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Evaluation of drum cavity size and planter tip on singulation and plant emergence in maize (*Zea mays* L.)

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ABSTRACT
Thirty million hectares of maize (*Zea mays* L.) in the developing world are planted and harvested by hand. Indigenous planting encumbers placing two to three seeds per hill and this results in uneven spacing and decreased yields. Oklahoma State University (OSU) built a new hand planter to deliver single seeds with each strike (singulation). This planter includes a range in cavity sizes so as to accommodate different seeds. At all sites, the OSU internal drum resulted in similar emergence as the checks were planted by hand, and a John Deere vacuum planter. Developing world maize producers can use the OSU hand planter with drum "450S" if seeds are in the 2500–4000 seeds/kg range using a conventional metal tip. This planter also removes the chemically treated seed from producer's hands, reduces health risks, and serves as a mid-season fertilizer applicator.

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KEYWORDS
hand planter; plant population; plant stand; side-dress N-fertilizer application; singulation

Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops produced in the world. By 2013, world maize production exceeded 1 billion metric tons (FAOSTAT, 2016) and accounts for the largest tonnage produced by any major cereal. Maize accounts for 30% of the total world food calories (Shiferaw et al. 2011). Despite the high production, 800 million people including women and children consume less than 2000 calories a day (Conway and Toenniessen 1999). According to Cairns et al. (2012), the demand for maize will double in developing countries by 2050; with the global population expected to exceed 9 billion and the highest population growth occurring in developing countries. To meet the demand of a growing population, agriculture production should be doubled on land already under cultivation (Borlaug and Dowswell 2003).

In developing countries, 30 Mha of maize is planted by hand where average yields are near 1.8 Mg ha^{-1} (FAOSTAT, 2016). Farmers in developing countries practice farming on a small scale (0.1–2 ha) and are resource poor (Ibeawuchi et al. 2009). Commonly used implements for hand planting include a stick planter, cutlass, dibbler, or hoe depending on local traditions, which are highly labor intensive (Adjei et al. 2003). Omara et al. (2016) observed that when planted by hand, two to three maize seeds are dropped per hill and covered by surrounding soil. This results in multiple seeds that emerge, non-uniform germination, seed rotting due to deep planting and loss of seed due to improper covering (Aikins, Bart-Plange, and Opoku-Baffour 2010).

Chim et al. (2014) reported that placing one instead of two or three seeds per hill could increase yields by 40%. Furthermore, many researchers have reported the importance of homogenous crop

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stands in order to achieve increased yields (Nafziger, Carter, and Graham 1991; Ford and Hicks 1992; Nielson 2004; Liu et al. 2004; Tollenaar et al. 2006; Rutto et al. 2014). Improved plant stand homogeneity should lead to increased water use efficiency, nutrient use efficiency, solar radiation, and biomass production (Shibles and Weber 1966; Bullock, Nielsen, and Nyquist 1988). This is currently lacking in many developing countries where two to three seeds are planted per hill resulting in heterogeneous competition and decreased yields. Single seed placement could help to reduce this in-field heterogeneity. Other reasons for heterogeneous emergence has been attributed to uneven depth of sowing (Alessi and Power 1971; Gupta, Schneider, and Swan 1988; Carter, Nafziger, and Lauer 1990). Uneven emergence results in yield loss (Nafziger, Carter, and Graham 1991; Martin et al. 2005), late emerging plants become weeds competing for moisture and nutrients (Raun, Sander, and Olson 1986), and every one-day delay in emergence can reduce yield by 1% (Nielson 2004).

It has been suggested that a semi-mechanized hand planter could enable small scale farmers to work with improved efficiency (Ukatu 2001; Aikins et al. 2011). Although there have been numerous attempts to develop maize hand planters for farmers in developing countries, there have been few products developed that actually singulate individual maize seed. Aikins, Bart-Plange, and Opoku-Baffour (2010) compared 30 local hand planters with five different maize varieties and four different fertilizer rates. They noted poor quality control in manufacturing the planters and this was the cause of the poor performance.

Oklahoma State University (OSU) developed a singulating maize hand planter (GreenSeeder) capable of placing one seed at a time, with up to 80% singulation efficiency and 20% multiple seed delivery over a range of seed sizes (Omara et al. 2016).

The OSU hand planter offers additional benefits like removal of chemically treated seeds from farmer's hands, decreased soil erosion due to improved homogeneity of the plant stand, and a method to accommodate mid-season fertilizer application. Most of the seeds that are available to the farmers *via* seed companies are pretreated with fungicides and insecticides. Using treated seeds have benefits like increased yields and improved food safety (Cooper and Dobson 2007; Wilde et al. 2007; Nuyttens et al. 2013), but it also has added health risks due to seed-to-skin exposure to the pesticides (Brown et al. 1990; Blakley et al. 1999: Van Maele-Fabry et al. 2010). Additionally, by simply changing the internal drum, the OSU hand planter can serve as a mid-season fertilizer applicator, where fertilizer can be placed beneath the soil surface. Applying fertilizer without incorporation results in lower yields (Fox and Hoffman 1981; Mengel, Nelson, and Huber 1982), increased fertilizer losses (Fowler and Brydon 1989; Bandel, Dzienia, and Stanford 1980; Ernst and Massey 1960; Hargrove, Kissel, and Fenn 1977; Terman 1979; Volk 1959), and decreased nitrogen use efficiency (Raun and Johnson 1999).

A comprehensive review and description of the OSU hand planter was delineated by Omara et al. (2016). The OSU hand planter can be easily operated by striking the ground surface with the planter leaning towards the operator, keeping the tip in the ground and moving the handle forward and then removing the planter from that strike while moving forward. With each strike, a reciprocating drum rotates upward and receives one seed; excess seeds are removed by an internal brush, and each individual seed is dropped as the planter is relaxed (moving upwards), thus rotating the internal drum. It is an all-terrain hand planter capable of being operated in topographically steep slopes (hilly areas) that are not well suited to being mechanized. Planting with the OSU hand planter is less labor intensive than the traditional hand planting operation of making a hole, bending to drop seeds within the hole, and covering it with surrounding soil.

The drum cavity and angle (internal drum) have proven to be crucial for delivering a single seed per strike during operation of the OSU hand planter (Omara et al. 2016). Previous testing has also shown that during planting, the depth to which the seed is planted can vary greatly. Heterogeneity of planting depth can lead to delayed emergence (Gupta, Schneider, and Swan 1988; Ford and Hicks 1992), and delayed emerging plants result in reduced yields (Nafziger, Carter, and Graham 1991; Lawles et al. 2012). Depth control (tip stop), recently installed, can aid in planting seeds at a uniform depth. This variable along with the different internal drums has not been comprehensively evaluated.

This study was conducted to evaluate the effect of drum cavity size and tip-depth control on emergence and yield of maize using a new hand planter developed by OSU.

Materials and methods

Experimental site

Maize trials were evaluated over six site-years. In June 2014, two experiments were established at the Stillwater Agronomy Research Station and Efaw, just north of the Stillwater. Also, two maize trials were established in April 2015 and 2016 at Lake Carl Blackwell (LCB) and Efaw. Soil classification at each site is reported in Table 1.

Experiment layout and management

Randomized complete block experimental designs were used at all sites with three replications. In 2014, nine treatments were evaluated at both experimental sites. Plant population was kept at 74,000 seeds ha^{-1} with a row spacing of 76 cm, and a plant-to-plant spacing of 18 cm. A string was marked to keep uniform spacing for all the hand planter treatments. Two manual checks were planted with a wooden stick planter, where a hole was made using the stick planter and one seed was dropped by hand, per hole. To keep the targeted population, 34 strikes were made with the hand planter in one row (over a distance of 76 cm). One check was planted using a John Deere MaxEmerge 2 vacuum planter (JD-planter), at 3.2 km/hr. This planter was adjusted to provide an 18-cm targeted plant spacing. In 2015 and 2016, 12 treatments were used at both sites. No tillage and conventional tillage were employed at Efaw and LCB, respectively, with a plant population of 64,000 seeds ha^{-1}, row spacing of 76 cm, and plant-to-plant spacing of 20.5 cm. A string was marked at each 20.5 cm to ensure uniform spacing; two manual checks were planted as in 2014. Thirty-one strikes were made to arrive at the targeted population with hand planted treatments. In 2015 and 2016, two checks were planted using a JD-planter, keeping the speed at 3.2 km/hr, and a targeted plant spacing of 20.5 cm. Field activities for all six site-years are presented in Table 2. Two internal drums were used, 450S and 260-20 (Figure 1). The drums differ by volume; 450S has a volume of 0.087 mL compared to 260-20, which has a 0.055-mL volume. Tips evaluated were conventional, and another with a welded stop (Figure 2). The conventional tip can achieve a planting depth of 6–10 cm depending upon the soil, tillage, and force applied by the operator. To ensure uniform depth, a welded stop was added that restricted planting depth to 6 cm. A uniform rate of 100 kg N/ha urea ammonium nitrate (UAN) preplant and side-dress (50 preplant, 50 side-dress) was applied in all treatments in 2014, 2015, and 2016.

Daily emergence data was collected from the center two rows until the 3 leaf stage. Because a fixed number of planter strikes were made, skips in emergence were considered as misses (no seed dropped).

Table 1. Description of soil series at Stillwater, Efaw, and Lake Carl Blackwell, OK.

Location	Soil Series
Stillwater, OK	Kirkland Silt Loam (fine, mixed, thermic Udertic Paleustolls)
Efaw, OK	Ashport silty clay loam (fine-silty, mixed, superactive, thermic Fluventic Haplustolls)
Lake Carl Blackwell, OK	Port Silt Loam (fine-silty, mixed, thermic Cumulic Haplustolls)

Table 2. Field activities for each location, 2014, 2015, and 2016.

	2014		2015		2016	
Field Activity	Efaw[†]	Stillwater	Efaw	LCB	Efaw	LCB
Pre-plant N-fertilization	July 02	July 02	April 07	April 07	April 06	April 06
Planting Side-dress	July 03 August 14	July 03 August 14	April 21 June 09	April 21 June 10	April 14 June 02	April 07 June 06
Harvest	November 13	November 13	September 03	September 02	August 25	September 06

[†]Efaw, Oklahoma Agricultural Experiment Station near Stillwater, OK; LCB, Oklahoma Agricultural Experiment Station west of Stillwater, OK near Lake Carl Blackwell.

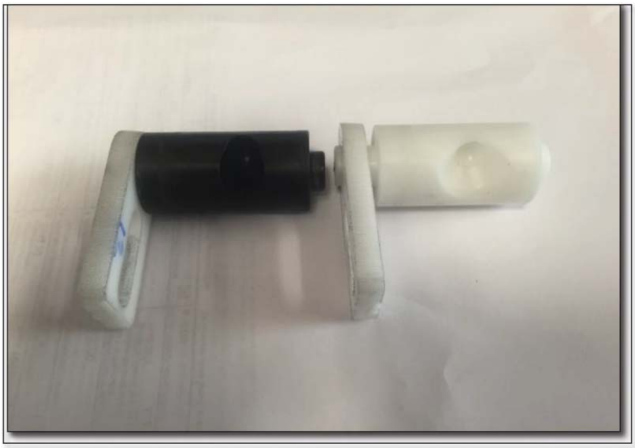

Figure 1. Drum 260-20 and drum 450S.

For emergence data, multiples were recorded as one plant, keeping emergence less than 100%. For JD-planter checks, plants that emerged between the targeted spacing were counted as multiples. Singulation is the same as “quality of feed” defined by Kachman and Smith (1995). It was computed by subtracting all the multiples from total emergence within that respective treatment. All plots were sensed using the GreenSeeker Handheld sensor (Trimble, Ukiah, CA) at different growth stages. Iowa State University terminology (1993) was used to determine maize growth stage.

Normalized difference vegetation index (NDVI) data was collected keeping the GreenSeeker^{TM} sensor approximately 70 cm above the crop canopy and collected over the center two rows. The GreenSeeker sensor calculates NDVI using the equation as follows:

$$\text{NDVI} = \frac{\rho NIR - \rho Red}{\rho NIR + \rho Red}$$

where near infrared (NIR) and red are reflectance measured in near infrared (780 nm) and red (650 nm) wavelengths, respectively (Bushong et al. 2016).

Figure 2. Conventional and tip with a welded stop.

In 2014 and 2016, experimental plots were harvested by hand while in 2015, a self-propelled Massey Ferguson 8XP Combine (AGCO Corp., Duluth, GA) equipped with harvest master (Juniper Systems Inc., Logan, UT) automated weighing system was used for harvesting the center two of four rows. Moisture content for final grain yield was adjusted to 15.5%. Plot subsamples were taken and then dried at 75°C for 2 days, ground to pass a 240-mesh screen and analyzed for total N using a LECO TruSpec CN dry combustion analyzer (Schepers, Francis, and Thompson 1989).

Data analysis

All data including total emergence, singulation, (NDVI) sensor data, number of ears (2014 and 2016), and grain yield were statistically analyzed using SAS (SAS Institute, Cary, NC, USA). Analysis of variance (ANOVA) was performed using PROC GLM and mean separation was performed using LSD ($\alpha = 0.05$). Single-degree-of-freedom contrasts were used to evaluate specific treatment differences.

Results

Efaw (2014)

Analysis of variance showed significant treatment differences in emergence ($\alpha = 0.05$) (Table 3). The maximum emergence was achieved with drum 450S, 3808 seeds/kg using the welded tip-stop, that also had higher emergence compared to other treatments. Non-orthogonal, single-degree-of-freedom contrasts, showed significantly better emergence with drum 450S over 260-20 (450S *vs* 260-20, Table 3). It was also observed with single-degree-of-freedom contrasts that when maize with 3449 seeds/kg was used, better emergence was recorded compared to 3808 seeds/kg (3449 *vs* 3808, Table 3). Differences in singulation due to treatments were significant ($\alpha = 0.05$) (Table 3). All the checks observed had better singulation than hand planter treatments using single-degree-of-freedom contrasts (check *vs* hand planter and JD-planter *vs* hand planter, Table 3). Overall, single-degree-of-freedom contrasts showed that drum 260-20 was better at singulating seed than 450S (450S *vs* 260-20, Table 3). Sensor NDVI data at the V10 growth stage showed highly significant treatment differences ($\alpha = 0.05$) (Table 3). Single-degree-of-freedom contrasts indicated higher NDVI values for the check treatments compared to

Table 3. Treatment structure, emergence, singulation, NDVI, grain yield, and number of ears as influenced by seed size (3449, 3808, seeds/kg), drum cavity size (450S, 260-20), and hand planter tip (N or normal, and WS or tip with welded stop), Efaw, OK, 2014.

Treatment	Drum Cavity	Planter Tip	Seeds, #/kg	Emergence, %	Singulation, %	NDVI	Ears Numbers, ha^{-1}	Grain Yield, Mg ha^{-1}
1	Check		3449	92^{AB}	91^{A}	0.80^{AB}	68889^{AB}	6.7^{A}
2	Check		3808	87^{ABC}	86^{A}	0.82^{A}	58125^{BC}	6.6^{A}
3	450S	N	3449	92^{AB}	62^{BC}	0.80^{AB}	72836^{A}	6.2^{BA}
4	450S	N	3808	78^{BCD}	45^{D}	0.78^{AB}	67095^{AB}	5.5^{ABC}
5	450S	WS	3808	100^{A}	57^{BC}	0.81^{AB}	70683^{AB}	6.1^{ABC}
6	260-20	N	3449	84^{ABCD}	65^{BC}	0.76^{B}	49873^{CD}	5.9^{ABC}
7	260-20	N	3808	66^{D}	53^{CD}	0.76^{B}	44850^{CD}	4.9^{BC}
8	260-20	WS	3808	72^{CD}	65^{B}	0.76^{B}	36239^{D}	4.7^{C}
9	JD-Planter		3808	87^{ABC}	86^{A}	0.79^{AB}	65301^{AB}	6.4^{A}
MSE				131	47	0.0009	63707353	0.70
SED				9	6	0.02	6517	0.70
CV,%				14	10	4	13	44
Contrasts		Treatments						
Check *vs* hand planter		1–2 *vs* 3–8		ns	*	***	***	**
JD-planter *vs* hand planter		3–8 *vs* 9		ns	*	ns	ns	ns
450S *vs* 260-20		3–5 *vs* 6–8		*	***	**	*	***
3449 *vs* 3808		1–3-6 *vs* 2–4–5–7–8–9		**	ns	***	*	ns

SED – standard error of the difference between two equally replicated means, CV – coefficient of variation, %, MSE -mean square error from analysis of variance, Check- entire plot planted by hand (stick planter), means followed by the same letter were not significantly different at the 5% probability level. ^{ns}, *, **, ***, non-significant or significant at $p \leq 0.01$, 0.05, and 0.10 probability level, respectively.

hand planter treatments (Treatments 1–2 *vs* 3–8 and 9 *vs* 3–8, Table 3). It was also observed that drum 450S had increased NDVI versus drum 260-20, indicating that better surface coverage was encountered, and possibly improved plant homogeneity (450S *vs* 260-20, Table 3). Analysis of variance showed significant treatment differences in number of ears ($\alpha = 0.05$) (Table 3). Single degree-of-freedom contrasts showed that drum 450S had elevated number of ears when compared to 260-20 (450S *vs* 260-20, Table 3). Number of ears was also higher using 3449 seeds/kg compared to 3808 seeds/kg (3449 *vs* 3808, Table 3). Maize grain yield values ranged from 4.7 to 6.7 Mg ha^{-1} (Table 3). Effect of seed size, drum cavity size, and planter tip showed very moderate differences (Table 3). Single-degree-of-freedom contrasts indicated an increase in grain yield with drum 450S compared to 260-20 (450S *vs* 260-20, Table 3).

Stillwater (2014)

Analysis of variance showed significant differences in emergence among treatments ($\alpha = 0.05$) (Table 4). It was observed that drum 450S resulted in significantly better emergence than drum 260-20 using single-degree-of-freedom contrasts (450S *vs* 260-20, Table 4). Furthermore, emergence in the check plots was higher than that observed for hand planter treatments (Treatments 1–2 *vs* 3–8 and 9 *vs* 3–8, Table 4). Analysis of variance also found significant treatment differences in singulation ($\alpha = 0.05$) (Table 4). Increased singulation in check treatments compared to the hand planter treatments was observed (Treatments 1–2 *vs* 3–8 and 9 *vs* 3–8, Table 4). At Efaw, NDVI was collected at the V10 growth stage, where significant treatment differences were observed ($\alpha = 0.05$) (Table 4). The use of drum 450S resulted in higher NDVI compared to drum 260-20 (Contrast 450S *vs* 260-20, Table 4). Also, NDVI values improved with the use of the weld stop tip compared to the normal tip (N *vs* WS, Table 4). Treatment differences for total number of ears per plot were also found ($\alpha = 0.05$) (Table 4). Drum 450S had more ears compared to drum 260-20 (450S *vs* 260-20, Table 4). Single-degree-of-freedom contrasts also showed a higher number of ears with 3449 seeds/kg, compared to 3808 seeds/kg (3449 *vs* 3808, Table 4). Grain yield ranged between 2.9 and 5.2 Mg ha^{-1} (Table 4). Effect of seed size, drum cavity size, and planter tip was not significant for yield (Table 4). However, grain yields were higher for the JD-planter compared to the hand planter treatments (Treatment 9 *vs* 3–8, Table 4).

Table 4. Treatment structure, emergence, singulation, NDVI, grain yield, and number of ears as influenced by seed size (3449, 3808, seeds/kg), drum cavity size (450S, 260-20), and hand planter tip (N or normal, and WS or tip with welded stop), Stillwater, OK, 2014.

Treatment	Drum Cavity	Planter Tip	Seeds, #/kg	Emergence, %	Singulation, %	NDVI	Ears Numbers, ha^{-1}	Grain Yield, Mg ha^{-1}
1	Check		3449	99^{A}	99^{A}	0.69^{AB}	63507^{A}	4.3^{ABC}
2	Check		3808	99^{A}	99^{A}	0.69^{AB}	48796^{BCD}	3.8^{BCD}
3	450S	N	3449	100^{A}	74^{AB}	0.68^{AB}	72118^{A}	4.1^{ABCD}
4	450S	N	3808	100^{A}	81^{AB}	0.61^{D}	45926^{CD}	3.3^{CD}
5	450S	WS	3808	100^{A}	74^{AB}	0.71^{A}	64583^{A}	3.1^{CD}
6	260-20	N	3449	77^{B}	62^{B}	0.63^{CD}	58125^{ABC}	4.6^{AB}
7	260-20	N	3808	82^{B}	71^{AB}	0.61^{D}	40903^{D}	2.9^{D}
8	260-20	WS	3808	61^{C}	61^{B}	0.65^{BCD}	43055^{D}	3.4^{BCD}
9	JD-Planter		3808	98^{A}	97^{A}	0.68^{ABC}	61713^{AB}	5.2^{A}
MSE				14	282	0.0011	71654562	0.55
SED				3	14	0.02	6911	0.60
CV,%				4	21	5	15	19
Contrasts		Treatments						
Check *vs* hand planter		1–2 *vs* 3–8		*	*	*	ns	ns
JD-planter *vs* hand planter		3–8 *vs* 9		*	*	ns	ns	*
450S *vs* 260-20		3–5 *vs* 6–8		*	ns	**	*	ns
3449 *vs* 3808		1–3–6 *vs* 2–4–5–7–8–9		*	ns	**	*	ns

SED – standard error of the difference between two equally replicated means, CV – coefficient of variation, %, MSE -mean square error from analysis of variance, Check-entire plot planted by hand (stick planter), means followed by the same letter were not significantly different at the 5% probability level. ^{ns}, *, **, ***, non-significant or significant at $p \leq 0.01$, 0.05, and 0.10 probability level, respectively.

Efaw (2015)

Analysis of variance showed significant differences in emergence for the treatments evaluated ($\alpha = 0.05$) (Table 5). Drum 450S resulted in significantly better emergence than drum 260-20 (450S *vs* 260-20, Table 5). Single-degree-of-freedom contrasts indicated that emergence in check plots was better than hand planter treatments (Treatments 1–2 *vs* 3–8 and 9 *vs* 3–8, Table 5). Differences in singulation were highly significant ($\alpha = 0.05$) (Table 5). Singulation was better in check plots than hand planter treatments (Treatments 1–2 *vs* 3–10 and 11–12 *vs* 3–10, Table 5). Sensor NDVI was collected at V5, V6, and V9 growth stages. This parameter showed no treatment differences ($\alpha = 0.05$) (Table 5). However, it was observed that 2651 seeds/kg had significantly higher NDVI when compared to 3962 seeds/kg (2651 *vs* 3962, Table 5). Grain yield ranged between 3.4 and 8.4 Mg ha^{-1} (Table 5). Effect of seed size, drum cavity size, and planter tip was not significant for yield (Table 5). Yields were greater using 2651 seeds/kg than 3962 seeds/kg (2651 *vs* 3962, Table 5).

Lake Carl Blackwell (2015)

Treatment differences in emergence were observed ($\alpha = 0.05$) (Table 6). Drum 450S had increased emergence compared to drum 260-20 (450S *vs* 260-20, Table 6). Furthermore, emergence in check plots was better than hand planter treatments (Treatment 1–2 *vs* 3–10 and 11–12 *vs* 3–10, Table 6) and emergence improved when using the weld stop tip (N *vs* WS, Table 6). Differences in singulation due to treatments were significant ($\alpha = 0.05$) (Table 6). Singulation was better in check plots when compared to the hand planter treatments (Treatments 1–2 *vs* 3–10 *vs* 11–12 *vs* 3–10, Table 6). Within hand planter treatments, drum 260-20 resulted in better singulation when compared to 450S (contrast 450S *vs* 260-20, Table 6) and singulation was improved with larger seed sizes (2651 *vs* 3962, Table 6). No differences were recorded for NDVI collected at V5, V6, and V9 growth stages. A trend for drum 450S to be higher compared to 260-20 was recorded (450S *vs* 260-20, Table 6). Grain yield ranged between 0.7 and 4.2 Mg ha^{-1} (Table 6). Effect of seed size, drum cavity size, and planter tip was significant for yield

Table 5. Treatment structure, emergence, singulation, NDVI, and grain yield as influenced by seed size (2651, 3962, seeds/kg), drum cavity size (450S, 260-20), and hand planter tip (N or normal, and WS or tip with welded stop), Efaw, OK, 2015.

Treatment	Drum Cavity	Planter Tip	Seeds, #/kg	Emergence, %	Singulation, %	NDVI	Grain Yield, Mg ha^{-1}
1	Check		2651	96^{A}	96^{A}	0.88^{A}	7.5^{AB}
2	Check		3962	88^{AB}	88^{A}	0.86^{AB}	4.9^{ABC}
3	450S	N	2651	77^{BCDE}	57^{C}	0.87^{AB}	7.2^{ABC}
4	450S	N	3962	87^{AB}	40^{D}	0.84^{B}	4.4^{BC}
5	450S	WS	2651	66^{DEF}	46^{CD}	0.84^{B}	5.2^{ABC}
6	450S	WS	3962	81^{ABCD}	45^{CD}	0.86^{AB}	3.4^{C}
7	260-20	N	2651	71^{CDEF}	54^{C}	0.86^{AB}	4.2^{BC}
8	260-20	N	3962	59^{F}	47^{CD}	0.83^{B}	4.2^{BC}
9	260-20	WS	2651	64^{EF}	53^{CD}	0.89^{A}	8.4^{A}
10	260-20	WS	3962	67^{DEF}	50^{CD}	0.85^{AB}	3.9^{BC}
11	JD-Planter		2651	85^{ABC}	84^{AB}	0.86^{AB}	6.7^{ABC}
12	JD-Planter		3962	81^{ABCD}	75^{B}	0.87^{AB}	4.5^{ABC}
MSE				82	63	0.0007	5.6
SED				7	6	0.02	1.9
CV,%				12	13	3	4
Contrast		Treatments					
Check *vs* hand planter		1–2 *vs* 3–10		*	*	ns	ns
JD-planter *vs* hand planter		3–10 *vs* 11–12		**	*	ns	ns
450S *vs* 260-20		3–6 *vs* 7–10		*	ns	ns	ns
2651 *vs* 3962		1–3–5–7–9–11 *vs* 2–4–6–8–10–12		ns	*	***	*

SED – standard error of the difference between two equally replicated means, CV – coefficient of variation, %, MSE -mean square error from analysis of variance, check-entire plot planted by hand (stick planter), means followed by the same letters were not significantly different at the 5% probability level. ^{ns}, *, **, ***, non-significant or significant at $p \leq 0.01$, 0.05, and 0.10, probability level respectively.

Table 6. Treatment structure, emergence, singulation, NDVI, and grain yield as influenced by seed size (2651, 3962, seeds/kg), drum cavity size (450S, 260-20), and hand planter tip (N or normal, and WS or tip with welded stop), Lake Carl Blackwell, OK, 2015.

Treatment	Drum Cavity	Planter Tip	Seeds, #/kg	Emergence, %	Singulation, %	NDVI	Grain Yield, Mg ha^{-1}
1	Check		2651	99^{A}	99^{A}	0.81^{AB}	3.7^{A}
2	Check		3962	98^{A}	98^{A}	0.79^{ABC}	2.8^{ABC}
3	450S	N	2651	80^{BC}	46^{D}	0.81^{BC}	2.4^{BCD}
4	450S	N	3962	96^{A}	28^{E}	0.81^{A}	1.5^{CDE}
5	450S	WS	2651	94^{A}	52^{CD}	0.79^{ABC}	0.7^{E}
6	450S	WS	3962	97^{A}	25^{E}	0.81^{AB}	0.9^{DE}
7	260-20	N	2651	75^{C}	73^{B}	0.79^{BC}	2.3^{BCDE}
8	260-20	N	3962	74^{C}	59^{C}	0.79^{BC}	1.6^{CDE}
9	260-20	WS	2651	85^{B}	83^{B}	0.79^{BC}	2.7^{ABC}
10	260-20	WS	3962	76^{C}	56^{CD}	0.78^{C}	0.9^{DE}
11	JD-Planter		2651	99^{A}	98^{A}	0.81^{AB}	4.2^{A}
12	JD-Planter		3962	99^{A}	98^{A}	0.79^{ABC}	1.9^{CDE}
MSE				25	42	0.0002	0.9
SED				4	5	0.01	0.8
CV,%				6	9	2	45
Contrast		Treatments					
Check *vs* hand planter		1–2 *vs* 3–10		*	*	ns	*
JD-planter *vs* hand planter		3–10 *vs* 11–12		*	*	ns	*
450S *vs* 260-20		3–6 *vs* 7–10		*	*	*	ns
2651 *vs* 3962		1–3–5–7–9–11 *vs* 2–4–6–8–10–12		ns	*	ns	*

SED – Standard error of the difference between two equally replicated means, CV – coefficient of variation, %, MSE -mean square error from analysis of variance, Check-entire plot planted by hand (stick planter), means followed by the same letter were not significantly different at the 5% probability level. ^{ns}, *, **, ***, non-significant or significant at $p \leq 0.01$, 0.05, and 0.10 probability level, respectively.

(Table 6). Increased yields in check plots were observed when compared to hand planter treatments (1–2 *vs* 3–10 and 11–12 *vs* 3–10, Table 6). Within hand planted treatments, the normal tip resulted in higher yields compared to the weld-stop tip (contrast N *vs* WS, Table 6).

Efaw (2016)

Analysis of variance showed significant differences in emergence for the treatments evaluated ($\alpha = 0.05$) (Table 7). Drum 450S resulted in significantly better emergence than drum 260-20 (Contrast 450S *vs* 260-20, Table 7). Emergence in check plots was better than hand planter treatments (Treatments 1–2 *vs* 3–8 and 9 *vs* 3–8, Table 7). Differences in singulation were highly significant ($\alpha = 0.05$) (Table 7). Singulation was better in check plots than hand planter treatments (Treatments 1–2 *vs* 3–10 and 11–12 *vs* 3–10, Table 7). The highest singulation achieved was with drum 260-20 (Treatment 7). NDVI was collected at V4, V8, and V10 growth stages. NDVI was not significantly different among treatments ($\alpha = 0.05$) (Table 7). Treatment differences for ear number were significant. Hand planted treatments with drum 450S had the highest number of ears (Treatment 4, Table 7). Grain yield ranged between 2.7 and 9.1 Mg ha^{-1} (Table 7). Effect of seed size, drum cavity size, and planter tip was not significant for yield (Table 7). Yields were greater using 3962 seeds/kg compared to 2651 seeds/kg (2651 *vs* 3962, Table 7). Furthermore, drum 260-20 had better yields compared to drum 450S (Table 7).

Lake Carl Blackwell (2016)

Emergence was not significantly different for treatments (Table 8). However, checks with the JD-planter had increased emergence compared to hand planted treatments (450S *vs* 260-20, Table 8). Differences in singulation due to treatments were significant ($\alpha = 0.05$) (Table 8). Singulation was better in check plots when compared to the hand planter treatments (Treatments 1–2 *vs* 3–10 *vs* 11–12 *vs* 3–10, Table 8). Within hand planter treatments, drum 450S resulted in better singulation when compared to 260-20 (Contrast 450S *vs* 260-20, Table 8). No differences were

Table 7. Treatment structure, emergence, singulation, NDVI, grain yield, and number of ears as influenced by seed size (2651, 3962, seeds/kg), drum cavity size (450S, 260-20), and hand planter tip (N or normal, and WS or tip with welded stop), Efaw, OK, 2016.

Treatment	Drum Cavity	Planter Tip	Seeds, #/kg	Emergence, %	Singulation, %	NDVI	Grain Yield, Mg ha^{-1}	Ears Number ha^{-1}
1	Check		2651	92^{B}	92^{A}	0.86^{A}	3.9^{GF}	66019^{C}
2	Check		3962	96^{AB}	96^{A}	0.88^{A}	8.1^{AB}	97952^{AB}
3	450S	N	2651	94^{AB}	17^{D}	0.87^{A}	2.7^{G}	60637^{C}
4	450S	N	3962	92^{B}	29^{CD}	0.84^{AB}	7.3^{ABC}	101539^{A}
5	450S	WS	2651	92^{B}	28^{CD}	0.86^{AB}	3.9^{GF}	69248^{C}
6	450S	WS	3962	93^{AB}	38^{C}	0.85^{AB}	6.7^{CDE}	72836^{C}
7	260-20	N	2651	80^{C}	59^{B}	0.85^{AB}	6.1^{CDE}	62430^{C}
8	260-20	N	3962	82^{C}	54^{B}	0.87^{A}	9.1^{A}	74271^{C}
9	260-20	WS	2651	82^{C}	51^{B}	0.82^{AB}	5.2^{DEF}	66377^{C}
10	260-20	WS	3962	94^{AB}	52^{B}	0.82^{AB}	7.4^{ABC}	77859^{BC}
11	JD-Planter		2651	98^{AB}	97^{A}	0.80^{B}	4.5^{EFG}	59201^{C}
12	JD-Planter		3962	99^{A}	97^{A}	0.85^{AB}	7.6^{ABC}	65660^{C}
MSE				17	55	0.0012	1.4	168814322
SED				3	6	0.03	1	10609
CV,%				4	13	4	20	18
Contrast	Treatments							
Check *vs* hand planter	1–2 *vs* 3–10			**	*	ns	ns	ns
JD-planter *vs* hand planter	3–10 *vs* 11–12 3–6 *vs* 7–10			*	*	ns	ns	***
450S *vs* 260-20	1–3–5–7–9–11 *vs* 2–4			*	*	ns	**	ns
2651 *vs* 3962	6–8–10–12			**	ns	ns	*	**

SED – Standard error of the difference between two equally replicated means, CV – coefficient of variation, %, MSE -mean square error from analysis of variance, Check-entire plot planted by hand (stick planter), means followed by the same letter were not significantly different at the 5% probability level. ^{ns}, *, **, ***, non-significant or significant at $p \leq 0.01$, 0.05, and 0.10 probability level, respectively.

recorded for NDVI collected at V4, V8, and V10 growth stages. Grain yield ranged between 3.2 and 7.3 Mg ha^{-1} (Table 8). Effect of seed size, drum cavity size, and planter tip was not significant for yield (Table 8). The highest yield was recorded with drum 450S, using the normal tip and 2651 seeds/kg (Treatment 3, Table 8).

Table 8. Treatment structure, emergence, singulation, NDVI, grain yield, and number of ears as influenced by seed size (2651, 3962, seeds/kg), drum cavity size (450S, 260-20), and hand planter tip (N or normal, and WS or tip with welded stop), Lake Carl Blackwell, OK, 2016.

Treatment	Drum Cavity	Planter Tip	Seeds, #/kg	Emergence, %	Singulation, %	NDVI	Grain Yield, Mg ha^{-1}	Ears Number ha^{-1}
1	Check		2651	85^{AB}	85^{A}	0.88^{AB}	4.8^{AB}	58843^{A}
2	Check		3962	92^{AB}	92^{A}	0.89^{AB}	5.0^{AB}	64584^{A}
3	450S	N	2651	88^{AB}	61^{BC}	0.90^{A}	7.3^{A}	64225^{A}
4	450S	N	3962	78^{AB}	42^{CDE}	0.88^{AB}	4.7^{AB}	52743^{A}
5	450S	WS	2651	84^{AB}	53^{BCD}	0.89^{AB}	3.6^{B}	43773^{A}
6	450S	WS	3962	92^{AB}	58^{BCD}	0.90^{A}	4.8^{AB}	55613^{A}
7	260-20	N	2651	76^{B}	50^{BCD}	0.87^{B}	3.2^{B}	45926^{A}
8	260-20	N	3962	79^{AB}	26^{E}	0.88^{AB}	4.4^{AB}	53819^{A}
9	260-20	WS	2651	85^{AB}	36^{DE}	0.89^{AB}	4.8^{AB}	61713^{A}
10	260-20	WS	3962	86^{AB}	54^{BCD}	0.88^{AB}	4.1^{AB}	55972^{A}
11	JD-Planter		2651	91^{AB}	70^{AB}	0.89^{B}	4.4^{AB}	54896^{A}
12	JD-Planter		3962	94^{A}	85^{A}	0.89^{AB}	4.3^{AB}	50232^{A}
MSE				1.6	193	0.0001	4	276152059
SED				1	11	0.008	2	13568F
CV,%				12	23	1	43	30
Contrast	Treatments							
Check *vs* hand planter	1–2 *vs* 3–10			ns	*	ns	ns	ns
JD-planter *vs* hand planter	3–10 *vs* 11–12 3–6 *vs* 7–10			***	**	ns	ns	ns
450S *vs* 260-20	1–3–5–7–9–11 *vs* 2–4			ns	**	***	ns	ns
2651 *vs* 3962	6–8–10–12			ns	ns	ns	ns	ns

SED – Standard error of the difference between two equally replicated means, CV – coefficient of variation, %, MSE – mean square error from analysis of variance, Check-entire plot planted by hand (stick planter), means followed by the same letter were not significantly different at the 5% probability level. ^{ns}, *, **, ***, non-significant or significant at $p \leq 0.01$, 0.05, and 0.10 probability level, respectively.

Conclusions

Results from this study demonstrated that drum 450S at all sites and years resulted in better emergence than 260-20. On an average over site years' treatments with drum 450S had 13% better emergence than treatments with 260-20. This drum was able to deliver seeds over the wide range of seed sizes evaluated. Emergence achieved with drum 450S was similar to mechanical and manual checks. Singulation achieved with drum 260-20 was better than 450S but at a cost of having increased misses and poor plant stands. Results demonstrated that planter tips did not affect emergence, singulation, and/or final grain yield.

Results from this work also suggest that maize producers in the developing world could use the new hand planter with the 450S drum and normal tip. The OSU hand planter has the added benefit of being able to apply mid-season fertilizer by simply changing the internal drum.

Including a "simulated" farmer check, where individual seeds were dropped by hand, and using a metal tipped stick, is not accurate concerning calling this a "check." Developing world farmers using this methodology also throw down 2–3 seeds per strike, resulting in a much higher level of plant heterogeneity than what is reported here.

The OSU hand planter improves the efficiency and time of planting, as no bending and/or squatting are involved in its operation, and one person can complete the seeding process. Furthermore, this planter eliminates seed-to-skin contact with chemically treated seed that has and continues to impose health risks for developing world producers. Side-dress fertilizer application using the OSU hand planter is an additional benefit for improving yields and use efficiency as has been demonstrated by others. Overall, improved ergonomics and human safety make the OSU hand planter a viable option now and in the future.

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