HP_A) at

Table 3. Sorghum (Sorghum bicolor (L.) Moench) grain yield and emergency as influenced by the number of seeds and plant to plant spacing at EFAW (2016 and 2017).

	2016		2017	
Treatment	Emergence	yield Mg ha-1	Emergence	yield Mg ha-1
1	59893	0.84	35574	1.01
2	64197	1.18	33324	0.65
3	52720	2.23	33396	1.51
4	56666	3.48	36590	2.58
5	92888	2.3	40729	1.9
6	87509	1.92	42543	1.41
7	97910	1.94	39276	1.51
8	98268	2.96	41164	2.17
9	130546	2.55	36518	2.84
10	155293	3.42	36590	2.86
11	138078	2.68	37244	4.00
12	125884	3.77	34920	4.06
13-check	36581	2.19	28677	1.45
MSE	357167671	0.14	19644566	0.43
SED	15430.87	0.3	3618	0.54
CV, %	20.53	15	12	30.66

SED – standard error of the difference between two equally replicated means, MSE- Mean square error, CV- Coefficient of variation (%), Check- Stick planter treatment, ns ***, **, * non-significant or significant at P ≤ 0.10, 0.05, 0.01probability level, respectively.

Table 4. Contrasts between different treatments at EFAW (2016 and 2017).

		p value			
		2016		2017	
Contrasts	Treatments	yield	Emergence	yield	Emergence
John Deere vs OSU-HP$_A$	1 to 4 vs 5 to 8	*	**	**	ns
John Deere vs OSU-HP$_B$	1 to 4 vs 9 to 12	*	*	ns	*
OSU-HP$_A$ vs OSU-HP$_B$	5 to 8 vs 9 to 12	*	*	ns	*
OSU-HP$_B$ vs check	12 vs 13	*	*	**	*
OSU-HP$_B$ vs check	11 vs 13	*	ns	**	*
0 N vs 60 kg N	1,2 vs 3,4	ns	*	ns	**
30 kg vs 60 kg (6 seeds)	5,6 vs 7,8	ns	ns	ns	ns

SED – standard error of the difference between two equally replicated means, MSE- Mean square error, CV- Coefficient of variation (%), Check- Stick planter treatment, ns ***, **, * non-significant or significant at P ≤ 0.10, 0.05, 0.01probability level, respectively.

a probability level of 0.05. The average yield obtained using OSU-HP$_A$ was 18% above the yield associated with JD (1.9 Mg ha^{-1}). This was possibly due to differences in N rates, and plant population assigned to the two planting methods where OSU-HP$_A$ had a higher emergency (38%) compared to the JD.

In general, it was observed that placing three seeds per hill at a closer spacing (0.3 m) resulted in higher yields compared to the six seeds and/or one seed. Average yield (1.9 Mg ha^{-1}) was at least 18% lower when 1 seed was planted per hill in comparison to planting more than 1 seed per hill. Also, the N rate played a role in the measured higher yield as observed in treatment 4, 8, and 12. On average, yields for treatments that received N were 167.6% higher than yields achieved without N application (1.0 Mg ha^{-1}).

EFAW (2017)

Added data were collected to estimate plant population associated with the different planting methods in 2017 and Analysis of variance showed that there were no significant differences in plant stands of the different treatments (p = .0727). The highest population was observed with treatment 6 which was planted using OSU-HP$_A$ and calibrated to drop six seeds per hill at a distance of 0.6 cm between plants. When comparing treatments 11 and 13, there was a significant difference in levels of emergence where treatment 11 had a 23% higher emergence compared to 13 and yet they received the same type of seed and fertilizer (60 kg N ha^{-1}). Comparing the John Deere planter with OSU-HP$_B$, there was a significant difference in population stands where OSU-HP$_B$ had increased emergence. This was expected because of the increased number of seeds per hole with Drum B compared to JD. Treatments 1 and 2 were not significantly different from 2 and 4 although these received different amounts of fertilizer where 1 and 2 received no N, while both 3 and 4 received 60 kg N ha^{-1} (Table 3)

Yield data were collected at harvest and analysis of variance showed that there was a significant difference in yield (p = .01). Based on a single-degree-of-freedom-contrast analysis, the JD planter showed a significant difference in yield compared to OSU-HP$_{B,}$ p = .0779 Average grain yield (0.8 Mg ha^{-1}) for treatments 1 and 2 was lower than the mean yield for treatments 3 and 4 by more than 146%. The yield difference could be due to 60 kg N ha^{-1} applied in treatments 3 and 4 but not treatments 1 and 2. Also, a single degree of freedom contrast between treatment 5, 6, and 7, 8 did not show any significant difference in yield.

Single degree of freedom contrasts between OSU-HP$_A$ and OSU-HP$_B$, showed that there was no significant difference in yield p = .5059 (Table 4). . The average yield with OSU-HP$_A$ was 79.87% lower than the average yield for OSU-HP$_B$. This could be due to competition resulting from 6 seeds planted per hill associated with OSU-HP$_A$ while OSU-HP$_B$ only delivered 3 seeds per hill.

In general, grain yield was variable with a minimum of 0.7 Mg ha^{-1} and 4.1 Mg ha^{-1} achieved with treatments 2 and 12 respectively. These results suggest that planting 3 sorghum seeds per hill at a spacing of 76 cm × 30 cm and 60 kg N ha^{-1} using OSU-HP$_B$ could improve yield.

Table 5. Sorghum (Sorghum bicolor (L.) Moench) grain yield and emergency as influenced by the number of seeds and plant to plant spacing at LCB in (2016, 2017 and 2019).

	2016		2017		2019	
Treatment	Emergence	yield Mg ha-1	Emergence	yield Mg ha-1	Emergence	yield Mg ha-1
1	61686	4.07	20764	0.35	13096	2.51
2	71370	4.24	14810	0.86	9867	3.2
3	58459	3.93	14955	1.97	10046	3.14
4	66707	3.84	19965	1.62	7535	2.9
5	67783	2.62	18005	0.52	19734	2.59
6	67425	3.4	17787	0.72	9508	2.39
7	73163	2.83	29839	0.93	20990	2.48
8	72446	4.16	10527	0.72	5561	2.7
9	72804	2.71	22070	1.04	10405	3.39
10	67425	4.03	19965	1.65	1615	4.24
11	79977	3.86	19892	0.79	12737	4.54
12	79269	5.55	19167	2.83	5561	5.2
13-check	25822	3.07	19167	0.79	18837	5.46
MSE	87086438	2.33	215813971	0.49	23139504	2.32
SED	7619.55	1.25	11994	0.57	3927.63	1.24
CV, %	14.03	41	60	61	42.98167	44.21

SED – standard error of the difference between two equally replicated means, MSE- Mean square error, CV- Coefficient of variation (%), Check- Stick planter treatment, ns ***, **, * non-significant or significant at P ≤ 0.10, 0.05, 0.01probability level, respectively.

Lake Carl Blackwell (2016)

Emergence data was collected to determine plant population and analysis of variance showed a significant difference in the population stands between the treatments. Treatment 11 had the highest emergence which was a hand planter treatment with Drum-B dropping three seeds per hole at a distance of 0.3 m between plants. However, single-degree-of–freedom-contrasts showed that there was no significant difference in the emergence between OSU-HP_A and OSU-HP_B.

Grain yield was not affected by the various treatment combinations applied at this site in 2016, thus, resulting in similar yield levels among treatments (Table 5). Grain yield varied between 2.6 and 5.6 Mg ha^{-1} with an average of 3.7 Mg ha^{-1}. Similar to results at Efaw in 2016, treatment 12 (OSU-HP_B, 30 cm plant to plant spacing, 3 seeds per hill, and 60 kg N ha^{-1}) had the highest yield when compared to the rest of the treatments with a yield of 5.6 Mg ha^{-1} (Table 5). This grain yield exceeded that of the second-highest yielding treatment 2 (JD mechanical planter, 10 cm within row spacing, 1 seed per hill, and 0 kg N ha^{-1} applied) by 30.9%.

Single-degree-of-freedom-contrasts showed no significant difference between treatments 12 and 13 (check) ($p > .05$). Similar yields were observed because both treatments were planted with three seeds per hole and received the same amount of fertilizer (60 kg N ha^{-1}). At this site, application of N resulted in 12.5% lower grain yield than the average yield for treatments that did not receive N. Yield averaged across N rates, spacing, and the number of seeds per hill revealed that planting sorghum using JD resulted in at least 10.3% yield above other planting methods. Nonetheless, the average yield (4.0 Mg ha^{-1}) achieved using OSU-HP resulted in 18.7% more yield than the conventional stick planter.

Lake Carl Blackwell (2017)

Emergence data was collected at LCB to determine the difference in plant stands for the different treatments and analysis of variance showed that there was no significant difference in emergence for the different treatments (p = .1380). Observations from single-degree-of-freedom-contrasts, showed no significant differences, with emergence being generally poor at this site compared to EFAW. This could have been due to the high level of weed infestation and herbicide damage.

Yield in 2017 at Lake Carl Blackwell is reported in Table 5. Analysis of variance showed that grain yield was not influenced by the different treatments applied (p = .0988). Maximum yield (2.8 Mg ha^{-1})

Table 6. Contrasts between different treatments at LCB (2016, 2017 and 2019).

		p value					
		2016		2017		2019	
Contrasts	Treatments	yield	Emergence	yield	Emergence	yield	Emergence
John Deere vs OSU-HP$_A$	1 to 4 vs 5 to 8	ns	ns	ns	ns	***	ns
John Deere vs OSU-HP$_B$	1 to 4 vs 9 to 12	**	ns	ns	ns	ns	ns
OSU-HP$_A$ vs OSU-HP$_B$	5 to 8 vs 9 to 12	ns	ns	ns	*	*	*
OSU-HP$_B$ vs check	12 vs 13	*	***	ns	*	*	ns
OSU-HP$_B$ vs check	11 vs 13	*	ns	ns	ns	ns	ns
0 N vs 60 kg N	1,2 vs 3,4	ns	ns	ns	*	ns	ns
30 kg vs 60 kg (6 seeds)	5,6 vs 7,8	ns	ns	ns	ns	ns	ns

SED – standard error of the difference between two equally replicated means, MSE- Mean square error, CV- Coefficient of variation (%), Check- Stick planter treatment, ns ***, **, * non-significant or significant at P ≤ 0.10, 0.05, 0.01probability level, respectively.

was obtained with treatment 12 and was followed by treatments 3, 10, and 4. The lowest yield was obtained with treatment 1 (JD planting method, 1 seed per hill at a 10 cm spacing and 0 kg N ha^{-1} applied). In general, planting three seeds per hill had a18.3 and 96.5% greater average yield than 1.2 and 0.7 Mg ha^{-1} generated with 1 and 6 seeds per hill respectively.

Lake Carl Blackwell (2019)

Analysis of variance revealed that the different treatments applied in this study significantly influenced sorghum emergence (p = .0017). Treatment 7 had the highest emergence followed by treatment 5. These two treatments were planted with Drum B calibrated to drop 6 seeds per hole. According to a single degree of freedom contrasts, there were no significant differences in emergence between the JD and the different Drums. Also, there were significant differences in emergency observed for OSU-HP$_A$ and OSU-HP-$_B$.

Analysis of variance showed that there were no significant differences in yield for all treatments at the 0.05 probability level (Table 5). Examining a single degree of freedom contrasts showed a significant difference in the average grain yield of treatment 5 to 8 (OSU-HP$_A$) vs treatment 9 to 12 (OSU-HP$_B$). This result showed that OSU-HP$_A$ yielded 71.0% more than 2.5 Mg ha^{-1} for OSU-HP$_B$. Treatment 13 had the highest yield, which was attributed to the high level of precision when planting since three seeds were deliberately planted. However, this was only noted in 2019 at LCB since this pattern was not exhibited in previous years and locations and the yield level was similar to other treatments.

Treatment 12 still had a high yield of 5.2 Mg ha^{-1}, and all treatments with 3 seeds performed better compared with 6 seeds per hill. One seed per hill also gave a relatively higher yield and based on contrasts, the JD planted treatments were significantly different from SOU-HP$_B$ planted treatments (p = .03) (Table 6).

Discussion

Based on yield results from five site years, grain yield was highly influenced by the different treatments (number of seeds per hill, spacing, and the N rate). Observations from all the site years except in 2019 at LCB showed that grain yields were highest in treatment 12. This particular treatment received 60 kg N ha^{-1} when compared with other treatments in the same group with the same number of seeds and spacing. High yields were associated with 3 seeds per hill compared to 1 seed and 6 seeds per hill. This was possibly due to reduced competition for nutrients within the plants. Bandaru et al. (2006) found that clumping of sorghum in groups of 3 to 6 reduced the number of tillers per plant to only one while uniform spacing would increase to 3 tillers and increased vegetative growth for uniform spacing. They concluded that clumping has the potential to conserve soil moisture, which can enhance grain yield.

Table 7. Total rainfall within the growing season from April to August.

Location	EFAW		Lake Carl Blackwell (LCB)		
year	2016	2017	2016	2017	2019
Rainfall, cm	48.44	63.75	46.28	60	86.36

The nitrogen rate also had a significant impact on grain yield, this was seen when average grain yield for treatment 3 and 4 (both 1 seed per hill), was compared to mean yield for treatment 11 and 12 (both 3 seeds per hill). This study found that when the yield was averaged across planting methods, within row spacing, number of seeds per hill, location, and year, application of N increased yield from 1.9 Mg ha^{-1} without N to 2.7 Mg ha^{-1}. This is consistent with observations made by Melaku et al. (2018) who reported higher yields with an increased rate of application. Teetor, Schmalzel, and Ray (2017) found that planting sweet sorghum in clumps of 3 to 5 resulted in thicker, sturdier stalks with more juice and did not decrease yield in conventionally planted plots. They concluded that planting sorghum in clumps has the potential to increase yields under irrigation.

Staggenborg et al. (1999) found that reducing row spacing below 76 cm, could increase grain yields in high yielding environments but not in low yielding environments. They also added that seeding rates may not necessarily be reduced when narrow rows are used. Conley, Stevens, and Dunn (2005) found non-uniform stands with frequent skips of 183 to 274 cm to have significantly reduced yields compared to the uniform stands of 91 cm skips.

Similar to this study, Snider, Raper, and Schwab (2012) observed maximum yields at a narrow row spacing of 19 cm and concluded that low seeding rates of 116,000 seeds ha^{-1} are preferable. Malik, Hussain, and Awan (2007) also found the greatest fodder yield (77.95 t ha^{-1}) with the highest seed rate (75 kg ha^{-1}) at a narrow row spacing.

The impact of the environment on these field results cannot be overlooked and this was an issue for the low yields reported in one of the three site years 2016, 2017, and 2019. This was observed in the low yields at the EFAW site (less than 3 Mg ha^{-1}) for the highest yield and these low yields were attributed to the reduced amount of rainfall received in the growing season (Table 7). Raun et al. (2019) explained in detail the effect of changes in the environment on grain yield and addressed the need for a midseason algorithm that can be used to accurately predict crop needs. Variability in yield from year to year and from location to location was also reported by Dhital and Raun (2016). This suggests that each year's needs or location need to be treated separately in terms of nutrient management.

Conclusions

Clumping of sorghum in groups of 3 seeds per hole at a uniform plant to plant spacing of 0.3 m increased grain yields compared to 6 seeds at a plant to plant spacing of 0.6 m. The lower plant population with a 0.76 m × 0.30 m configuration could have contributed to reduced competition for nutrients and moisture. Applying N also improved sorghum grain yield for most of the site years used in this study. Results from this study suggest the need to use correct spacing and the number of seeds planted per hill while also supplementing it with N application as dictated by demand from the environment. This work showed that producers could improve sorghum grain yield by integrating OSU-HP as one of the tools for agronomic practices used in crop production.

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References

Aula, L., J. S. Dhillon, P. Omara, G. B. Wehmeyer, K. W. Freeman, and W. R. J. A. J. Raun. 2019. World sulfur use efficiency for cereal crops. *Agronomy Journal* 111 (2485–2492). doi:10.2134/agronj2019.02.0095.

Bandaru, V., B. Stewart, R. Baumhardt, S. Ambati, C. Robinson, and A. Schlegel. 2006. Growing dryland grain sorghum in clumps to reduce vegetative growth and increase yield. *Agronomy Journal* 98 (4):1109–20. doi:10.2134/agronj2005.0166.

Bayu, W., N. Rethman, and P. Hammes. 2005. Growth and yield compensation in sorghum (Sorghum bicolor L. Moench) as a function of planting density and nitrogen fertilizer in semi-arid areas of northeastern Ethiopia. *South African Journal of Plant and Soil* 22 (2):76–83. doi:10.1080/02571862.2005.10634685.

Berenji, J., and J. Dahlberg. 2004. Perspectives of sorghum in Europe. *Journal of Agronomy and Crop Science* 190 (5):332–38. doi:10.1111/j.1439-037X.2004.00102.x.

Chala, A., A. Tronsmo, and M. Brurberg. 2011. Genetic differentiation and gene flow in Colletotrichum sublineolum in Ethiopia, the centre of origin and diversity of sorghum, as revealed by AFLP analysis. *Plant Pathology* 60 (3):474–82. doi:10.1111/j.1365-3059.2010.02389.x.

Chim, B. K., P. Omara, N. Macnack, J. Mullock, S. Dhital, and W. Raun. 2014. Effect of seed distribution and population on maize (Zea mays L.) grain yield. *International Journal of Agronomy 2014* 2014:1–8. doi:10.1155/2014/125258.

Conley, S. P., W. Stevens, and D. D. Dunn. 2005. Grain sorghum response to row spacing, plant density, and planter skips. *Crop Management* 4 (1):0–0. doi:10.1094/CM-2005-0718-01-RS.

Dahlberg, J., J. Berenji, V. Sikora, and D. Latkovic. 2011. Assessing sorghum [Sorghum bicolor (L) Moench] germplasm for new traits: Food, fuels & unique uses. *Maydica* 56:85–92.

Dhillon, J. S., E. Eickhoff, R. Mullen, and W. R. J. A. J. Raun. 2019. World potassium use efficiency in cereal crops. *Agronomy Journal* 111 (889–896). doi:10.2134/agronj2018.07.0462.

Dhital, S., and W. R. Raun. 2016. Variability in optimum nitrogen rates for maize. *Agronomy Journal* 108 (6):2165–73. doi:10.2134/agronj2016.03.0139.

Dicko, M. H., H. Gruppen, A. S. Traoré, A. G. Voragen, and W. J. Van Berkel. 2006. Sorghum grain as human food in Africa: Relevance of content of starch and amylase activities. *African Journal of Biotechnology* 5:384–95.

Dykes, L., W. L. Rooney, and L. W. Rooney. 2013. Evaluation of phenolics and antioxidant activity of black sorghum hybrids. *Journal of Cereal Science* 58 (2):278–83. doi:10.1016/j.jcs.2013.06.006.

Fernandez, C. J., D. D. Fromme, and W. J. Grichar. 2012. Grain sorghum response to row spacing and plant populations in the Texas Coastal Bend Region. *International Journal of Agronomy 2012* 2012:1–6. doi:10.1155/2012/238634.

Godsey, C., J. Linneman, D. Bellmer, and R. Huhnke. 2012. Developing row spacing and planting density recommendations for rainfed sweet sorghum production in the southern plains. *Agronomy Journal* 104 (2):280–86. doi:10.2134/agronj2011.0289.

Heslehurst, M. 1983. Effect of population design and planting pattern on yield response of grain sorghum. *Field Crops Research* 7:213–22. doi:10.1016/0378-4290(83)90024-2.

Malik, M. F. A., M. Hussain, and S. I. Awan. 2007. Yield response of fodder sorghum (Sorghum bicolor) to seed rate and row spacing under rain-fed conditions. *Journal of Agriculture and Social Sciences* 3:95–97.

Melaku, N. D., W. Bayu, F. Ziadat, S. Strohmeier, C. Zucca, M. L. Tefera, B. Ayalew, A. Klik. 2018. Effect of nitrogen fertilizer rate and timing on sorghum productivity in Ethiopian highland Vertisols. *Archives of Agronomy and Soil Science* 64 (4):480–91. doi:10.1080/03650340.2017.1362558.

Moges, S. M., K. Girma, R. K. Teal, K. W. Freeman, H. Zhang, D. B. Arnall, S. L. Holtz, B. S. Tubaña, O. Walsh, B. Chung, et al. 2007. In-season estimation of grain sorghum yield potential using a hand-held optical sensor. *Archives of Agronomy and Soil Science* 53 (6):617–28. doi:10.1080/03650340701597251.

Raun, W. R., J. Dhillon, L. Aula, E. Eickhoff, G. Weymeyer, B. Figueirdeo, T. Lynch, P. Omara, E. Nambi, F. Oyebiyi, et al. 2019. Unpredictable nature of environment on nitrogen supply and demand. *Agronomy Journal* 111 (6):2786–91. doi:10.2134/agronj2019.04.0291.

Rooney, W. 2004. Sorghum improvement—integrating traditional and new technology to produce improved genotypes. *Advances in Agronomy* 83:37–109.

Snider, J. L., R. L. Raper, and E. B. Schwab. 2012. The effect of row spacing and seeding rate on biomass production and plant stand characteristics of non-irrigated photoperiod-sensitive sorghum (Sorghum bicolor (L.) Moench). *Industrial Crops and Products* 37 (1):527–35. doi:10.1016/j.indcrop.2011.07.032.

Staggenborg, S., D. Fjell, D. Devlin, W. Gordon, and B. Marsh. 1999. Grain sorghum response to row spacings and seeding rates in Kansas. *Journal of Production Agriculture* 12 (3):390–95. doi:10.2134/jpa1999.0390.

Steiner, J. 1986. Dryland grain sorghum water use, light interception, and growth responses to planting geometry. *Agronomy Journal* 78:720–26. doi:10.2134/agronj1986.00021962007800040032x.

Teetor, V., C. Schmalzel, and D. T. Ray. 2017. Growing sweet sorghum (Sorghum bicolor [L.] moench) in clumps potentially reduces lodging in the arid-southwestern United States. *Industrial Crops and Products* 107:458–62. doi:10.1016/j.indcrop.2017.05.064.