EVALUATION OF DRUM CAVITY SIZE AND PLANTER TIP ON SINGULATION AND PLANT EMERGENCE IN MAIZE (ZEA mays L.)

By

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2010

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2016

EVALUATIONOF DRUM CAVITY SIZE AND

PLANTER TIP ON SINGULATION AND PLANT

EMERGENCE IN MAIZE (ZEA mays L.)

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Date of Degree: MAY, 2016

Title of Study: EVALUATION OF DRUM CAVITY SIZE AND PLANTER TIP ON SINGULATION AND PLANT EMERGENCE IN MAIZE (ZEA MAYS L.)

Major Field: PLANT AND SOIL SCIENCE

Abstract: Average maize grain yields in developing countries are 1.8 Mg ha^{-1} compared to 9.9 Mg ha^{-1} in the USA, with much of this due to planter technology. Thirty million hectares in the world are planted by hand, where 2 to 3 seeds are placed per hill at uneven spacing resulting in heterogeneous plant stands. A hand planter was built to deliver single seeds with each strike (singulation) and to improve low grain yields encountered in developing countries. This study was conducted to evaluate drum cavity size and planter tip on singulation and plant emergence in maize, using the OSU hand planter. Two drum cavity sizes, two planter tips and four different seed sizes were used in a two-year study, started in 2014. On all four site years drum cavity 450S resulted in significantly similar emergence as those checks planted by hand and a John Deere vacuum planter. Over site years 17% better emergence was achieved with 450S vs 260-20 drums. Drum 260-20 was better at delivering singulation than 450S however, over four site years 27% misses (no seed delivered) were recorded with drum 260-20. No significant difference was seen with different tips on emergence, singulation and final grain yield. This data suggests that maize producers in developing world could use the OSU hand planter with drum 450S and the conventional tip. This planter can be used as a side-dress N-fertilizer applicator by simply changing the internal drum, that incorporates urea into the soil, minimizing volatilization losses. It also removes chemically treated seed from producer hands thus reducing health risks.

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CHAPTER I

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereals in the world. Maize production in the world exceeded 1 billion metric tons in 2013 (FAOSTAT, 2013) and accounts for the largest tonnage produced by any major cereal. Maize delivers 30% of the total food calories, besides rice and wheat, to more than 4.5 billion people in 94 developing countries (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).

In developing countries, 29 M ha of maize is planted by hand and 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 said to be 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. (2015) 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).

Many researchers have reported the importance of homogenous crop stand to achieve higher crop yields (Nafziger et al., 1991; Ford and Hicks, 1992; Nielson, 2004; Liu et al., 2004; Tollenaar et al., 2006; Rutto et al., 2014). Improved 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 nations 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.

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., 2010). 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 and concluded poor seed and fertilizer distribution. They inferred poor quality control in manufacturing planters as the reason 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., 2015).

The OSU hand planter also 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. It’s an allterrain 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 OSU hand planter is made up of a polyvinyl chloride round pipe (PVC) with a diameter of 5.8 cm which is connected to a metering delivery system. The seed metering system consists of an aluminum/plastic tube which contains a reciprocating drum, spring and brush. The bottom end of the metering system is connected to a pointed tip/shovel, which can plant to a depth of 6 cm to 10 cm depending on the force applied by the operator. The OSU hand planter is 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 picking it up. 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 moved upwards, thus rotating the internal drum.

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., 2015). 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 results 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. However, its effect on emergence and yield has not been investigated.

This study was conducted to evaluate the effect of drum cavity size and depth control on emergence and yield of maize.

CHAPTER II

REVIEW OF LITERATURE

Hand Planter Importance

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 lands that are already in cultivation (Borlaug and Dowswell, 2003).

Current planting techniques adopted in developing countries are highly inefficient, as apparent from the low average yields 1.8 Mg ha^{-1} (FAOSTAT, 2013). In most of the developing countries seeding is done by hand, two to three maize seeds are dropped per hill and covered by surrounding soil (Omara et al., 2015). This results in multiple seeds that emerge, non-uniform germination, seed rotting due to deep planting and loss of viable 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%. Planting maize with the hand planter was advantageous, when compared to traditional planting practices. This was also observed when comparing cutlass, dibbler, hoe plating methods in Ghana (Aikins et al., 2011).

In earlier work, Aikins et al. (2010) evaluated the performance of 30 hand planters for maize planting and inorganic fertilizer application. According to their findings they experienced poor seed and fertilizer metering of hand planters, and thus concluded that quality control for the metering mechanism of hand planters is vital. The OSU hand planter has been shown to achieve 80% singulation, in other words deliver a single seed per strike. Omara et al. (2015) reported that by using the OSU hand planter, yields could be increased by > 20%.

An additional significant feature of the OSU hand planter is the prevention of direct handling chemically treated seed. Most of the seed that is available to the farmers through seed companies is pretreated with fungicides and insecticides. Most commonly used fungicides include fludioxonil (Maxim®, Medallion®, Scholar®), mefenoxam (Apron XL®, Ridomil Gold®, Subdue Maxx®), azoxystrobin (Abound®, Quadris®, Heritage®) and tebuconazole and insectisides include thiamethoxam (Crusier ®), clothianidin (Pancho ®) and bacillus firmus (Poncho-votivo ®). 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 exposure to the pesticides (Brown et al., 1990; Blakley et al., 1999: Van Maele-Fabry et al., 2010).

By simply changing the internal drum, the OSU hand planter can also be used as mid-season fertilizer applicator. 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; Hangrove et al., 1977; Terman, 1979; Volk, 1959) and decreased NUE (Raun and Johnson. 1999).

Effect of depth of sowing and uneven emergence on corn yield

According to Alessi and Power (1971) a 10 mm increase in planting depth at a constant temperature of 13^oC results in a delay in emergence by 1 day. Gupta et al. (1988) deduced that with an increase in planting depth from 25 mm to 75 mm, time to corn emergence increased, due to a decline in temperature with depth and the increase in distance the cotyledon has to travel before emergence.

Carter et al. (1989) concluded that uneven plant emergence creates competition between early emerging and late emerging plants and tends to decrease production of late emerging plants. Various reasons for uneven emergence include inconsistency in soil moisture, soil temperature, seed depth and other reasons like soil crusting, herbicide injury, or insect/disease damage (Carter et al., 1989).

Martin et al. (2005) depicted delayed and uneven emergence as the reason for plant grain yield differences with uneven planting depth being the main cause for this irregular emergence. Raun et al. (1986) disclosed that the late emerging plants become weeds competing for moisture and nutrients and have no chance of reproductive development.

According to Nielsen (2004), a two-leaf stage difference between adjacent plants can reduce yield by up to 1% with every 1-day delay in emergence. Delayed emergence of plants in unevenly emerged fields for over more than two weeks will result in yield loss (Nafziger et al., 1991).

In their study on emergence and spacing variability, Liu et al., (2004) and Tollenar et al., (2006) found that plants next to a gap demonstrated some compensatory yield gain but no compensation is provided in yield by plants near late emerging plants.

Effect of Singulation and plant spacing on corn yield

In 2013, average maize production in the USA was 9.9 Mg ha^{-1} whereas developing country yields hover near 1.8 Mg ha^{-1} (FAOSTAT, 2013). The reason behind this large gap in production level is that in the USA, highly mechanized planters are used which are accurate at planting single seeds with uniform spacing and depth.

Liu et al. (2004) reported a 6 to 10% reduction in yield with double and triple stands within 0-3 cm compared with uniforms stands. Tollenar et al. (2006) studied crowding stress related to increase in inter-row spacing and concluded that plants within close proximity suffer yield reduction.

Nafziger (1996) reported a yield reduction from 0.22 to 0.18 kg per plant with two seeds per hill as the number of hills per hectare increased from 44460 to 74100 plants ha^{-1}, and grain yields increased from 10.6 to 13.2 Mg ha^{-1}.

Teasdale (1994) concluded that an increase in plant population resulted in an increase in corn leaf area and a decrease in light transmission to the soil, which helps in suppression of weeds. He also observed a decrease in yield with an increase in plant population beyond the optimum range (75000 and 100000 plants ha^{-1}). This is possible due to a reduction in the number of kernels and ears per plant.

CHAPTER III

OBJECTIVE

The objective of this study was to evaluate the effect of drum cavity size, and planter tip on resulting seed singulation and emergence of maize over a range of seed sizes.

CHAPTER IV

METHODOLOGY

Experimental site

Maize trials were evaluated over four site years. In June 2014, two experiments were established at Stillwater Agronomy Research Station and Efaw, north of the Stillwater Agronomy Research Station. Also, two maize trials were established in April 2015 at Lake Carl Blackwell (LCB) and Efaw. Soil classification of each site are described 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 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 wooden stick planter, where a hole was made by using the stick planter and one seed was dropped per hole. To keep the targeted population 34 Strikes were made with hand planter in one row. One check was planted using John Deere MaxEmerge 2 vacuum planter, planter was droved at 3.2 km/hour. Planter was adjusted to give 18 cm targeted plant spacing. In 2015, 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 keep the uniform spacing; two manual checks were planted same as 2014. 31 Strikes were made to get the targeted population with hand planted treatments. In 2015, two checks were planted using John Deere MaxEmerge 2 vacuum planter, keeping the speed of 3.2 Km/hour, and targeted plant spacing of 20.5 cm. Field activities for all four site years are presented in Table 2. Two internal drums were used, 450S and 260-20 (Figure 1). 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, welded stop was added that restricted planting depth to 6 cm.

Climatic data including total rainfall, average monthly temperature in Stillwater (2014), Efaw (2014), Efaw (2015) and Lake Carl Blackwell (2015) are shown in Figures 3, 4, 5 and 6, respectively.

Daily emergence data was collected from the center two rows until the 3 leaf stage. As fixed number of strikes were made with the planter, the skips in emergence were considered as misses (no seed dropped). While emergence data collection multiples were recorded as one plant to keep emergence less than 100%. In John Deere checks plants emerged in between the targeted spacing were counted as multiples. Singulation is 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 the growth stages of maize.

NDVI data was collected by keeping the GreenSeeker™ sensor approximately 70 cm above the crop canopy. GreenSeeker sensor calculates NDVI using the equation:

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

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

In 2014, 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 middle two 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, and grain yield were statistically analyzed using SAS version 9.3 (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 was utilized to evaluate specific treatment differences. Linear regression employed the proc REG procedure, and was utilized to identify the relationships between growth components and final grain yield.

CHAPTER V

RESULTS

Efaw (2014)

Emergence data was collected till three leaf stage. Analysis of variance showed significant difference in emergence among treatments (α = 0.05) (Table 3). Maximum emergence was achieved with drum 450S, 3808 seed/kg using the welded stop tip, and had higher emergence compared to other treatments. Non-orthogonal, single degree of freedom contrast, showed significantly better emergence with drum 450S over 260-20 (Contrast 450S vs 260-20, Table 3). It was also observed with single-degree-of-freedom contrasts that seed 3449 seeds/kg had better emergence than seed 3808 seeds/kg (Contrasts 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 (Contrast check vs hand planter and JD-planter vs hand planter, Table 3). Overall, single-degree-of-freedom contrast, showed that Drum 260-20 was better at singulating seed than 450S (Contrast 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 observed from contrast that drum 450S had increased NDVI versus drum 260-20, indicating that better surface coverage was encountered, and possibly improved plant homogeneity (Contrast 450S vs 260-20, Table 3). Analysis of variance showed significant difference in number of ears within different treatments ($\alpha = 0.05$) (Table 3). Single degree-of-freedom-contrasts showed that drum 450S had elevated number of ears when compared to 260-20 (Contrast 450S vs 260-20, Table 3). Number of ears were also higher using 3449 seeds/kg compared to 3808 seeds/kg (Contrast 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 (Contrast 450S vs 260-20, Table 3).

The linear regression of emergence, singulation, number of ears and NDVI with final grain yield are reported in Table 4. Emergence had limited impact on final grain yield. Singulation, NDVI and number of ears were correlated with final grain yield but with low coefficients of determination (r^2).

Stillwater (2014)

Analysis of variance showed significant differences in emergence among treatments ($\alpha = 0.05$) (Table 5). It was observed that drum 450S resulted in significantly better emergence than drum 260-20 using single-degree-of-freedom-contrasts (Contrast 450S vs 260-20, Table 5). Single-degree-of-freedom-contrasts indicated that emergence in the check plots was better than hand planter treatments (Treatments 1-2 vs 3-8 and 9 vs 3-8, Table 5). Analysis of variance also indicated that a significant treatment differences existed in measured singulation ($\alpha = 0.05$) (Table 5). 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 5). As Efaw, NDVI was collected at the V10 growth stage, where significant treatment differences were observed ($\alpha = 0.05$) (Table 5). The use of drum 450S resulted in having higher NDVI compared to drum 260-20 (Contrast 450S vs 260-20, Table 5). It was also observed that NDVI values improved with the use of the welded stop tip compared to the normal tip (Contrasts N vs WS, Table 5). The total number of ears per plot were different by treatment ($\alpha = 0.05$) (Table 5). Drum 450S was observed to have more number of ears compared to drum 260-20 using single-degree-of-contrasts (Contrast 450S vs 260-20, Table 5). Single-degree-of-contrasts also showed a higher number of ears with 3449 seeds/kg, compared to 3808 seeds/kg (Contrast 3449 vs 3808, Table 5). Grain yield ranged between 2.9 to 5.2 Mg ha^{-1} (Table 5). Effect of seed size, drum cavity size and planter tip were not highly significant for yield (Table 5). However, single-degree-of–freedom-contrasts showed that grain yields were higher for the John Deere planter compared to the hand planter treatments (Treatment 9 vs 3-8, Table 5)

Linear regression of emergence, singulation, number of ears and NDVI with final grain yield are reported in Table 6. Emergence, singulation and NDVI did not affect final grain yield. Number of ears had a direct influence on final grain yield but was weakly correlated.

Efaw (2015)

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). 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 7). Differences in singulation were highly significant ($\alpha = 0.05$) (Table 7). According to single-degree-of-freedom contrasts singulation was better in check plots than hand planter treatments (Treatments 1-2 vs 3-10 and 11-12 vs 3-10, Table 7). NDVI was collected at V5, V6 and V9 growth stages. NDVI was not significantly different among treatments ($\alpha = 0.05$) (Table 7). However, according to single-degree-of-freedom contrasts it was observed that seed 2651 seeds/kg had significantly higher NDVI when compared to 3962 seeds/kg (Contrast 2651 vs 3962, Table 7). Grain yield ranged between 3.4 to 8.4 Mg ha^{-1} (Table 7). Effect of seed size, drum cavity size and planter tip was not significant for yield (Table 7). Single-degree-of-freedom contrasts revealed that yields were greater using 2651 seeds/kg than 3962 seeds/kg (Contrast 2651 vs 3962, Table 7).

The linear regression of emergence, singulation, and NDVI with final grain yield are reported in Table 8. Emergence and singulation did not affect final grain yield while NDVI had a direct influence on final grain yield.

Lake Carl Blackwell (2015)

Differences in plant emergence over treatments was observed ($\alpha = 0.05$) (Table 9). Single-degree-of-freedom contrast revealed that drum 450S had increased emergence compared to drum 260-20 (Contrast 450S vs 260-20, Table 9). Furthermore, emergence in check plots was better than hand planter treatments (Treatment 1-2 vs 3-10 and 11-12 vs 3-10, Table 9) and emergence improved when using the welded stop tip (Contrast N vs WS, Table 9). Differences in singulation due to treatments was significant ($\alpha = 0.05$) (Table 9). 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 9). Within hand planter treatments, drum 260-20 resulted in better singulation when compared to 450S (Contrast 450S vs 260-20, Table 9) and singulation was better with bigger seed sizes (Contrast 2651 vs3962, Table 9). No differences were recorded for NDVI collected at V5, V6 and V9 growth stages A trend for seed 450S to be higher compared to 260-20 was recorded (Contrast 450S vs 260-20, Table 9). Grain yield ranged between 0.7 to 4.2 Mg ha^{-1} (Table 9). Effect of seed size, drum cavity size and planter tip was significant for yield (Table 9). Increased yields in check plots were observed when compared to hand planter treatments (Contrast 1-2 vs 3-10 and 11-12 vs 3-10, Table 9). Within hand planted treatments the normal tip resulted in higher yields compared to the welded-stop tip (Contrast N vs WS, Table 9).

Linear regression of emergence, singulation, and NDVI with final grain yield are reported in Table 10. Emergence and NDVI did not affect final grain yield. Singulation had a direct influence on final grain yield but was only weakly correlated.

CHAPTER VI

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 drum 450S delivered 17% better emergence than 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 the cost of having increased misses and poor plant stands. Results demonstrated that planter tips did not affect emergence, singulation and final grain yield.

This data indicates that maize producers in third 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. Concerning ergonomics, the OSU hand planter improves the efficiency and time of planting, as no bending and/or squatting are involved in its operation, only one person can complete the seeding process. Its additional benefit is no direct contact of skin with chemically treated seed that has and continues to impose health risks on third world producers.

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TABLES

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 and 2015.

	2014		2015	
Field Activity	Efaw†	Stillwater	Efaw	LCB
Pre-plant N fertilization	July 2	July 2	April 07	April 07
Planting	July 3	July 3	April 21	April 21
Side-dress	August 14	August 14	June 9	June 10
Harvest	November 13	November 13	September 3	September 2

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

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), values with different letters are significantly different at the 5% probability level. ns, *, **, ***, non-significant or significant at P ≤0.01, 0.05, and 0.10 probability level, respectively.

Table 4. Linear regression of maize grain yield with emergence, singulation, NDVI and number of ears, Efaw, OK 2014.

Dependent Variable: Maize grain yield			
Independent variable	**Equation**	**Prob F**	**r^2**
Emergence	y = 4.79 + 0.013*x	0.1783	0.07
Singulation	y = 4.62 + 0.019*x	0.6419	0.14
NDVI	y = -0.78 + 8.51*x	0.0112	0.23
Number of ears	y = 3.44 + 0.00004*x	0.0009	0.36

Table 5. 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), Values with different letters are significantly different at the 5% probability level. ns, *, **, ***, non-significant or significant at P ≤0.01, 0.05, and 0.10 probability level, respectively.

Table 6. Linear regression of maize grain yield with emergence, singulation, NDVI and number of ears, Stillwater, OK 2014.

Dependent Variable: Maize grain yield			
Independent variable	**Equation**	**Prob F**	**r^2**
Emergence	y = 2.97 + 0.009*x	0.5063	0.02
Singulation	y = 3.80 + 0.0007*x	0.9375	0.00
NDVI	y = 4.56 - 1.06*x	0.7380	0.00
Number of ears	y = 2.51 + 0.00002*x	0.0611	0.13

Table 7. 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), values with different letters are significantly different at the 5% probability level. ns, *, **, ***, non-significant or significant at P ≤ 0.01, 0.05 and 0.10, probability level respectively.

Table 8. Linear regression of maize grain yield with emergence, singulation, and NDVI , Efaw, OK 2015.

Dependent Variable: Maize grain yield			
Independent variable	**Equation**	**Prob F**	$\mathbf{r^2}$
Emergence	y = 4.35 + 0.013*x	0.6776	0.00
Singulation	y = 3.66 + 0.027*x	0.1986	0.05
NDVI	y = -43.01 + 56.37*x	0.0001	0.41

Table 9. 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), values with different letters are significantly different at the 5% probability level. ns, *, **, ***, non-significant or significant at P ≤ 0.01, 0.05 and 0.10 probability level, respectively.

Table 10. Linear regression of maize grain yield with emergence, singulation, and NDVI , Lake Carl Blackwell, OK 2015.

Dependent Variable: Maize grain yield			
Independent variable	**Equation**	**Prob F**	**r^2**
Emergence	y = 0.66 + 0.019*x	0.4192	0.01
Singulation	y = 0.26 + 0.256*x	0.0008	0.32
NDVI	y = -12.06 + 17.79*x	0.2031	0.04

FIGURES

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

Figure 2. Conventional and tip with a welded stop.

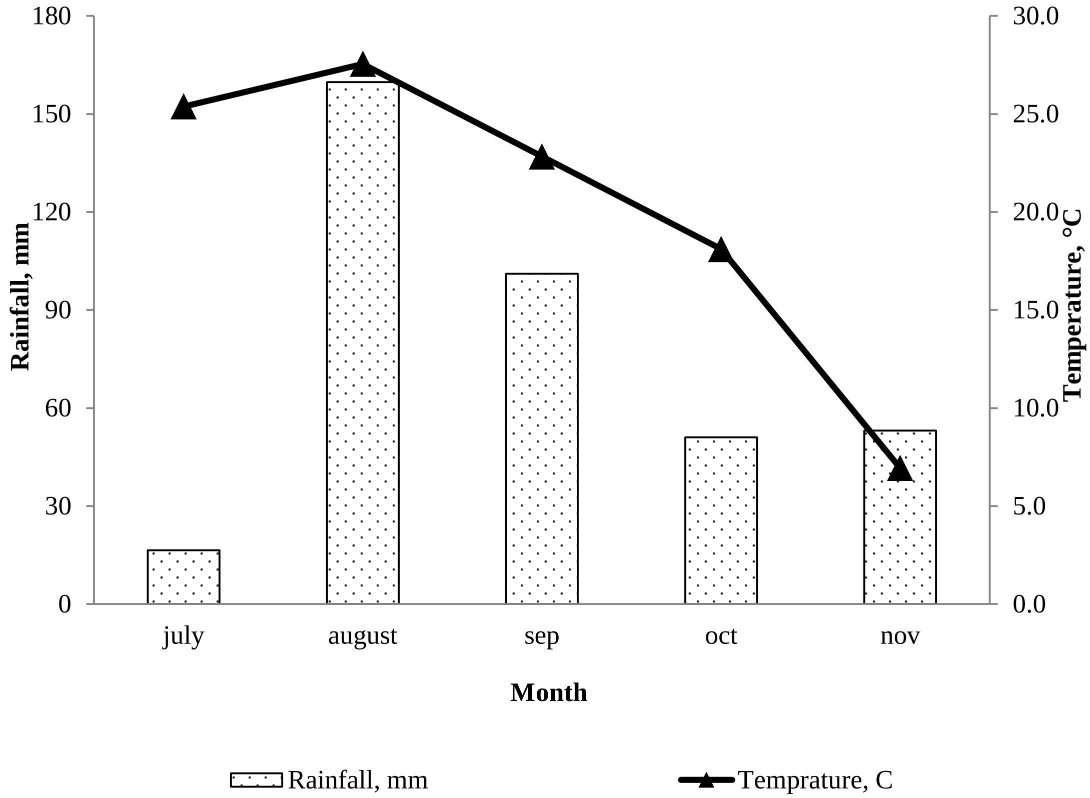

Figure 3. Average monthly air temperatures and total monthly rainfall from July to November 2014 at Stillwater, OK.

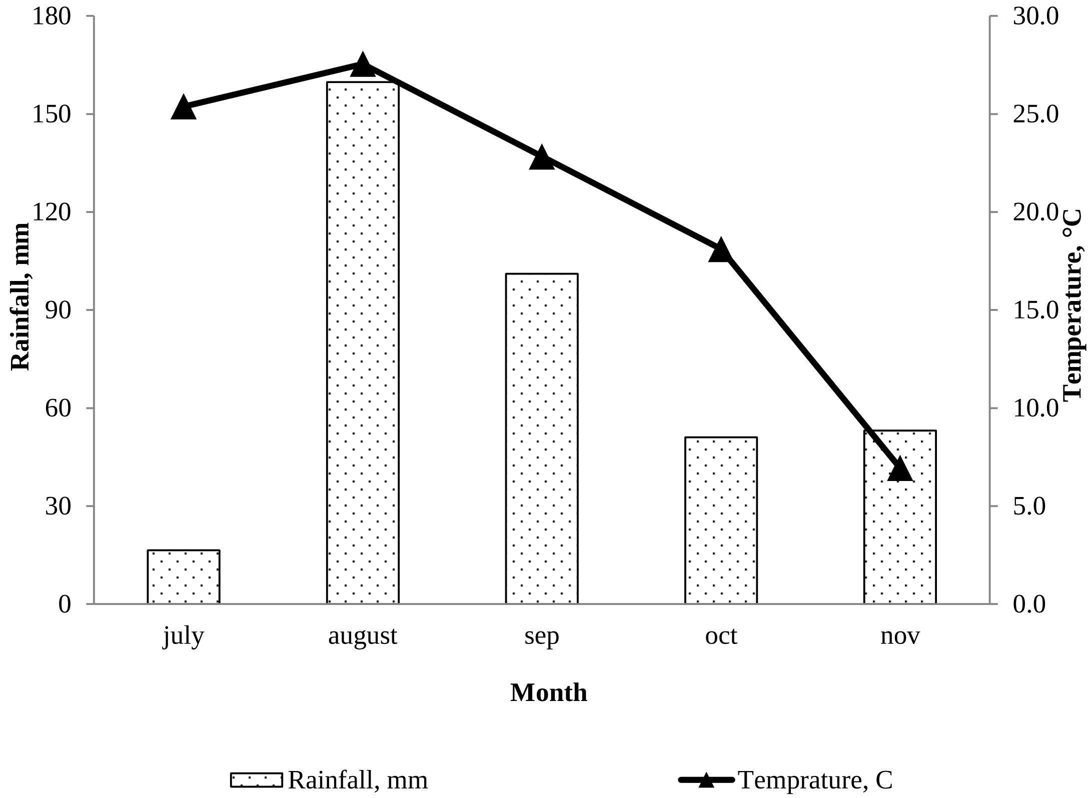

Figure 4. Average monthly air temperatures and total monthly rainfall from July to November 2014 at Efaw, OK.

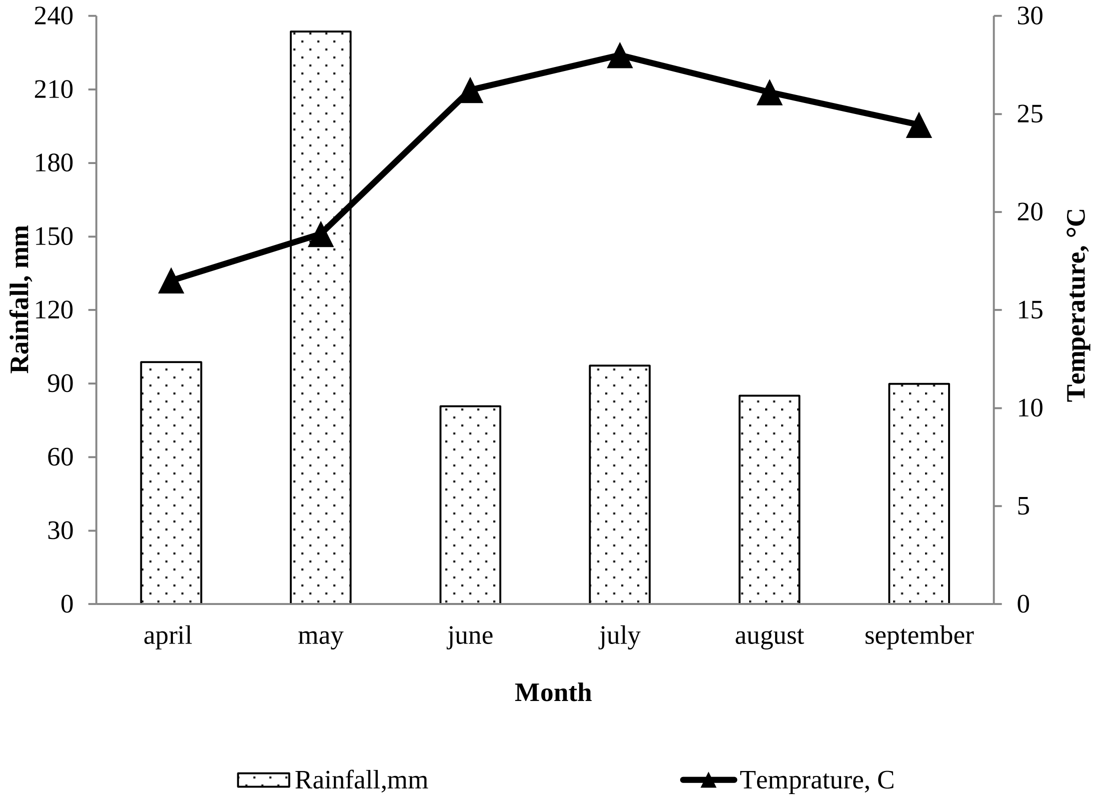

Figure 5. Average monthly air temperatures and total monthly rainfall from April to September 2015 at Efaw, OK.

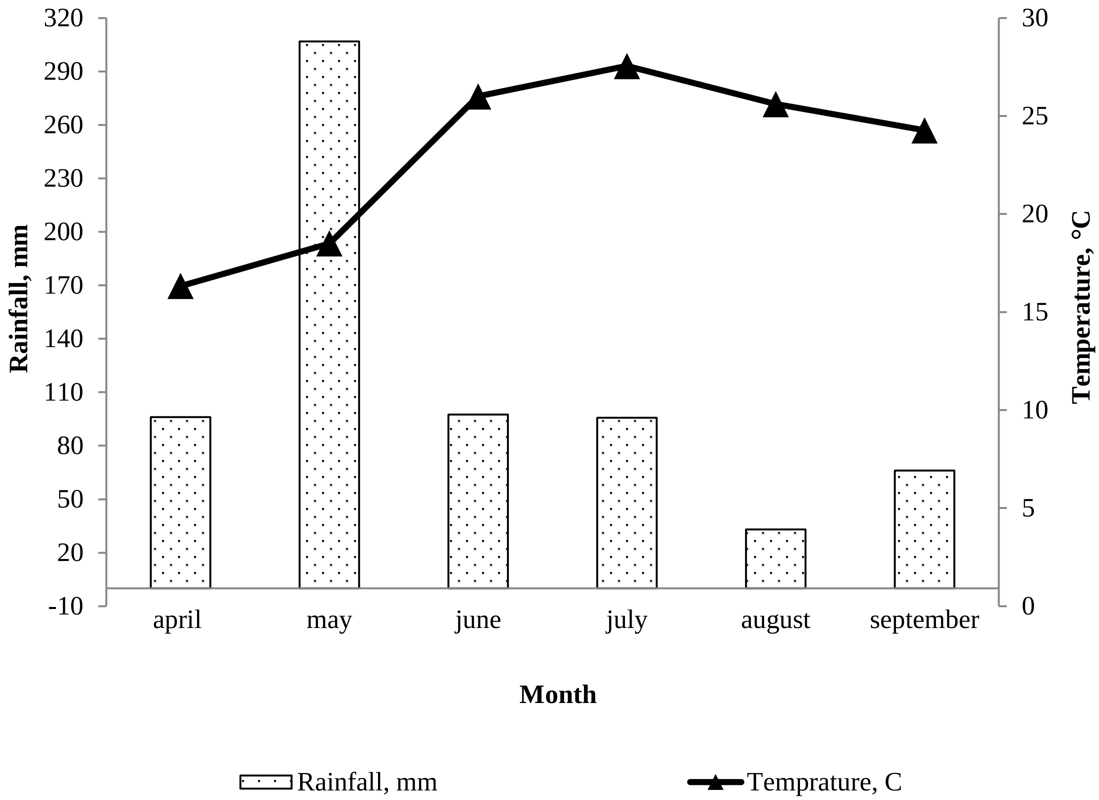

Figure 6. Average monthly air temperatures and total monthly rainfall from April to September 2015 at Lake Carl Blackwell, OK

VITA

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