**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 that 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 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 chemically treated seed from producer hands, reduces health risks, and serves as a mid-season fertilizer applicator.

**Keywords**: hand planter, singulation, plant population, plant stand, side-dress N-fertilizer application

**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, 2013) 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 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 M ha of maize is planted by hand where average yields are near 1.8 Mg ha-1 (FAOSTAT, 2013). Farmers in developing countries practice farming on a small scale (0.1 to 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 et al., 2010).

Chim et al. (2014) reported that placing 1 instead of 2 or 3 seeds per hill could increase yields by 40%. Furthermore, many researchers have reported the importance of homogenous crop stands in order to achieve increased yields (Nafziger et al., 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 et al., 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 et al., 1988; Carter et al., 1990). Uneven emergence results in yield loss (Nafziger et al., 1991; Martin et al., 2005), late emerging plants become weeds competing for moisture and nutrients (Raun et al., 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 et al. (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 cause for 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 seed that is available to the farmers via seed companies is pretreated with fungicides and insecticides. Using treated seeds have benefits like increased yields and improved food safety (Cooper and Dobson, 2007; Wilde et al., 2008; 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, and where fertilizer can be placed beneath the soil surface. Applying fertilizer without incorporation results in lower yields (Fox et al., 1981; Mengel et al., 1982), increased fertilizer losses (Fowler and Brydon, 1989; Bandel et al., 1980; Ernst and Massey, 1960; Hargrove et al., 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 et al., 1988; Ford and Hicks, 1992), and delayed emerging plants result in reduced yields (Nafziger et al., 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 Oklahoma State University.

**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 3 replications. In 2014, 9 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/hour. 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 Lake Carl Blackwell, 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; 450 S 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 as Urea ammonium nitrate (UAN) preplant and side-dress (50 preplant, 50 sidedress) 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). 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 Hand Held 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™ sensor approximately 70 cm above the crop canopy and collected over the center two rows. The GreenSeeker sensor calculates NDVI using the equation:



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

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 et al., 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 (𝝰 = 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 (α = 0.05) (Table 3). Maximum emergence was achieved with drum 450S, 3808 seeds/kg using the welded tip-stop, and 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 (α = 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 (α = 0.05) (Table 3). Single-degree-of-freedom-contrasts indicated higher NDVI values for the check treatments compared to 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 (α = 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 were 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 (α = 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 (α = 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 (α = 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 (α = 0.05) (Table 4). Drum 450S had more ears compared to drum 260-20 (450S vs 260-20, Table 4). Single-degree-of-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 to 5.2 Mg ha-1 (Table 4). Effect of seed size, drum cavity size, and planter tip were 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)

**Efaw (2015)**

Analysis of variance showed significant differences in emergence for the treatments evaluated (α = 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 (α = 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 (α = 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 to 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 (α = 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 was significant (α = 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 vs3962, 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 to 4.2 Mg ha-1 (Table 6). Effect of seed size, drum cavity size and planter tip was significant for yield (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 (α = 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 (α = 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). 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 (α = 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 450 S (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 was significant (α = 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 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 were 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).

**CONCLUSIONS**

Results from this study demonstrated that drum 450S at all sites and years resulted in better emergence than 260-20. On 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 wider 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. Sidedress 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 into the future.

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**TABLES**

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| 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) |

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| 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 2 | July 2 | April 07 | April 07 | April 06 | April 06 |
| PlantingSide-dress | July 3August 14 | July 3August 14 | April 21June 9 | April 21June 10 | April 14June 2 | April 07June 6 |
| Harvest | November 13 | November 13 | September 3 | September 2 | August 25 | September 6 |
| † Efaw, Oklahoma Agricultural Experiment Station near Stillwater, OK;  LCB, Oklahoma Agricultural Experiment Station west of Stillwater, OK near Lake Carl Blackwell |

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| 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 | 92AB | 91A | 0.80AB | 68889AB | 6.7A |
| 2 | Check |  | 3808 | 87ABC | 86A | 0.82A | 58125BC | 6.6A |
| 3 | 450S | N | 3449 | 92AB | 62BC | 0.80AB | 72836A | 6.2BA |
| 4 | 450S | N | 3808 | 78BCD | 45D | 0.78AB | 67095AB | 5.5ABC |
| 5 | 450S | WS | 3808 | 100A | 57BC | 0.81AB | 70683AB | 6.1ABC |
| 6 | 260-20 | N | 3449 | 84ABCD | 65BC | 0.76B | 49873CD | 5.9ABC |
| 7 | 260-20 | N | 3808 | 66D | 53CD | 0.76B | 44850CD | 4.9BC |
| 8 | 260-20 | WS | 3808 | 72CD | 65B | 0.76B | 36239D | 4.7C |
| 9 | JD-Planter |  | 3808 | 87ABC | 86A | 0.79AB | 65301AB | 6.4A |
| MSE |  |  |  | 131 | 47 | 0.0009 | 63707353 | 0.70 |
| SED |  |  |  | 9 | 6 | 0.02 | 6517 | 0.70 |
| CV,% |  |  |  | 14 | 10 | 4 | 13 | 44 |
| ContrastsCheck vs hand planterJD-planter vs hand planter450S vs 260-203449 vs 3808 | Treatments1-2 vs 3-83-8 vs 93-5 vs 6-81-3-6 vs 2-4-5-7-8-9 | nsns\*\*\* | \*\*\*\*\*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 ≤0.01, 0.05, and 0.10 probability level, respectively. |

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| 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 | 99A | 99A | 0.69AB | 63507A | 4.3ABC |
| 2 | Check |  | 3808 | 99A | 99A | 0.69AB | 48796BCD | 3.8BCD |
| 3 | 450S | N | 3449 | 100A | 74AB | 0.68AB | 72118A | 4.1ABCD |
| 4 | 450S | N | 3808 | 100A | 81AB | 0.61D | 45926CD | 3.3CD |
| 5 | 450S | WS | 3808 | 100A | 74AB | 0.71A | 64583A | 3.1CD |
| 6 | 260-20 | N | 3449 | 77B | 62B | 0.63CD | 58125ABC | 4.6AB |
| 7 | 260-20 | N | 3808 | 82B | 71AB | 0.61D | 40903D | 2.9D |
| 8 | 260-20 | WS | 3808 | 61C | 61B | 0.65BCD | 43055D | 3.4BCD |
| 9 | JD-Planter |  | 3808 | 98A | 97A | 0.68ABC | 61713AB | 5.2A |
| MSE |  |  |  | 14 | 282 | 0.0011 | 71654562 | 0.55 |
| SED |  |  |  | 3 | 14 | 0.02 | 6911 | 0.60 |
| CV,% |  |  |  | 4 | 21 | 5 | 15 | 19 |
| ContrastsCheck vs hand planterJD-planter vs hand planter450S vs 260-203449 vs 3808 | Treatments1-2 vs 3-83-8 vs 93-5 vs 6-81-3-6 vs 2-4-5-7-8-9 |  |  |  |  |  |
| \*\*\*\* | \*\*nsns | \*ns\*\*\*\* | nsns\*\* | ns\*nsns |
| 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 ≤0.01, 0.05, and 0.10 probability level, respectively. |
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| 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 | 96A | 96A | 0.88A | 7.5AB |
| 2 | Check |  | 3962 | 88AB | 88A | 0.86AB | 4.9ABC |
| 3 | 450S | N | 2651 | 77BCDE | 57C | 0.87AB | 7.2ABC |
| 4 | 450S | N | 3962 | 87AB | 40D | 0.84B | 4.4BC |
| 5 | 450S | WS | 2651 | 66DEF | 46CD | 0.84B | 5.2ABC |
| 6 | 450S | WS | 3962 | 81ABCD | 45CD | 0.86AB | 3.4C |
| 7 | 260-20 | N | 2651 | 71CDEF | 54C | 0.86AB | 4.2BC |
| 8 | 260-20 | N | 3962 | 59F | 47CD | 0.83B | 4.2BC |
| 9 | 260-20 | WS | 2651 | 64EF | 53CD | 0.89A | 8.4A |
| 10 | 260-20 | WS | 3962 | 67DEF | 50CD | 0.85AB | 3.9BC |
| 11 | JD-Planter |  | 2651 | 85ABC | 84AB | 0.86AB | 6.7ABC |
| 12 | JD-Planter |  | 3962 | 81ABCD | 75B | 0.87AB | 4.5ABC |
| MSE |  |  |  | 82 | 63 | 0.0007 | 5.6 |
| SED |  |  |  | 7 | 6 | 0.02 | 1.9 |
| CV,% |  |  |  | 12 | 13 | 3 | 4 |
| ContrastCheck vs hand planterJD-planter vs hand planter450S vs 260-202651 vs 3962 | Treatments1-2 vs 3-103-10 vs 11-123-6 vs 7-101-3-5-7-9-11 vs 2-4-6-8-10-12 |  |  |  |  |
| \* | \* | ns | ns |
| \*\* | \* | ns | 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 ≤ 0.01, 0.05 and 0.10, probability level respectively. |

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| 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 | 99A | 99A | 0.81AB | 3.7A |
| 2 | Check |  | 3962 | 98A | 98A | 0.79ABC | 2.8ABC |
| 3 | 450S | N | 2651 | 80BC | 46D | 0.81BC | 2.4BCD |
| 4 | 450S | N | 3962 | 96A | 28E | 0.81A | 1.5CDE |
| 5 | 450S | WS | 2651 | 94A | 52CD | 0.79ABC | 0.7E |
| 6 | 450S | WS | 3962 | 97A | 25E | 0.81AB | 0.9DE |
| 7 | 260-20 | N | 2651 | 75C | 73B | 0.79BC | 2.3BCDE |
| 8 | 260-20 | N | 3962 | 74C | 59C | 0.79BC | 1.6CDE |
| 9 | 260-20 | WS | 2651 | 85B | 83B | 0.79BC | 2.7ABC |
| 10 | 260-20 | WS | 3962 | 76C | 56CD | 0.78C | 0.9DE |
| 11 | JD-Planter |  | 2651 | 99A | 98A | 0.81AB | 4.2A |
| 12 | JD-Planter |  | 3962 | 99A | 98A | 0.79ABC | 1.9CDE |
| MSE |  |  |  | 25 | 42 | 0.0002 | 0.9 |
| SED |  |  |  | 4 | 5 | 0.01 | 0.8 |
| CV,% |  |  |  | 6 | 9 | 2 | 45 |
| ContrastCheck vs hand planterJD-planter vs hand planter450S vs 260-202651 vs 3962 | Treatments1-2 vs 3-103-10 vs 11-123-6 vs 7-101-3-5-7-9-11 vs 2-4-6-8-10-12 |  |  |  |  |
| \* | \* | 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 ≤ 0.01, 0.05 and 0.10 probability level, respectively. |

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| 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 | 92B | 92A | 0.86A | 3.9GF | 66019C |
| 2 | Check |  | 3962 | 96AB | 96A | 0.88A | 8.1AB | 97952AB |
| 3 | 450S | N | 2651 | 94AB | 17D | 0.87A | 2.7G | 60637C |
| 4 | 450S | N | 3962 | 92B | 29CD | 0.84AB | 7.3ABC | 101539A |
| 5 | 450S | WS | 2651 | 92B | 28CD | 0.86AB | 3.9GF | 69248C |
| 6 | 450S | WS | 3962 | 93AB | 38C | 0.85AB | 6.7CDE | 72836C |
| 7 | 260-20 | N | 2651 | 80C | 59B | 0.85AB | 6.1CDE | 62430C |
| 8 | 260-20 | N | 3962 | 82C | 54B | 0.87A | 9.1A | 74271C |
| 9 | 260-20 | WS | 2651 | 82C | 51B | 0.82AB | 5.2DEF | 66377C |
| 10 | 260-20 | WS | 3962 | 94AB | 52B | 0.82AB | 7.4ABC | 77859BC |
| 11 | JD-Planter |  | 2651 | 98AB | 97A | 0.80B | 4.5EFG | 59201C |
| 12 | JD-Planter |  | 3962 | 99A | 97A | 0.85AB | 7.6ABC | 65660C |
| MSE |  |  |  | 17 | 55 | 0.0012 | 1.4 | 168814322 |
| SED |  |  |  | 3 | 6 | 0.03 | 1 | 10609 |
| CV,% |  |  |  | 4 | 13 | 4 | 20 | 18 |
| ContrastCheck vs hand planterJD-planter vs hand planter450S vs 260-202651 vs 3962 | Treatments1-2 vs 3-103-10 vs 11-123-6 vs 7-101-3-5-7-9-11 vs 2-4-6-8-10-12 |  |  |  |  |  |
| \*\* | \* | ns | ns | ns |
| \* | \* | ns | 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 ≤ 0.01, 0.05 and 0.10 probability level, respectively. |

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| 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 | 85AB | 85A | 0.88AB | 4.8AB | 58843A |
| 2 | Check |  | 3962 | 92AB | 92A | 0.89AB | 5.0AB | 64584A |
| 3 | 450S | N | 2651 | 88AB | 61BC | 0.90A | 7.3A | 64225A |
| 4 | 450S | N | 3962 | 78AB | 42CDE | 0.88AB | 4.7AB | 52743A |
| 5 | 450S | WS | 2651 | 84AB | 53BCD | 0.89AB | 3.6B | 43773A |
| 6 | 450S | WS | 3962 | 92AB | 58BCD | 0.90A | 4.8AB | 55613A |
| 7 | 260-20 | N | 2651 | 76B | 50BCD | 0.87B | 3.2B | 45926A |
| 8 | 260-20 | N | 3962 | 79AB | 26E | 0.88AB | 4.4AB | 53819A |
| 9 | 260-20 | WS | 2651 | 85AB | 36DE | 0.89AB | 4.8AB | 61713A |
| 10 | 260-20 | WS | 3962 | 86AB | 54BCD | 0.88AB | 4.1AB | 55972A |
| 11 | JD-Planter |  | 2651 | 91AB | 70AB | 0.89B | 4.4AB | 54896A |
| 12 | JD-Planter |  | 3962 | 94A | 85A | 0.89AB | 4.3AB | 50232A |
| MSE |  |  |  | 1.6 | 193 | 0.0001 | 4 | 276152059 |
| SED |  |  |  | 1 | 11 | 0.008 | 2 | 13568F |
| CV,% |  |  |  | 12 | 23 | 1 | 43 | 30 |
| ContrastCheck vs hand planterJD-planter vs hand planter450S vs 260-202651 vs 3962 | Treatments1-2 vs 3-103-10 vs 11-123-6 vs 7-101-3-5-7-9-11 vs 2-4-6-8-10-12 |  |  |  |  |  |
| ns | \* | ns | ns | ns |
| \*\*\* | \*\* | ns | ns | ns |
| ns | \*\* | \*\*\* | ns | ns |
| 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 ≤ 0.01, 0.05 and 0.10 probability level, respectively. |

**FIGURES**



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



Figure 2. Conventional and tip with a welded stop.