INFLUENCE OF TILLAGE AND SIDE-DRESS NITROGEN ON MAIZE (Zea mays L.) PLANT STAND AND GRAIN YIELD USING THE OSU HAND PLANTER WITH ALTERED DRUM CAVITY SIZES

by

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PLANT SOIL SCIENCES

Abstract:

Average production for maize (Zea mays L) in the United States is 9.9 Mg ha^{-1} compared to averages of 1.8 Mg ha^{-1} in the developing world. Many factors account for these low yields, specifically highly advanced agricultural mechanization not available in the third world. Over the last twelve years, the Division of Agriculture at Oklahoma State University has worked to develop an improved hand planter, for subsistence farmers in developing countries. Two sites evaluating the Greenseeder hand planter were initiated to further evaluate drum cavity size (Efaw and Lake Carl Blackwell). This study further analyzed the amount of urea applied per plant (0.58 to 1.16g). Added variables included two different drums and tillage (no-till, conventional). The scientific notion that plant stand, singulation and grain yield in maize (Zea mays L.) are dependent on tillage and mid-season side-dress N application, solidifies the importance of the hand planter in third world agricultural systems. Coefficients of variation from collected normalized difference vegetative index (NDVI) sensor readings showed varying N uptake by plants; this is useful in determining N fertilizer rates for individual plants. Results showed a significant difference in singulation under conventional tillage (CT) at LCB. Drum 260-20 with 50 kg ha^{-1} and 100 kg ha^{-1} side-dress N had 99 and 98 percent singulation, respectively, and that was higher than drum 450s at 72 and 68 percent. Grain yield results indicated certain instances of drum 260-20 producing higher yields, yet these were statistically limited. The OSU hand planter can be recommended for use in both no-till and conventional tillage systems.

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CHAPTER 1

INTRODUCTION

World population is expected to increase from 7.2 to 9.6 billion by 2050, where much of this increase will be in Africa (Gerland et al., 2014). Along with population, growth in food consumption rates is expected to increase for another 40 years (Godfray et al. 2010). Changes in climate and climatic zones have influenced agriculture, and will continue to increase dependency of the developing world on foreign food aid (Schmidhuber and Tubiello. 2007). The present changing global climate has also impacted growth and unemployment as many people are directly and indirectly employed by the agricultural sector (Godfray et al., 2010). Increased efficiency in all sectors of agriculture is vital to achieve worldwide food security.

Besides rice and wheat, maize provides 30% of the food calories to over 4.5 billion people in developing countries (Shiferaw et al., 2011). In the Sub Saharan Africa (SSA) maize is widely grown and accounts for 70% of the total human caloric intake (Byerlee and Heisey, 1996).

It has been asserted that maize production needs to double in third world countries by the year 2050 (Ray et al., 2013). Current planting techniques employed in developing countries deprive possible productivity and can be improved. Planting is done using sticks and hand hoes (Adjei et al., 2003). A hole (also referred to as hill) is made using sticks and hand hoes, depending on the tradition, and where two to three seeds are deposited into the hole and covered by surrounding soil (Omara et al., 2015). Aikins et al. (2010) indicated that these traditional planting methods are labor intensive and result in multiple seed emergence and non-uniform crop stands. Omara et al. (2015) offered an alternative, the GreenSeeder^{TM} hand planter developed at Oklahoma State University (OSU).

The GreenSeeder^{TM} hand planter delivers seed singulation and removes chemically treated seed from the hands of producers, reducing health risks. The OSU hand planter can also accommodate mid-season fertilizer applications to crops by replacing the internal drum. Many researchers have reported the importance of incorporation of urea below the soil surface (Fox et al., 1981; Mengel et al., 1982; Fowler and Brydon, 1989; Bandel et al., 1980; Ernst and Massey, 1960; Hargrove et al., 1977; Terman, 1979; Volk, 1959; Raun and Johnson, 1999). This research further documents the need to incorporate urea fertilizer by using the OSU hand planter.

Furthermore, the planter works well in various tillage systems, but has not been evaluated extensively. Minimum or no tillage is also tied to the term conservation tillage (Unger and McCalla, 1980), and many researchers have reported its benefits (Edwards et al., 1988; Blevins et al., 1971; Hargrove, 1985; Lal and Kimble, 1997).

The objective of this study was to investigate the influence of tillage (conventional and no-till) and sidedress N on maize plant stands and grain yield using the GreenSeeder^{TM} hand planter with altered drum cavity sizes.

CHAPTER II

LITERATURE REVIEW

Influence of tillage

Conservation agriculture has gained global approval as a way to practice modern agriculture over the years (FAO, 2002). It is a highly recommended management practice for improving soil conservation and grain yields (Lal and Kimble. 1997). According to Fowler and Rockstrom (2001) conservation tillage is a collective term used to refer to agricultural practices that aim at conserving natural resources. However, no-till is defined as a farming system in which crop residues remain on top of the soil, leaving the soil undisturbed following harvest, and nutrient amendments can be added at any time on the surface or injected into the soil (Horowitz et al., 2011).

Long-term adoption of no-till practices leads to increased soil organic carbon (SOC) when compared to those under conventional tillage (Ismail et al., 1992). This is due to buildup of soil organic matter embedded in deeper soil layers as reported by Balesdent et al. (2000). No-till has other benefits such as decreased soil erosion (Al Darby and Lowery, 1986). They also reported that too much surface residue before and during planting leads to slow soil warming, hence slower plant emergence, which has adverse effects on plant stands and development of the crop compared to conventional tillage.

Reicosky et al. (1995) reported that the rate at which plant residues are broken down in the soil is slower in soils under conservation tillage, due to reduced contact of the residue with soil aggregates, of which contain the microbial engines that drive decomposition. Epplin et al. (2006) noted that in order to implement no-till management successfully, information regarding distribution of nutrients, soil fertility and pH in the soil are required. Furthermore, these differ greatly in the case of conventional tillage due to reduced co-mixing of soils.

Maguta (2009) urged that reduced tillage leads to increased macro aggregation, which decreases the portion of micro aggregates, and free silt-clay loam portions. Large soil macro-aggregates proportion was 30% to 89% higher in reduced tillage compared to conventional tillage at different depths at 10-15 cm depth. However, macro aggregates were also lower in reduced tillage by 23-28% compared to conventional tillage. Lipps and Deep (1991) observed that tillage has a large impact on corn grain yields. This followed work from long-term trials in Ohio (reference?) that showed corn yields being positively influenced by no tillage when corn was planted on well-drained, silty, clay loam soils. Improved yields with no-till on well-drained soils were attributed to better water retention and absence of late-season water stress.

Midseason Applications of N

Scharf et al. (2002) reported that the application of N fertilizer in corn could be performed before planting. However, a number of reasons can be cited for its mid-way season and some of these are, to distance the workload away from the tedious planting season. Furthermore, this helps when wet field conditions are present during the spring and to avoid N losses in wet years (Scharf et al., 2002). Sangoi et al. (2007) noted that the application of N either before or at planting increases available N in soils, during the early stages of plant growth and this could help reduce immobilization effects due to a high C/N ratio.

For proper N application, Doerge et al. (1991) indicated that it is recommended that N be side dressed or applied via irrigation water between 3 to 4 leaf stages. If N is to be applied at silking and beyond, it should be done when N is deficient and has been identified through plant tissue analysis or visual symptoms. Nitrogen fertilizer application rates can change based on the past and current climatic conditions, management practices, and crop response to N in the soil (Doerge et al. 1991; Scharf and Lory 2009).

Murrell and Snyder (2006) and Butzen (2011) suggested that one of the main reasons for proper N management is to ensure that crops have enough N, but it's not accessible due to the high mobility of N compounds in the soils. At rapid vegetative growth stages, N deficiencies in corn can lead to significant yield loss, likewise if applied in excess it can lead to a reduction in profits and negatively impact the environment.

Hanninger (2012) explained that N applications could be done any time after planting through the tasseling stage. Plants have different amounts of N needs based on their growth stages, V10 is a vital growth stage as N needs by the plant are at the peak. However, to ensure that plants utilize applied N, it is important to apply side-dress N at the V10 growth stage when N demands peak and plants can fully utilize it to the maximum.

Murrell and Snydert (2006) and Butzen (2011) found that mid-season (side-dress) applications enable alterations in planned N supply based on variations in weather. In cases where high temperatures and varying rainfall result in high N mineralization from organic matter, side-dress rates can be reduced. When using the sufficiency approach, various soil testing methods and/or plant sensing can be used.

World cereal grain nitrogen use efficiency (NUE) is estimated to be 33% (Raun and Johnson. 1999). A number of factors affect NUE in soil and some of these include the general health of the plant food factory (photosynthesis), and plant exposure to N losses. Three pathways for N losses in corn include leaching and denitrification of of NO_3-N, and surface volatilization as NH_3 (Neilson 2006).

Fageria and Baligar (2005) noted that surface runoff is one of the many ways in which N is lost from the soil. In some cases, plants will lose N by gaseous emission during anthesis.

Francis et al. (1993) stressed that plant N losses in the form of ammonia (NH_3) accounted for 52-73% of known N loss in maize production leading to poor NUE in crop production. Similar work by Lees et al. (2000) found that plant N losses during the growing season could exceed 40 kg N ha^{-1} in winter wheat.

Ciampitti and Vyn (2011) observed that N uptake and use efficiency in narrow rows with a high plant density, enabled plants to occupy spaces between the rows, hence utilizing the N fertilizer more efficiently.

Importance of the hand planter

M'mboyi et al. (2010) reported that maize is a main staple food for most countries in Africa, being grown by over 24 million households in East and Southern Africa. Omara et al. (2015) reported that heavy sticks are used to plant 2-3 seeds per strike over large areas under maize production in the developing world. This farming practice is largely dictated by terrain and prevailing climatic conditions, and that cannot employ mechanization.

Aikins et al. (2011) noted that hand planter seeded maize has better emergence and plant stands when compared to that planted using traditional methods such as hoes, cutlasses, and dibble sticks.

However, the metering system of most hand seed planters needs to be assessed for a better output of seed as this affects emergence and plant stands in the fields. (Aikins et al., 2010) analyzed the planting and fertilizer application efficiency of 30 hand planters used to plant maize and according to their results, the planters reported 53.3% chance of delivering two seeds for all the five seed varieties tested. They further exhibited poor rates of seed delivery, with metering being a problem and that called for more improvements.

The Greenseeder^{TM} further aids in incorporating fertilizer N, helping to prevent losses from volatilization and reliance on timely rains. Rather than broadcasting fertilizer over the soil surface, the hand planter can be used to apply N fertilizer using fertilizer drums, resulting in having the fertilizer closer to the plant and below the soil surface (Fisher, 2016).

CHAPTER III

OBJECTIVE

The objective of this study was to investigate the influence of tillage (conventional and no-till) and sidedress N on maize plant stands and grain yield using the GreenSeeder^{TM} hand planter with 2 different drum cavity sizes.

CHAPTER IV

METHODOLOGY

Experimental sites

Four maize trials were established and studied for a two-year period (2015-2016) at EFAW and Lake Carl Blackwell (LCB) experiment stations near Stillwater, OK. For the first year (2015) at each site, one experiment was kept under conventional tillage and the other employed no-tillage using the treatment structure shown in Table 3. However, for the second year (2016) the two sites at Efaw were both maintained as no-tillage and those at Lake Carl Blackwell maintained as conventional tillage. Soil classification at both sites is as described in Table 1. Description of soils at Lake Carl Blackwell and Efaw are Port Silt Loam (Fine-silty, mixed, thermic cumulic Haplustolls) and Ashport silty clay loam (fine-silty, mixed, superactive, thermic fluventic halplustolls) respectively.

Experiment design and Layout

A Greenseeder^{TM} hand planter with altered drum cavity sizes was used to plant the trials. A specialized fertilizer drum (Figure 2) was used for applying side-dress N fertilizer, which applied 0.50 or 0.10 grams (g) of urea per strike. Using a plant population of 64,000 seeds/ha, these amounts applied per plant resulted in N rates of 50 and 100 kg/ha, respectively. Side-dress applications were applied at the V10 growth stage in maize.

A randomized complete block design with 18 treatments and 3 replications was used at all experimental sites. Pre-plant N was applied at a rate of 56 kg N ha^{-1} in all treatments for each experimental year. Pioneer hybrid seed 'P1395YHR' (2651 seeds/kg) was planted at a population of 64,000 seeds ha^{-1}. Row spacing was 76cm, with plant to plant spacing being 20.5 cm using a black tape marked string to maintain proper plant spacing ensuring uniformity in all trials. In order to achieve the desired plant population, 31 strikes were made per row.

At both locations, two trials were maintained for both years with each trial having 3 replications and 6 treatments. Table 2 highlights the various field activities for both years. Internal drums used for seed singulation were 450S and 260-20 (Figure 1).

Climatic data during the two-year experimental period for average monthly temperature and total rainfall at Lake Carl Blackwell (2015 and 2016), and Efaw (2015 and 2016) are reported in Figures 4, 5, 6 and 7.

Emergence counts were collected from the two middle rows, noting singles, multiples and the overall totals that resulted from each individual strike and the entire row. In order to achieve this the formula below was used.

$$\textbf{Percentage Singulation} = \frac{\textbf{\textit{Total number of Emergent Plants}} - \textbf{\textit{Multiples Emergent Plants}}}{\textbf{\textit{Total number of strikes in a row}}} \times \mathbf{100}$$

Where:

Total number of Emergent Plants = the overall number of seeds that emerged after planting.

Multiple Emergent Plants = the number of seeds that emerged as multiple seedlings.

Total number of strikes in a row = the number of strikes made per row during planting.

Knowledge of singulation percentages is vital in improving yields, the more singles emergent plants in the field, the better the yields because Nitrogen Use Efficiency by the plants is improved due to less competition for Nitrogen by plants. It further improves plant spacing in the field a practice needed to improve yields.

In some cases, there were emergence failures and these were attributed to misses (lack of seed drop) during planting. Chim et al. (2014) observed poor seed emergence having a profound effect on plant density and spacing as it interfered with canopy structure and the radiation efficiency in some trials. Multiple seed emergence in the same spot was accounted for as a single plant count as observed by Kachman and Smith (1995). Sensor readings for normalized difference vegetation index (NDVI) were collected at different growth stages (V6, V8 and V10) using the active Trimble Ukiah CA, Greenseeker^{TM} hand held sensor to evaluate NDVI and plant response to hand planter applied fertilizer N, and to have an earlier prediction of final grain yields after harvest. Based on the Iowa State University extension article reprinted version (1996), growth stages for maize were determined. During sensor NDVI reading collection care was taken to ensure that the Greenseeker^{TM} sensor head was kept at least 70 cm above the maize plant canopies. The Greenseeker^{TM} uses the formula shown below to calculate NDVI for each individual maize plant.

$$\mathbf{NDVI} = \frac{\mathbf{(NIR - Red)}}{\mathbf{(NIR + Red)}}$$

Where: NIR and Red are reflectance band 2 and 1. (Mkhabela et al., 2010).

Trials were harvested (middle two rows) using a self-propelled combine, Massey Ferguson 8XP (AGCO Corp. Duluth GA). Plot grain weights were determined using a computerized automated digital weighing system (Juniper Systems Inc. Logan, UT) at both locations in 2015, and where final moisture content was adjusted to 15.5%. For each plot a subsample was taken and oven dried for at least 2 days at 75 degrees C and later ground to pass a 240 mesh screen. A sample from the resultant finely ground maize grain was tested for total N by the LECO Truspec CN dry combustion analyzer (Nieuwenhuize et al., 1989).

Statistical Analysis of Data

Using SAS version 9.3 (SAS Institute, Cary, NC, USA.), the collected emergence, singulation and NDVI data was analyzed using proc GLM. The main effects of tillage, drum cavity, and side-dress N rates were all partitioned accordingly. Mean separation was accomplished using the least significance difference method (LSD) at an alpha level of 0.05.

CHAPTER V

RESULTS

Efaw (2015)

Conventional Tillage (CT)

Emergence

Emergence rates for this location ranged from 79% (with drum 450S at 0 kg N ha^{-1} to 91% (with drum 260-20 at 50 kg N ha^{-1}) (Table 4). There was no significant difference among treatments for emergence rates ($\alpha = 0.05$) (Table 4). However, drum 260-20 achieved numerically higher emergence rates than 450S at N rates of 0 and 50 kg N ha^{-1}. Emergence rates for this conventionally tilled plot were higher than its no-till counterpart. This is an indication of the variability in emergence likely due to the residue on the soil surface.

Singulation

At this site, singulation percentages ranged from 48% (with drum 260-20 at 100 kg N ha^{-1}) to 68% (with drum 260-20 at 0 kg N ha^{-1}) (Table 4). There was no significant difference among the 6 treatments for singulation rates ($\alpha = 0.05$) (Table 4). Drum 260-20 achieved higher singulation at 0 and 50 kg N ha^{-1} when compared to drum 450S at the same N rates. Drum 450S possessed higher singulation at 100 kg N ha^{-1}, where it achieved a rate of 57%, compared to the 48% witnessed from drum 260-20.

Yield

At this location, grain yield ranged from 1.9 Mg ha^{-1} (drum 450S at 0 kg N ha^{-1}) to 4.01 Mg ha^{-1} (drum 260-20 at 100 kg N ha^{-1}). Significant differences were seen for treatment 6 (260-20 at 100 kg N ha^{-1}) that was higher than treatments 1, 3, 4, and 5 ($\alpha = 0.05$) (Table 4). At 0 kg N ha^{-1}, drum 260-20 achieved a higher yield than drum 450S. The inverse occurred at 50 kg N ha^{-1}, where drum 450S had the highest yield. Grain yields were maximized at 100 kg N ha^{-1} (Table 4)

No-Tillage (NT)

Emergence

Emergence rates at this site showed no significant differences among treatments ($\alpha = 0.05$) (Table 5). Emergence rates ranged from 68% (450S at 0 kg N ha^{-1}) to 85% (260-20 at 100 kg N ha^{-1}, Table 5). Drum 260-20 had higher emergence rates than drum 450S at all 3 N rates. Lower emergence rates were present in this no till system than in the conventionally tilled trial. This is likely due to residue impacting the emergence of seedlings. Additionally, during early portions of the growing season, excessive standing water impacted seedling growth and vigor, further impacting the overall emergence rates.

Singulation

Singulation rates at this site ranged from 44% (450S at 100 kg N ha^{-1}) to 63 % (260-20 at 100 kg N ha^{-1}) (Table 5). Singulation rates were not significantly different among the six treatments ($\alpha = 0.05$) (Table 5). Drum 260-20 produced the numerically highest singulation rates across all three levels of the treatment when comparing it to the performance of drum 450S at the same respective N rates. Although not significant, drum 260-20 was higher when it came to seed singulation. Excessive standing water during the early portion of the growing season is a likely contributor to the varying nature of the singulation rates.

Yield

At this location, grain yields ranged from 1.6 Mg ha^{-1} (450S, 100 kg N ha^{-1}) to 4.2 Mg ha^{-1} (260-20, 100 kg ha^{-1}) (Table 5). Although variable, grain yields were not statistically different across all treatments. ($\alpha = 0.05$) (Table 5). Excessive standing water during portions of the growing season contributed to the variability seen in the range of grain yields. Grain yields were maximized with 100 kg N ha^{-1} utilizing drum 260-20. Drum 450S achieved a maximum yield at 50 kg N ha^{-1}, which was higher than the yield achieved with 50 kg N ha^{-1} using drum 260-20 (Table 5)

Efaw 2016

No-Tillage (NT) 1.1

Emergence

At this location, analysis of variance showed no significant difference in emergence rates when comparing 450S and 260-20 drums ($\alpha = 0.05$) (Table 8). Emergence percentages ranged from 79% with drum 450S at 100 kg ha^{-1} of midseason N to 93% at 50 kg N ha^{-1} using drum 450S. (Table 8) Differences in emergence rates suggest micro-environmental variation throughout the trial. Influences from surface residue and land layout are likely causes for the small variations seen in emergence rates.

Singulation

Singulation percentages ranged from 25% with drum 260-20 at 0 kg N ha^{-1} to 47% with drum 260-20 at 50 kg N ha^{-1} (Table 8). Although values varied among treatments, there were no significant treatment differences ($\alpha = 0.05$) (Table 8). The lack of reported differences in singulation within this trial indicate that microenvironments have the potential to vary dramatically from area to area. Furthermore, other locations within this experiment were visually variable and likely due to treatment effects. Some of this variability can be attributed to operator effects. Dividing the treatments into two groups based off drum cavity size, drum 450S achieved numerically higher singulation rates in treatments 1 and 3 when compared to treatments 4 and 6 using drum 260-20 at respective N rates (Table 8).

Yield

Grain yields at this location ranged from 0.98 Mg ha^{-1} (450S, 100 kg N ha^{-1}) to 2.87 Mg ha^{-1} (260-20, 100 kg N ha^{-1}) (Table 10). Drum 260-20 held numerically higher yields at each N tier; however, no significant difference was present among all of the treatments ($\alpha = 0.05$) (Table 8). Strong environmental variability within the trial contributed to this result, as drought stress was magnified from the sloping nature of the experimental plot area. Drought stress is the likely result of poor ear quality; as evident tip dieback and leaf curling were present. Additionally, poor pollination occurred throughout much of the trial, further reducing yields.

No-Tillage (NT) 1.2

Emergence

Emergence rates for this site ranged from 84% (260-20 at 100 kg N ha^{-1}) to 90% (260-20 at 50 kg N ha^{-1}) (Table 9). No significant differences were present among the six treatments ($\alpha = 0.05$). Numerically, the drums performed similarly, with the exception of plots receiving seed from drum 260-20 at 100 kg N ha^{-1}. This treatment was noticeably lower than the other treatment means, but not significant. The strong emergence rates from this location indicates that conservation tillage did not impact emergence rates.

Singulation

Singulation percentages ranged from 19% (450S at 50 kg N ha^{-1}) to 66% (260-20 at 100 kg N ha^{-1}) (Table 9). A significant difference was present between the two drums, as treatment 6 ($\alpha = 0.05$) (260-20 at 100 kg N ha^{-1}) was higher than treatment 3 (450S at 100 kg N ha^{-1}). It should be noted that treatment 6 did outperform treatment 4, which utilized the same drum (260-20), but at with no N applied. There was no significant difference between treatments 3 and 4. Numerically, drum 260-20 was higher than drum 450S at two of the three N rates.

Yield

Yields at this site ranged from 3.32 Mg ha^{-1} (450S at 50 kg N ha^{-1}) to 6.31 Mg ha^{-1} (Table 9). No significant difference was observed at this location ($\alpha = 0.05$). Numerically, yields from drum 260-20 were higher at all three N rates when compared to drum 450S. The low yields at this site can be attributed to drought stress and poor pollination. This also aids in explaining the variability seen in yields, where maximum yields were achieved in treatment 4, which received 0 kg N ha^{-1}.

Lake Carl Blackwell (LCB 2015)

Conventional Tillage (CT)

Emergence

Emergence rates at this location were not significantly different ($\alpha = 0.05$) (Table 6). Emergence rates ranged from 65% (450S at 0 kg N ha^{-1}) to 77% (260-20 at 0 kg N ha^{-1}) (Table 6). Drum 260-20 produced numerically higher emergence rates at 2 of the 3 N rates when compared to drum 450S. Overall, emergence rates were relatively uniform, with the exception of treatment 4 (260-20 at 0 kg N ha^{-1}). Only 8 percentage points (Table 6) separated all treatments.

Singulation

Singulation rates at this site ranged from 48% (450S at 0 and 450S at 100 kg N ha^{-1}) to 75% (260-20 at 0 kg N ha^{-1}) (Table 6). Statistical differences were evident, as drum 260-20 had significantly higher singulation rates when comparing treatments 5 and 6 (260-20 at 50 and 100 kg N ha^{-1}, respectively) to treatments 2 and 3 (450S at 50 and 100 kg N ha^{-1} ($\alpha = 0.05$) (Table 6). Treatment 4 (260-20 at 0 kg N ha^{-1}) was not significantly different from any treatment, likely due to the variation encountered over the three replications. Drum 260-20 produced the best singulation rates for this location (Table 6).

Yield

At this location, grain yields ranged from 1.2 Mg ha^{-1} (260-20, 0 kg N ha^{-1}) to 3.41 Mg ha^{-1} (260-20, 50 kg ha^{-1}) (Table 6). Significant differences were present, as 50 kg N ha^{-1} produced significantly higher yields compared to the 0 N checks (treatments 1 and 4), and for each drum ($\alpha = 0.05$) (Table 6). Yields were maximized with 50 kg N ha^{-1} at this location (Table 6). No clear numeric trend was found that would favor one drum over the other.

No-Tillage (NT)

Emergence

Emergence rates ranged from 25% (260-20 at 0 kg N ha^{-1}) to 50% (450S at 50 kg N gha^{-1}) (Table 7). Significant differences were present, as drum 450S at 0 kg N ha^{-1} achieved a higher emergence rate than drum 260-20 at 0 kg N ha^{-1}($\alpha = 0.05$) (Table 7). Additionally, drum 450S continued to produce numerically higher emergence rates than drum 260-20 at N rates of 50 and 100 kg N ha^{-1} (Table 7). Overall, emergence rates were lower than anticipated at this location. Likely factors contributing to this was excessive standing water during the initial weeks of the growing season, combined with heavy residue impacting seedling growth and performance.

Singulation

Singulation rates ranged from 24% (260-20 at 0 kg N ha^{-1}) to 38% (450S at 50 kg N ha^{-1} and 260-20 at 100 kg N ha^{-1}) (Table 7). There were no significant differences among the six treatments ($\alpha = 0.05$) (Table 8). Drum 450S had improved singulation as compared to drum 260-20 (Table 7). Emergence rates at this location were impacted by excessive standing water and residue. This helped to better explain the lower singulation rates. This with knowledge that poor emergence can have a [direct impact on the identification of reliable singulation data.

Yield

Grain yields ranged from 1.3 Mg ha^{-1} (260-20 at 0 kg N ha^{-1}) to 3.7 Mg ha^{-1} (450S at 50 kg N ha^{-1}) (Table 7). Significant yield differences were present in this trial ($\alpha = 0.05$) (Table 7). Drum 450S achieved a significantly higher yield than drum 260-20 at the N rate of 50 kg ha^{-1} (Table 8). Furthermore, numeric trends favored drum 450S at N rates of 0 and 100 kg ha^{-1}. Overall, drum 450S produced the best yield throughout this trial (Table 7). However, this does not discount the possibility that the environmental impact of excessive standing water could be a likely contributor to the low yields witnessed with drum 260-20.

Lake Carl Blackwell (LCB 2016)

Conventional Tillage (CT) 1.1 2016

Emergence

Emergence rates within this trial ranged from 83% (450S, 50 kg N ha^{-1}) to 91% (260-20, 100 kg N ha^{-1}) (Table 10). There was no significant difference across all treatments for emergence rates. ($\alpha = 0.05$) (Table 10). This suggests adequate growing conditions for the initial germination and growth of the trial. Emergence was relatively similar across all treatments in this trial.

Singulation

Singulation percentages ranged from 26% (450S, 100 kg N ha^{-1}) to 55% (260-20, 50 kg N ha^{-1}) (Table 10). There were limited differences between treatments, with the exception of those utilizing drum 450S, specifically100 kg N ha^{-1} ($\alpha = 0.05$) (Table 10). This treatment was significantly lower than drum 450S at 50 kg N ha^{-1} and drums 260-20 at 0 and 50 kg N ha^{-1} (α =0.05) (Table 10). Numeric differences were evident, as drum, 260-20 produced elevated singulation when compared to drum 450S. At each tier of N rates, singulation rates for 260-20 were higher than those of 450S (Table 10).

Yield

Grain yield values ranged from 1.83 Mg ha^{-1} from drum 260-20 at 0 kg N ha^{-1} to 2.76 Mg ha^{-1} with drum 450S at 50 kg N ha^{-1}(Table 10). No statistical difference was present among the six treatments ($\alpha = 0.05$). There was a clear numeric trend from the positive benefit of midseason N; however, differences were not strong enough to declare significance ($\alpha = 0.05$) (Table 10). Both drums recorded similar trends. From the different midseason N rates, 50 kg N ha^{-1} produced the highest yields for each set of drums (Table 10).

Conventional Tillage (CT) 1.2 2016

Emergence

Emergence rates for this site ranged from 85% (450S at 0 kg N ha^{-1}) to 92% (260-20 at 50 kg N ha^{-1}) (Table 11) and where treatment differences did exist. Plots planted with drum 260-20 (50 kg N ha^{-1}) had significantly higher emergence rates than plots receiving seed from drum 450S (0 kg N ha^{-1}) ($\alpha = 0.05$). Aside from this observation, differences were small. Adequate growing conditions early in the season allowed for good seedling establishment. Two of the three treatments that utilized drum 450S were not different from the three treatments that received seed from drum 260-20. However, a minimal numeric trend was present where drum 260-20 had numerically higher emergence rates at two of the three N rates, and an emergence rate equal to 450S at 100 kg N ha^{-1}.

Singulation

Singulation rates ranged from 52% (450S at 50 kg N ha^{-1}) to 56% (450S at 100 kg N ha^{-1}) (Table 11). There was no significant difference in singulation rates for this location. Singulation rates were not highly variable ($\alpha = 0.05$). Drum 450S had a numerically higher singulation rate at two of the three N rates, however, these differences were small. This data suggests equal performance of the two drums for singulating seed in this conventionally tilled system.

Yield

Yields ranged from 0.9 Mg ha^{-1} (450S at kg N ha^{-1}) to 1.41 Mg ha^{-1} (450S at 100 kg N ha^{-1}) ($\alpha = 0.05$) (Table 11). No significant differences were present that were due to treatment ($\alpha = 0.05$). Numeric trends were in favor of drum 450S for higher grain yields at N rates of 50 and 100 kg ha^{-1}. Low yields were not a result of stand establishment; as adequate emergence rates were present throughout the trial. Poor ear fill suggests inadequate pollination. Furthermore, leaf curling during the season was evidence of drought stress both vegetative and during the reproductive season. This further supports observing such low yields.

CHAPTER VI

CONCLUSIONS

Emergence and singulation rates, along with grain yield displayed similar results under different tillage practices. Environmental influences limited the statistical differences observed and to accurately determine grain yield differences among N rates and for both drums. Emergence rates were relatively uniform from location to location, generally staying in the mid-to upper 80's and low 90's. Singulation rates were highly variable from location to location, even within locations. Drum 260-20 generally possessed more variable singluation rates, versus drum 450S, which was relatively consistent from treatment to treatment. Despite this variability, drum 260-20 generally had numerically higher singulation rates.

Efaw yields were maximized when 100 kg N ha^{-1} was applied side-dress. LCB yields were maximized when 50 kg N ha^{-1} was applied side-dress. Variability in grain yields was high. Results showed that both drums 450S and 260-20 had limited differences in performance despite having uneven plant stands.

Based on the reported results, both drums 450S and 260-20 are likely to be of use for farmers hoping to increase maize yields when planted by hand. Tillage influenced production significantly but not so much as to affect average yields. The use of the GreenSeeder^{TM} has benefit and can be used to place midseason N below the surface of the soil. This is a better method of fertilizer application as it places the N fertilizer below the soil surfaces, which prevents ammonia losses to the environment. Furthermore, the placement of N fertilizers as close as possible to the plant root zone provides an immediate source of N fertilizer. The farmer places a predetermined quantity of fertilizer N for each individual plant in the field, hence improving Nitrogen Use Efficiencies in the soil. Viable economics are necessary to ensure that farmers find the highest profit margins.

Excessive spending on fertilizer and seed can be minimized when the GreenSeeder^{TM} is used to plant fields and apply midseason N. This is achieved through the uniform placement of seed and even application of N fertilizer. Overall, drum 260-20 possessed benefits in singulation over drum 450S, which will aid in the reduction of seed lost to “doubles.” Through the utilization and implementation of the GreenSeeder^{TM} planter into the farming practices of the developing world, global maize supplies can be better secured.

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TABLES

Table 1. Description of soils at Lake Carl Blackwell and Efaw, Oklahoma

Location	Soil Series
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, 2015 and 2016.

	2015		2016	
Field Activity	Efaw	LCB	Efaw	LCB
Planting	21-Apr	21-Apr	April 14	April 7
Sidedress	9-Jun	10-Jun	2-Jun	6-Jun
NDVI Collection	12-Jun	12_Jun	4-Jun	27-May
Harvest	3-Sep	2-Sep	25-Aug	6-Sep

Efaw, Oklahoma Agricultural Experimental Station near Stillwater, OK.

LCB, Oklahoma Agricultural Experimental Station west of Stillwater, OK near Lake Carl Blackwell.

Table 3. Treatment structure employed at EFAW and Lake Carl Blackwell, 2015 and 2016.

Treatment	Drum	Sidedress N rate, kg ha^{-1}
1	450S	0
2	450S	50
3	450S	100
4	260-20	0
5	260-20	50
6	260-20	100

Table 4. Emergence, singulation, NDVI and grain yields as influenced by drum cavity size (450S, 260-20), tillage practice, (conventional tillage, CT and no tillage, NT), and sidedress N rates, Efaw, Lake Carl Blackwell, OK, 2015.

		Emergence, %				Singulation, %				Grain yield, Mg ha^{-1}				NDVI			
		Efaw		LCB		Efaw		LCB		Efaw		LCB		Efaw		LCB	
Drum Cavity	Sidedress N rate kg ha^{-1}	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT
450S	0	79^{A}	68^{A}	65^{A}	36^{AB}	61^{AB}	45^{A}	48^{B}	27^{A}	1.90^{B}	1.71^{A}	1.30^{B}	2.60^{AB}	0.82^{C}	0.80^{A}	0.52^{A}	0.80^{A}
450S	50	81^{A}	77^{A}	71^{A}	50^{A}	58^{AB}	53^{A}	51^{B}	38^{A}	3.01^{AB}	2.80^{AB}	3.31^{A}	3.71^{A}	0.81^{BC}	0.91^{A}	0.55^{A}	0.83^{A}
450S	100	85^{A}	78^{A}	73^{A}	38^{AB}	57^{AB}	44^{A}	48^{B}	31^{A}	2.62^{B}	1.60^{A}	2.30^{AB}	2.21^{AB}	0.90^{ABC}	0.83^{A}	0.64^{A}	0.82^{A}
260-20	0	88^{A}	72^{A}	77^{A}	25^{B}	68^{A}	53^{A}	75^{AB}	24^{A}	2.41^{B}	1.71^{A}	1.20^{B}	1.30^{B}	0.90^{A}	0.80^{A}	0.50^{A}	0.79^{A}
260-20	50	91^{A}	82^{A}	72^{A}	29^{AB}	62^{AB}	60^{A}	71^{A}	28^{A}	2.51^{B}	1.72^{A}	3.41^{A}	1.83^{B}	0.81^{A}	0.81^{A}	0.52^{A}	0.79^{A}
260-20	100	82^{A}	85^{A}	72^{A}	38^{AB}	48^{AB}	63^{A}	70^{A}	38^{A}	4.01^{A}	4.20^{A}	1.80^{AB}	2.50^{AB}	0.90^{AB}	0.82^{A}	0.51^{A}	0.82^{A}
MSE		60	305	59	200	169	175	83	440	0.57	0.91	1.27	0.78	0.0015	0.001	0.0010	0.0006
SED		6	14	6	11	11	11	7	17	0.61	0.77	0.92	0.50	0.03	0.02	0.04	0.02
CV,%		9	23	11	41	18	19	11	61	26	37	46	37	11	9	10	7

SED – Standard error of the difference between two equally replicated means, CV – coefficient of variation, %, MSE -mean square error from analysis of variance, values with different letters were significantly different at the 5% probability level, CT - conventional tillage, NT - no tillage.

Table 5. Maize emergence, singulation, grain yield and NDVI, Efaw conventional tillage, 2015

Drum Cavity	Sidedress N, kg ha^{-1}	Emergence, %	Singulation, %	Grain yield, Mg ha^{-1}	NDVI
450S	0	79^{A}	61^{AB}	1.90^{B}	0.820^{C}
450S	50	81^{A}	58^{AB}	3.01^{AB}	0.81^{BC}
450S	100	85^{A}	57^{AB}	2.62^{B}	0.90^{ABC}
260-20	0	88^{A}	68^{A}	2.41^{B}	0.87^{A}
260-20	50	91^{A}	62^{AB}	2.51^{B}	0.84^{A}
260-20	100	82^{A}	48^{AB}	4.01^{A}	0.85^{AB}
MSE		60	169	0.57	0.001
SED		6	11	0.67	0.03
CV,%		9	18	26	11

SED -	Standard error of the difference between two equally replicated means.
MSE -	Mean square error from analysis of variance.
CV% -	Coefficient of variation, %
NDVI -	Normalized difference vegetation index

Means followed by the same letter were not statistically different using the least significance difference (LSD) mean separation procedure, alpha = 0.05.

Table 6. Maize emergence, singulation, grain yield and NDVI, Efaw, no tillage, 2015.

		Emergence,%	Singulation,%	Grain yield, Mg ha^{-1}	NDVI
Drum Cavity	Sidedress N rate kg ha^{-1}				
450S	0	68^{A}	45^{A}	1.71^{A}	0.80^{A}
450S	50	77^{A}	53^{A}	2.80^{AB}	0.86^{A}
450S	100	78^{A}	44^{A}	1.60^{A}	0.81^{A}
260-20	0	72^{A}	53^{A}	1.71^{A}	0.80^{A}
260-20	50	82^{A}	60^{A}	1.72^{A}	0.83^{A}
260-20	100	85^{A}	63^{A}	4.20^{A}	0.83^{A}
MSE		305	175	0.91	0.001
SED		14	11	0.77	0.02
CV,%		23	21	37	4

SED - Standard error of the difference between two equally replicated means.

MSE - Mean square error from analysis of variance.

CV% - Coefficient of variation, %

NDVI - Normalized difference vegetation index

Means followed by the same letter were not statistically different using the least significance difference (LSD) mean separation procedure, alpha = 0.05.

Table 7. Maize emergence, singulation, grain yield and NDVI, Lake Carl Blackwell, conventional tillage, 2015

		Emergence, %	Singulation, %	Grain yield, Mg ha^{-1}	NDVI
Drum Cavity	Sidedress N rate, kg ha^{-1}				
450S	0	65^{A}	48^{B}	1.30^{B}	0.52^{A}
450S	50	71^{A}	51^{B}	3.31^{A}	0.54^{A}
450S	100	73^{A}	48^{B}	2.30^{AB}	0.64^{A}
260-20	0	77^{A}	75^{AB}	1.20^{B}	0.50^{A}
260-20	50	72^{A}	71^{A}	3.41^{B}	0.52^{A}
260-20	100	72^{A}	70^{A}	1.80^{AB}	0.51^{A}
MSE		59	83	1.27	0.001
SED		6	7	0.92	0.04
CV,%		11	11	46	13

SED - Standard error of the difference between two equally replicated means.

MSE - Mean square error from analysis of variance.

CV% - Coefficient of variation, %

NDVI - Normalized difference vegetation index

Means followed by the same letter were not statistically different using the least significance difference (LSD) mean separation procedure, alpha = 0.05

Table 8. Maize emergence, singulation, grain yield and NDVI , Lake Carl Blackwell no-tillage, 2015

		Emergence,%	Singulation,%	Grain yield, Mg ha^{-1}	NDVI
Drum Cavity	Sidedress N rate, kg ha^{-1}				
450S	0	36^{AB}	27^{A}	2.60^{AB}	0.8 0 ^{A}
450S	50	50^{A}	38^{A}	3.71^{A}	0.83^{A}
450S	100	38^{A}	31^{A}	2.21^{AB}	0.82^{A}
260-20	0	25^{B}	24^{A}	1.30^{B}	0.79^{A}
260-20	50	29^{AB}	28^{A}	1.83^{B}	0.79^{A}
260-20	100	38^{AB}	38^{A}	2.50^{AB}	0.82^{A}
MSE		200	440	0.78	0.0006
SED		11	17	0.03	0.02
CV,%		41	61	37	3

SED - Standard error of the difference between two equally replicated means.
MSE - Mean square error from analysis of variance.
CV% - Coefficient of variation, %
NDVI - Normalized difference vegetative index

Means followed by the same letter were not statistically different using the least significance difference (LSD) mean separation procedure, alpha = 0.05

Table 9. Emergence, singulation, NDVI and grain yields as influenced by drum cavity size (450S, 260-20), tillage practice, (conventional tillage CT and no tillage NT), and sidedress N rates, Efaw, Lake Carl Blackwell, OK 2016.

		Emergence,%				Singulation,%				Grain yield, Mg ha^{-1}				NDVI			
		Efaw		LCB		Efaw		LCB		Efaw		LCB		Efaw		LCB	
Drum Cavity	Sidedress N rate, kg ha^{-1}	NT1.1	NT1.2	CT1.1	CT1.2	NT1.1	NT1.2	CT1.1	CT1.2	NT1.1	NT1.2	CT1.1	CT1.2	NT1.1	NT1.2	CT1.1	CT1.2
450S	0	86^{A}	89^{A}	89^{A}	85^{B}	34^{A}	43^{AB}	40^{AB}	54^{A}	2.80^{A}	3.96^{A}	2.20^{A}	0.90^{A}	0.87^{A}	0.79^{AB}	0.87^{A}	0.85^{A}
450S	50	93^{A}	87^{A}	83^{A}	90^{A}	33^{A}	19^{AB}	48^{A}	52^{A}	1.19^{A}	3.35^{A}	2.76^{A}	1.36^{A}	0.87^{A}	0.77^{B}	0.87^{A}	0.86^{A}
450S	100	79^{A}	88^{A}	84^{A}	89^{AB}	40^{A}	30^{B}	26^{B}	56^{A}	0.98^{A}	4.70^{A}	2.63^{A}	1.46^{A}	0.88^{A}	0.80^{AB}	0.88^{A}	0.85^{A}
260-20	0	90^{A}	89^{A}	88^{A}	88^{AB}	25^{A}	26^{B}	54^{A}	53^{A}	2.19^{A}	6.33^{A}	1.83^{A}	1.00^{A}	0.88^{A}	0.82^{AB}	0.88^{A}	0.85^{A}
260-20	50	87^{A}	90^{A}	88^{A}	92^{A}	47^{A}	50^{AB}	55^{A}	56^{A}	1.60^{A}	4.49^{A}	2.66^{A}	1.26^{A}	0.87^{A}	0.85^{A}	0.87^{A}	0.86^{A}
260-20	100	89^{A}	84^{A}	91^{A}	89^{AB}	29^{A}	66^{A}	39^{AB}	54^{A}	2.87^{A}	4.95^{A}	2.46^{A}	1.13^{A}	0.87^{A}	0.87^{AB}	0.87^{A}	0.85^{A}
MSE		120	23	35	7	190	316	80	206	1.44	3.67	0.42	0.17	0.0001	0.002	0.003	0.0006
SED		9	4	5	2	11	15	7	12	0.69	1.10	0.37	0.22	0.002	0.036	0.044	0.02
CV,%		13	6	7	3	40	46	21	27	62	41	27	35	6	5	1	1

SED – Standard error of the difference between two equally replicated means, CV – coefficient of variation, %, MSE -mean square error from analysis of variance, values with different letters are significantly different at the 5% probability level, NT 1.1 -No tillage site 1.1, NT 1.2 - No tillage site 1.2, CT 1.1 - Conventional tillage site 1.1, CT 1.2 - Conventional tillage site 1.2.

Table 10. Maize emergence, singulation, grain yield, and NDVI, Efaw No-Tillage 1.1, 2016

Drum Cavity	Sidedress N rate, kg ha^{-1}	Emergence,%	Singulation,%	Grain yield, Mg ha^{-1}	NDVI
450S	0	86^{A}	34^{A}	2.70^{A}	0.87^{A}
450S	50	93^{A}	33^{A}	1.11^{A}	0.87^{A}
450S	100	79^{A}	40^{A}	0.98^{A}	0.88^{A}
260-20	0	90^{A}	25^{A}	2.10^{A}	0.88^{A}
260-20	50	87^{A}	47^{A}	1.61^{A}	0.87^{A}
260-20	100	89^{A}	29^{A}	2.87^{A}	0.87^{A}
MSE		120	190	1.44	0.0001
SED		9	11	0.69	0.002
CV,%		13	40	62	6

SED -	Standard error of the difference between two equally replicated means.
MSE -	Mean square error from analysis of variance.
CV% -	Coefficient of variation, %
NDVI -	Normalized difference vegetation index
Note-	Means followed by the same letter were not statistically different using the least significance difference (LSD) mean separation procedure, alpha = 0.05

Table 11. Maize emergence, singulation, grain yield and NDVI, Efaw No-Tillage 1.2, 2016

		Emergence,%	Singulation,%	Grain yield, Mg ha^{-1}	NDVI
Drum Cavity	Sidedress N rate, kg ha^{-1}				
450S	0	89^{A}	43^{AB}	3.91^{A}	0.79^{AB}
450S	50	87^{A}	19^{AB}	3.32^{A}	0.77^{B}
450S	100	88^{A}	30^{B}	4.70^{A}	0.80^{AB}
260-20	0	89^{A}	26^{B}	6.31^{A}	0.82^{AB}
260-20	50	90^{A}	50^{AB}	4.42^{A}	0.85^{A}
260-20	100	84^{A}	66^{A}	4.93^{A}	0.87^{AB}
MSE		23	316	3.67	0.002
SED		4	15	1.10	0.036
CV,%		6	46	41	5

SED - Standard error of the difference between two equally replicated means.

MSE - Mean square error from analysis of variance.

CV% - Coefficient of variation, %

NDVI - Normalized difference vegetation index

Note- Means followed by the same letter were not statistically different using the least significance difference (LSD) mean separation procedure, alpha = 0.05

Table 12. Maize emergence, singulation, grain yield and NDVI, LCB Conventional Tillage 1.1, 2016

		Emergence,%	Singulation,%	Grain yield, Mg ha^{-1}	NDVI
Drum Cavity	Sidedress N rate, kgha^{-1}				
450S	0	89^{A}	40^{AB}	2.20^{A}	0.87^{A}
450S	50	83^{A}	48^{A}	3.31^{A}	0.87^{A}
450S	100	84^{A}	26^{B}	2.63^{A}	0.88^{A}
260-20	0	88^{A}	54^{A}	1.80^{A}	0.88^{A}
260-20	50	88^{A}	55^{A}	2.62^{A}	0.87^{A}
260-20	100	91^{A}	39^{AB}	2.41^{A}	0.87^{A}
MSE		35	80	0.42	0.003
SED		5	7	0.37	0.044
CV,%		7	21	27	1

SED -	Standard error of the difference between two equally replicated means.
MSE -	Mean square error from analysis of variance.
CV% -	Coefficient of variation, %
NDVI -	Normalized difference vegetation index
Note-	Means followed by the same letter were not statistically different using the least significance difference (LSD) mean separation procedure, alpha = 0.05

Table 13. Maize emergence, singulation, grain yield and NDVI, LCB Conventional Tillage 1.2, 2016

		Emergence,%	Singulation,%	Grain yield, Mg ha^{-1}	NDVI
Drum Cavity	Sidedress N rate, kg ha^{-1}				
450S	0	85^{B}	54^{A}	0.92^{A}	0.85^{A}
450S	50	90^{A}	52^{A}	1.30^{A}	0.86^{A}
450S	100	89^{AB}	56^{A}	1.41^{A}	0.85^{A}
260-20	0	88^{AB}	53^{A}	1.02^{A}	0.85^{A}
260-20	50	92^{A}	56^{A}	1.21^{A}	0.86^{A}
260-20	100	89^{AB}	54^{A}	1.10^{A}	0.87^{A}
MSE		7	206	0.17	0.0006
SED		2	12	0.22	0.02
CV,%		3	27	35	1

SED - Standard error of the difference between two equally replicated means.

MSE - Mean square error from analysis of variance.

CV% - Coefficient of variation, %

NDVI - Normalized difference vegetation index

Note- Means followed by the same letter were not statistically different using the least significance difference (LSD) mean separation procedure, alpha = 0.05

FIGURES

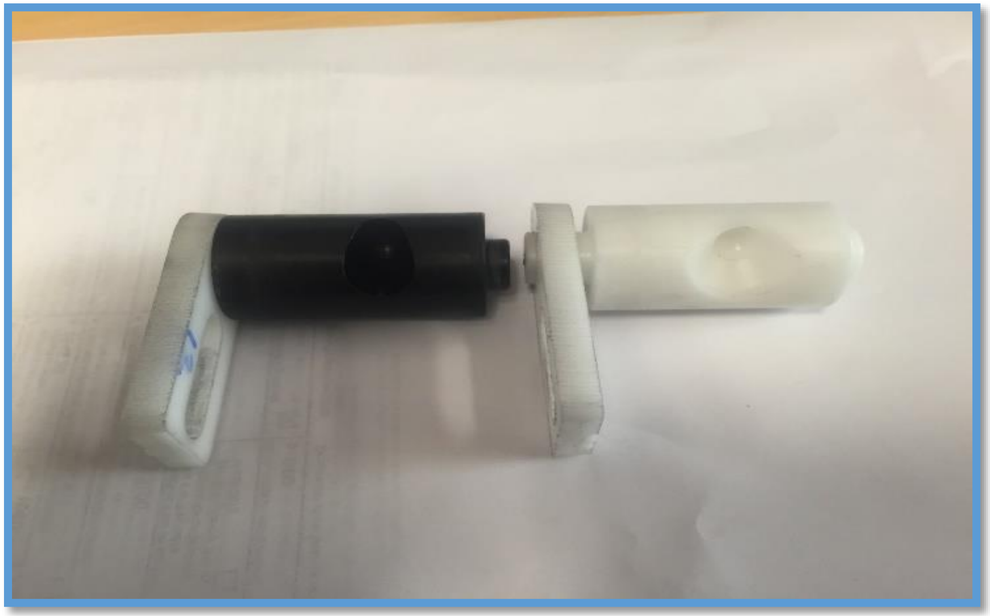

Figure 1. Drum 260-20 and Drum 450S.

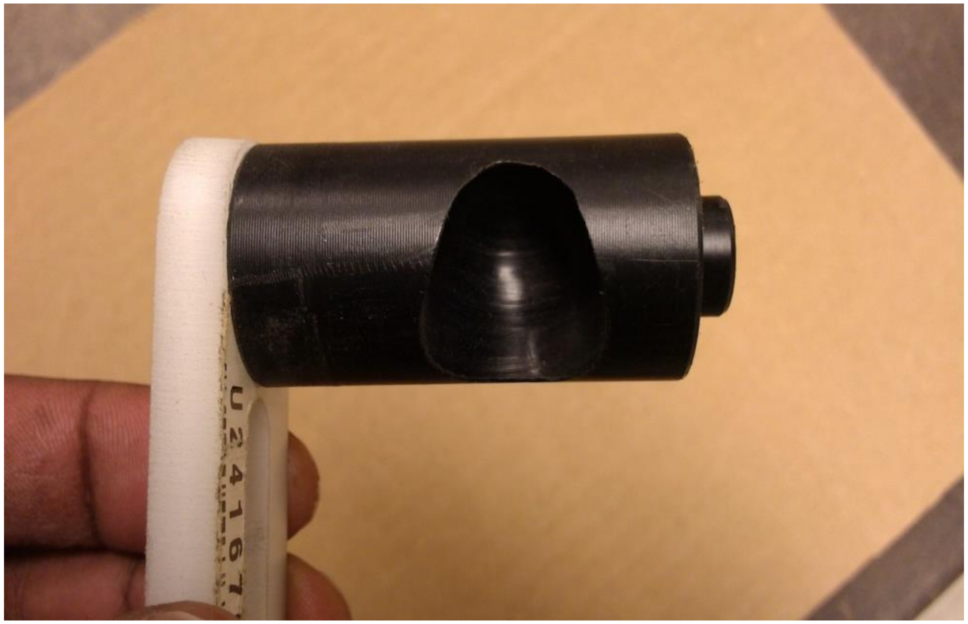

Figure 2. Fertilizer drum.

Figure 3. The OSU GreenSeeder^{TM} Hand planter fertilizer application.

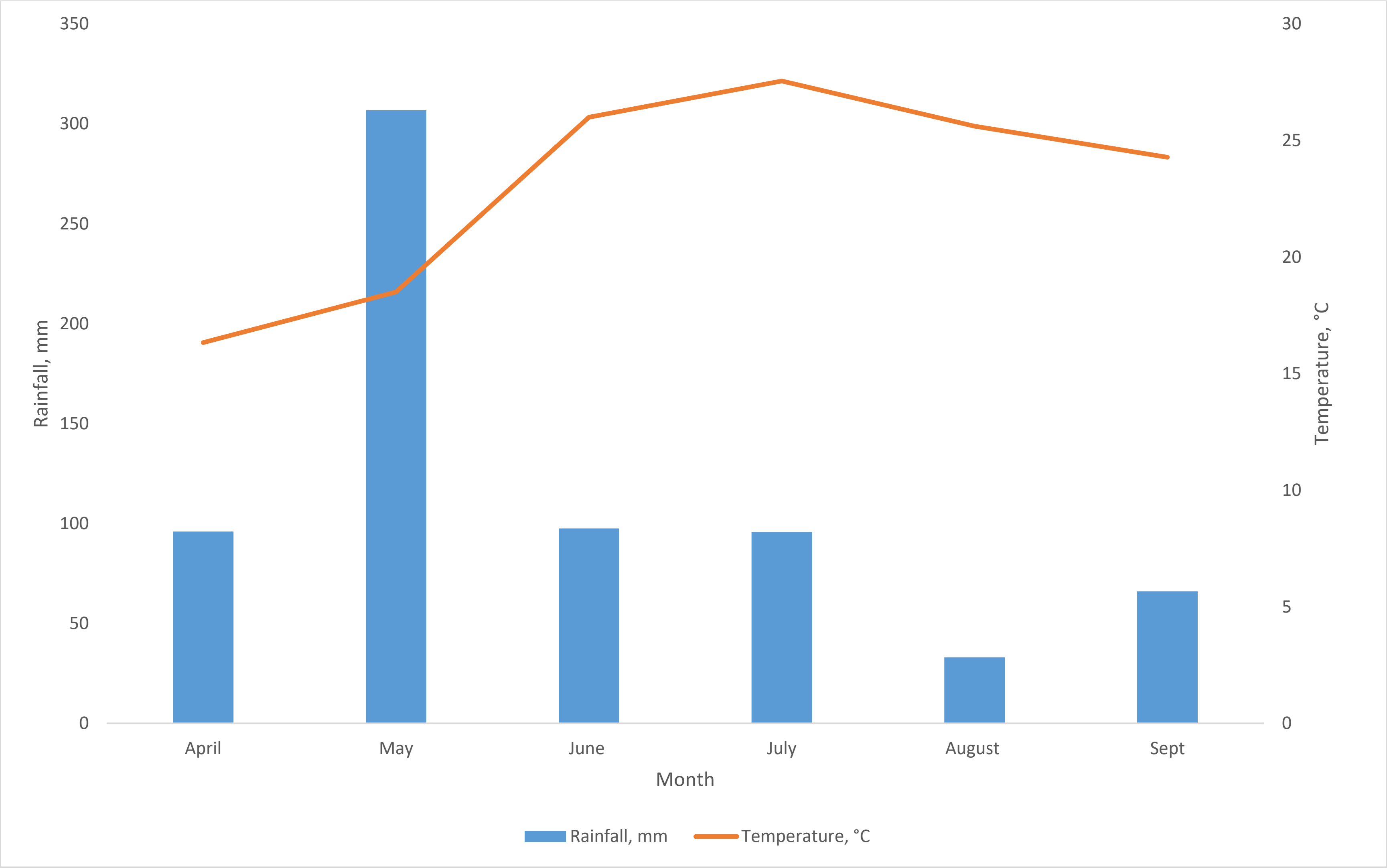

Figure 4: Average monthly air temperature and total monthly rainfall from April to September 2015 at Lake Carl Blackwell, Oklahoma.

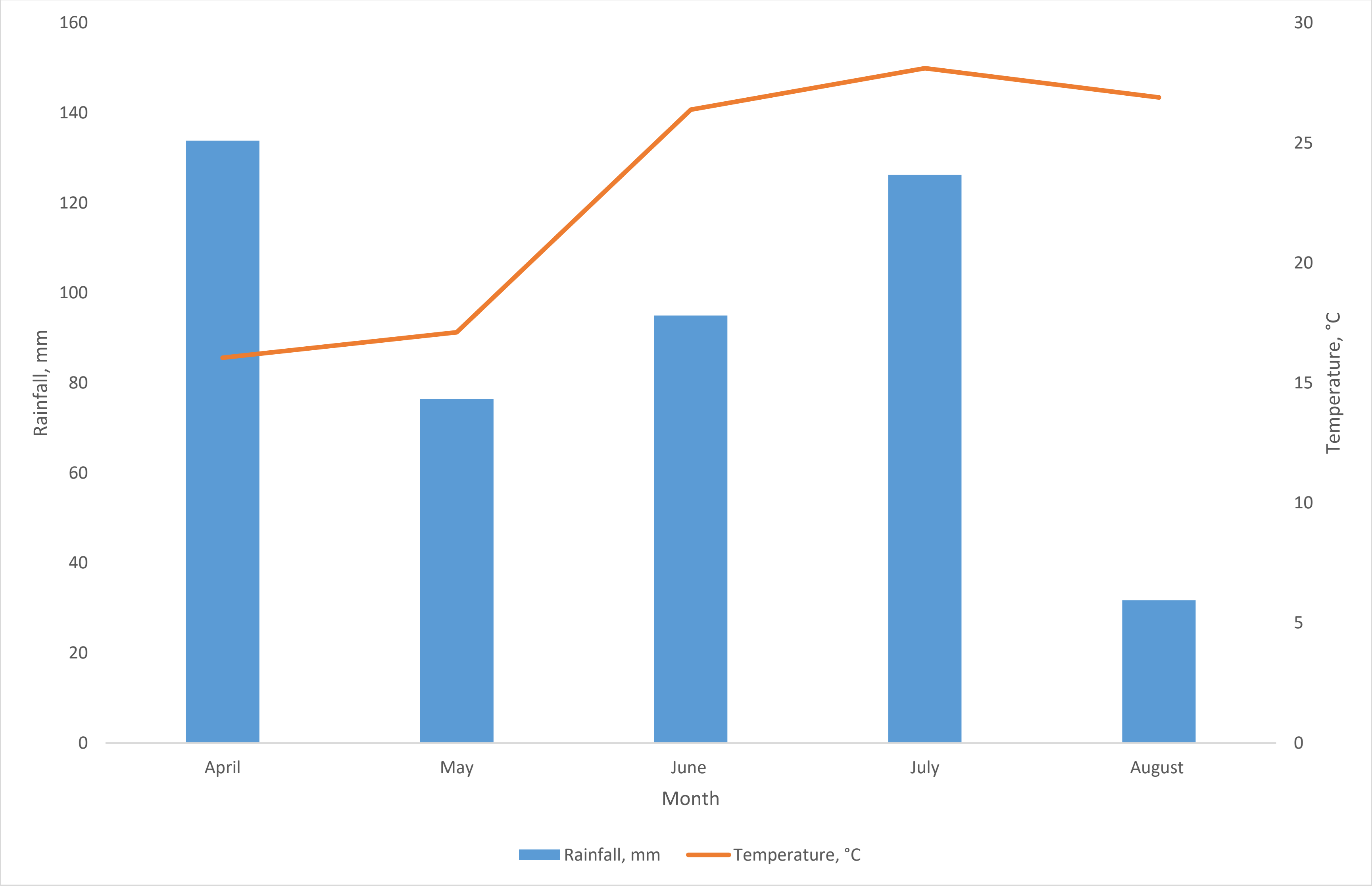

Figure 5: Average monthly air temperature and total monthly rainfall from April to August 2016 at Lake Carl Blackwell, Oklahoma.

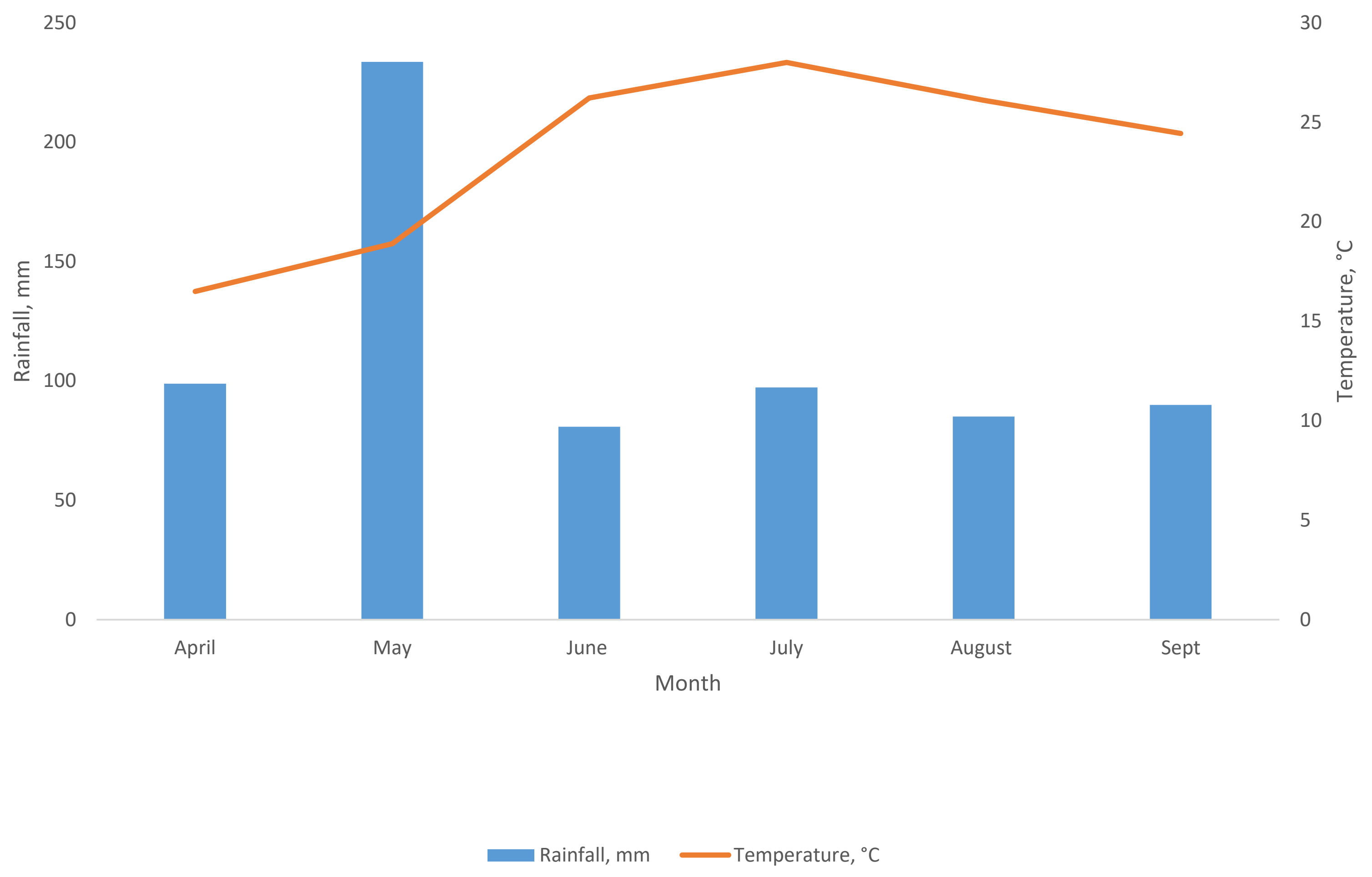

Figure 6: Average monthly air temperature and total monthly rainfall from April to September 2015 at Efaw, Oklahoma.

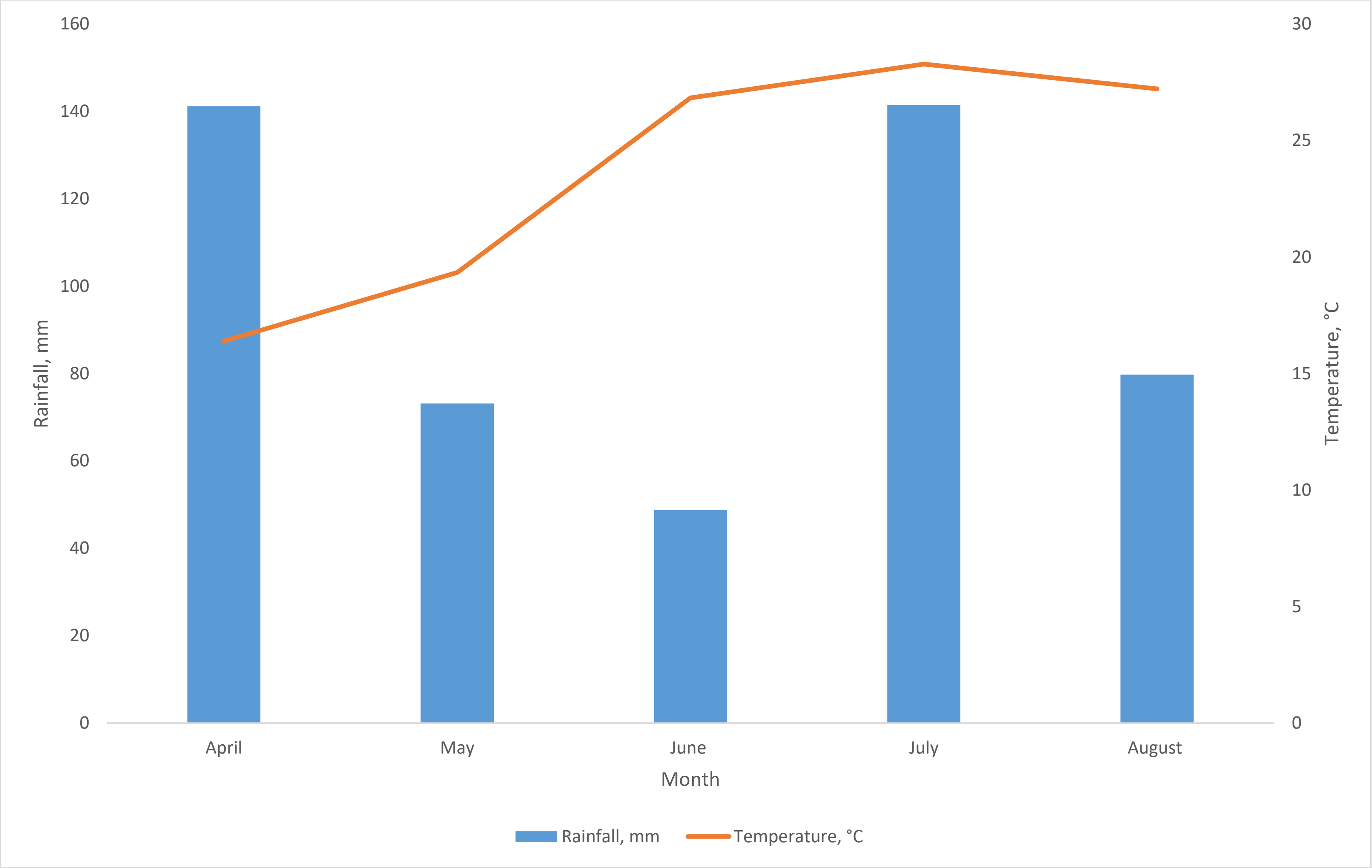

Figure 7: Average monthly air temperature and total monthly rainfall from April to August 2016 at Efaw, Oklahoma.

VITA

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