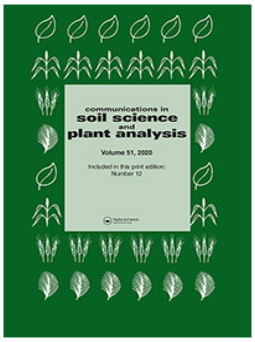

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Effect of Spacing, Planting Methods and Nitrogen on Maize Grain Yield

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ABSTRACT

Maize (*Zea mays* L.) production in the developing countries takes place on marginal landscapes using indigenous planting methods that conflict with appropriate **row spacing (RS) and plant to plant spacing (PPS)**. A study was conducted to determine the effect of different **RS**, variable plant densities and different planting methods on maize grain yield. This study was conducted for two years at three locations in Oklahoma including Lake Carl Blackwell (Port silt loam), Efaw (Ashport silty clay loam), and Perkins (Teller sandy loam-fine-loamy). Fourteen treatments were evaluated at each location in a randomized complete block design with three replications. Treatments included two **RS** (0.51 m, 0.76 m), three nitrogen **(N)** application rates (0, 60, 120 kg N ha^{-1}), two **PPS** (0.15 m, 0.30 m) and two planting methods (Greenseeder hand planter; farmers practice). Results showed an increase in grain yield by 34% in 2017 and 44% in 2018 for the narrow RS of 0.51 m compared to the 0.76 m RS. This was likely due to increased plant population at the narrow **RS**. This study suggests that maize producers in developing countries could use narrow RS (0.51 m) with wide PPS (0.30 m) to increase grain yields.

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Maize Grain Yield; row spacing; plant spacing; nitrogen rate; maize planter

Introduction

Maize (*Zea mays* L.) is one of the most important crops cultivated throughout the world due to its high productivity of grain and biomass (Lee et al. 2007). In 2018, by volume, maize was the largest cereal produced worldwide surpassing 1 billion metric tons (USDA 2018). Maize supplies 30% of the food calories to over 4.5 billion people in 94 countries (Shiferaw et al. 2011). However, 800 million people still consume less than 2000 calories daily (Conway and Toenniessen 1999). According to Cairns et al. (2012), the demand for maize would double in developing countries by 2050. Therefore, to meet the growing population demand, food production needs to increase on already cultivated agricultural land (Borlaug and Dowsell 2003). According to FAOSTAT (2016), 29 M ha of maize was planted by hand in developing countries, and the average yields were approximately 1.8 Mg ha^{-1}. In comparison, the average maize production in the United States is 9.9 Mg ha^{-1}. Many factors account for these higher yields in the U.S, specifically highly advanced agricultural mechanization not available in developing countries.

Omara et al. (2016) reported that when maize is planted by hand, there is a tendency to drop/plant two or more seeds per hill and cover with soil. This leads to uneven emergence and germination of multiple seeds. Aikins, Bart-Plange, and Opoku-Baffour (2010) also noted that seed rotting due to deep planting and inadequate seed covering may influence the final grain yield. Many studies have

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reported the relevance of homogenous crop stand in attaining higher yields (Ford and Hicks 1992; Liu et al. 2004; Nafziger, Carter, and Graham 1991; Nielsen 2004; Rutto et al. 2014; Tollenaar et al. 2006). Homogeneity of crops can increase water use efficiency, nutrient use efficiency, and solar radiation, which ultimately affects yields. Subsequently, researchers have invested time, energy, and resources to develop a hand planter for smallholder farmers in developing countries. Continued focus targets maize singulation for each planter strike, in-order to reduce competition among plant for nutrient, water and sunlight. Hence, Oklahoma State University **(OSU)** developed a hand planter that produces at least 80% singulation and removes chemically treated seeds from the hands of the farmers (Omara et al. 2016).

Aikins, Bart-Plange, and Opoku-Baffour (2010) compared different commercial hand planters and reported that 70% of the time, planters drop three seeds while 53% of the time, planters delivered two or less maize seeds. Over the last two decades, the Division of Agriculture **OSU** has worked to develop an improved hand planter, for subsistence farmers in developing countries (Dhillon et al. 2017, 2018; Omara et al. 2016). Farming in developing countries is often subsistent with production area ranging from 0.1 to 2 ha, and accompanied by little or no input of modern agricultural methods and techniques (Ibeawuchi et al. 2009). Thus, resource-poor farmers use stick planters, machete, dibbler or handheld hoe for planting maize, and these methods are labor intensive (Adjei et al. 2003; Tweneboah 2000). The variability in rainfall and temperature pattern posses an added threat to changing food production from year to year (Fornah et al. 2020). The OSU hand planter has 80% singulation efficiency with different seed types (Omara et al. 2016). Using the Greenseeder hand planter, chemically treated seeds are removed from the hands of farmers while also decreasing the rate of soil erosion by improving plant-to-plant spacing **(PPS)**. Furthermore, by merely changing the internal drum this planter can be used as a mid-season applicator of urea-N, placing urea below the soil surface, hence, reducing NH_3 losses, and fertilizer runoff (Dhillon et al. 2017, 2018).

Recent studies on narrow row spacing **(RS)** for maize production have produced inconsistent results. These results are varied concerning the relationship between narrow **RS** and yield (Farnham 2001; Testo, Reyneri., and Blandino 2017; William and Thelen 2002). At present, limited work has tested different **RS** combined with **PPS** with the hand planter. Optimal plant density level and row width for maize grain yield may vary with location, primarily latitude, season length, temperature, rainfall, sunlight and humidity. Improving field management techniques can increase maize productivity and reduce the environmental impact of modern agriculture. The optimal **RS** and plant density for maize production continue to vary as maize genetics evolve (Duvick and Cassman 1999).

Thus, the objective of this study was to determine the effect of **RS, PPS**, nitrogen **(N)** rates and variable plant density levels on maize grain yield.

Materials and methods

Field research was conducted in 2017 and 2018 at Perkins, Lake Carl Blackwell (LCB), and Efaw experimental stations of **OSU**. The respective soil types for each site (Perkins, Efaw and LCB) were Konawa fine sandy loam (fine-loamy, mixed, thermic Ultic haplustalfs Paleustolls), Ashport silty clay loam (fine-silty, mixed, superactive, thermic Fluventic Haplustolls) and Port Silt Loam (fine-silty, mixed, thermic cumulic Haplustolls). Trial locations were chosen that best represented the diverse soil and cultural practices (till and no-till) utilized in the state of Oklahoma. Trial locations selected had maize grown prior to this study. The experimental sites (Table 1) were divided into tillage, no-tillage and irrigated locations. In 2017, the Perkins location was no-till and non-irrigated while LCB was tilled and irrigated. Similarly, in 2018, LCB was tilled, and irrigated while Efaw was no- till and non-irrigated. No experiment was conducted in the Perkins location in 2018 due to ear worm infestation and poor soil structure. Therefore, Perkins and Efaw locations were only one year each, whiles LCB site was two years. Also, at the LCB location, the experiment was moved to a different plot area in 2018.

The experiment was designed as a randomized complete block with three replications and fourteen treatments. The treatment combination consisted of two planting methods (OSU-Hand Planter [OSU-

Table 1. Field activities for each location, 2017 and 2018.

	2017		2018	
Field Activity	Perkins	LCB	Efaw	LCB
Pre-plant N fertilization	April 11	May 5	April 25	April 25
Planting	April 19	May 9	April 30	May 1
Side-dress	June 22	Jun 23	June 14	June 15
Harvest	August 30	August 29	September 10	September 11

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

HP] and the Farmers Practice [FP or Stick Planter]), two-**RS** (0.51 and 0.76 m). Detailed information about OSU-hand planter's design and operation has been noted in Omara et al. (2016) and Dhillon et al. (2017), Dhillon et al. (2018)). Additionally, two **PPS** (0.15 and 0.30 m), three rates of N fertilizer application (0, 60, and 120 kg N ha^{-1}), and four plant populations (43,859; 65,359; 87,719; and 130,718 seeds ha^{-1}) were used. The fertilizer was applied in a strip to the side of the row before planting and mid season. Maize was planted in an area of 3.03 m x 6.06 m at 0.76 and 0.51 m **RS**. Maize was planted 5 cm deep (Table 1), and PPS was maintained by marking a string at 15 cm or 30 cm according to the treatment structure to ensure uniformity. Twenty-one strikes were made at 15 cm **PPS**, whiles forty strikes were made at 30 cm **PPS**. For each strike, one maize seed is dropped per hole. Two checks were included and planted with the simulated farmer practice (stick planter), where a hole was made by using the stick planter, and two or three seeds were dropped per hole. Urea fertilizer was applied pre-plant and mid-season side-dress at three different rates 0, 60 and 120 kg N ha^{-1}. The OSU-hand planter was used to side-dress as per the treatment structure while the simulated farmer's practice, N was dribble applied next to each plant. The middle rows of each plot were harvested for yield. Harvesting was done in August and September in 2017 and 2018 planting season respectively.

Plots were harvested manually at all locations. At the Perkins station, forage samples were collected from a 1.5 × 6.0 m area, dried and weighed accordingly. The ear count was collected for all trials and grain was shelled from collected cobs. Moisture content for final grain yield was adjusted to 15.5%. Plot subsamples were taken and then dried at 75°C for two days, ground to pass a 240-mesh screen and analyzed for total N using a LECO Truspec CN dry combustion analyzer (Schepers, Francis, and Thompson 1989).

All data were analyzed using SAS version 9.4 (SAS Institute Inc 2008). The Generalized linear model (GLM) procedure was used to determine the effect of treatments on maize yield. Mean separation was performed using LSD (α = 0.05). Single-degree-of-freedom-contrasts were also used to partition treatment differences.

Results

Lake Carl Blackwell, OK (2017)

Analysis of variance showed significant treatment effect for **RS, PPS**, N rate and planter type on ear count at Lake Carl Blackwell 2017 (Table 2). It was also observed that with a single-degree-of-freedom-contrasts, the farmer's practice (stick planter) resulted in a 4% higher ear count than the OSU hand planter. The N rate of 120 kg ha^{-1} showed significantly (p < .01) higher ear count compared to 60 kg ha^{-1}. A plant population of 65,359 seeds ha^{-1} produced the highest ear count compared to other plant populations. Nonorthogonal, single-degree-of-freedom contrasts, showed significantly better ear count from the combination of reduced **PPS** (0.15 m), reduced **RS** (0.51 m) with farmers planting (FP) method at 120 kg N ha^{-1} (treatment 13). This was most likely due to a higher plant density and high N rate (Table 2).

Analysis of variance showed significant treatment effect on grain yield (p < .05) (Table 3). A non-orthogonal, single degree of freedom contrast, showed a significant difference between narrow **RS** and

Table 2. Mean ear counts as influenced by side-dress N and plant-to-plant spacing, Lake Carl Blackwell, Perkins and Efaw, OK 2017–2018.

					Ear Count			
					LCB		Perkins	Efaw
Treatment	Side-dress N (kg ha^{-1})	PPS (m)	RS (m)	Planter	2017	2018	2017	2018
1	0	0.15	0.51	FP	83	87	62	117
2	0	0.15	0.76	FP	67	78	56	81
3	60	0.15	0.51	HP	104	136	79	115
4	60	0.15	0.76	HP	94	102	74	87
5	60	0.30	0.51	HP	84	89	69	90
6	60	0.30	0.76	HP	71	136	65	67
7	60	0.15	0.51	FP	121	103	79	123
8	60	0.15	0.76	FP	105	112	73	99
9	60	0.30	0.51	FP	99	91	78	94
10	60	0.30	0.76	FP	85	121	68	75
11	120	0.30	0.51	HP	101	126	66	115
12	120	0.30	0.76	HP	80	86	60	103
13	120	0.15	0.51	HP	135	138	71	132
14	120	0.15	0.76	HP	104	109	64	103
SED					12.31	4.49	4.38	4.19
CV, %					16	5	8	5
Contrasts			**Treatments**					
Row spacing 60 kg ha^{-1} 0.51 vs 0.76			3vs4 5vs6 7vs8 9vs10		**	*	*	*
Row spacing 120 kg ha^{-1} 0.51 vs 0.76			11vs12 13vs14		*	*	**	*
HP vs FP			3 4 5 6 vs 7 8 9 10		**	*	ns	*
Plant spacing 0.30 vs 0.15			11 12 vs 13 14		*	*	ns	*
NRate 0 vs 60			1 2 vs 7 8		*	*	*	*
NRate 60 vs 120			3 4 5 6 vs 11 12 13 14		*	ns	*	*

SED, standard error of the difference between two equally replicated means
CV, the coefficient of variation, %
FP, farmer practice
HP, OSU Hand planter
ns, not-significant *, **, ***, significant at 0.01, 0.05 and 0.10 probability levels, respectively.

wide **RS** ($p < .01$) (Table 3). Narrow **RS** resulted in higher yields than wider **RS**. The maximum yield was recorded from the combination of narrow **RS** (0.51 m), wide **(PPS)** (0.3 cm), with an N rate of 60 kg ha^{-1}. However, **PPS** and planter type was not significantly different. This might have been due to the brief drought period during the growing season. William and Thelen (2002) reported a 1.4 Mg ha^{-1} yield increase when **RS** was reduced from 0.76 m to 0.56 m. The plant population of 65,359 resulted in higher yields compared to other plant populations.

Perkins, OK (2017)

Analysis of variance showed significant differences in ear count among treatments ($p < .05$) (Table 2). A non-orthogonal, single-degree-of-freedom-contrast showed that narrow RS (0.51 m) had significantly ($p < .01$) higher ear counts than wider RS (0.76 m) (Table 2). An N rate of 120 kg ha^{-1} showed significantly higher ear count compared to 60 kg ha^{-1}. The maximum number of ears were recorded from the combination of reduced **PPS** (0.15 m), and reduced **RS** (0.51 m) at 60 kg N ha^{-1}. Nonetheless **PPS** and planter type did not affect ear count. A plant population of 65,359 seeds ha^{-1} resulted in higher ear count over all other plant populations.

Analysis of variance also showed that grain yield was significant affected by the different treatments ($p < .01$) (Table 3). Comparison of treatments using a non-orthogonal, single-degree-of-freedom-contrasts showed that narrow **RS** resulted in significantly higher yields compared to wide **RS** ($p < .01$, Table 3). Furthermore, wider **PPS** produced higher yields compared to the narrow **PPS** ($p < .05$). Similarly, the OSU hand planter produced higher yields compared to the farmer's practice ($p < .1$). However, N rate was not significantly different (Table 3). The highest yield of 4.47 Mg ha^{-1} was recorded from narrow **RS** (0.51 m), wider **PPS** (0.30 m), and an N rate of 60 kg ha^{-1} using the OSU

Table 3. Grain yield means as influenced by side-dress N and plant-to-plant spacing, Lake Carl Blackwell, Perkins and Efaw 2017–2018.

					Grain yield, Mg ha^{-1}			
					LCB		Perkins 2012017	Efaw
Treatment	Side-dress N (kg ha^{-1})	PPS (m)	RS (m)	Planter	2017	2018	2017	2018
1	0	0.15	0.51	FP	3.52	3.74	3.27	2.51
2	0	0.15	0.76	FP	2.36	2.53	2.66	1.76
3	60	0.15	0.51	HP	4.91	6.48	3.61	5.7
4	60	0.15	0.76	HP	3.77	4.66	2.67	3.79
5	60	0.30	0.51	HP	5.92	7.37	4.47	6.01
6	60	0.30	0.76	HP	4.52	5.26	3.03	4.57
7	60	0.15	0.51	FP	5.55	5.73	4.09	3.73
8	60	0.15	0.76	FP	3.88	4.02	3.25	2.07
9	60	0.30	0.51	FP	6.29	5.83	4.15	3.83
10	60	0.30	0.76	FP	5.03	4.15	3.13	2.06
11	120	0.30	0.51	HP	5.94	14.25	4.09	10.84
12	120	0.30	0.76	HP	4.22	8.67	3.41	7.12
13	120	0.15	0.51	HP	4.99	10.28	3.81	7.2
14	120	0.15	0.76	HP	3.70	7.88	2.87	5.24
SED					0.91	0.97	0.24	0.55
CV, %					24	18	8	11
Contrasts			**Treatments**					
Row spacing 60 kg/ha 0.51 vs 0.76			3vs4 5vs6 7vs8 9vs10		*	*	*	*
Row spacing 120 kg/ha 0.51 vs 0.76			11vs12 13vs14		**	*	*	*
HP vs FP			3 4 5 6 vs 7 8 9 10		ns	**	***	*
Plant spacing 0.30 vs 0.15			11 12 vs 13 14		ns	*	**	*
NRate 0 vs 60			1 2 vs 7 8		*	*	*	*
NRate 60 vs 120			3 4 5 6 vs 11 12 13 14		ns	*	ns	*

SED, standard error of the difference between two equally replicated means
CV, the coefficient of variation, %
FP, farmer practice
HP, OSU Hand planter
ns, not-significant *, **, ***, significant at 0.01, 0.05 and 0.10 probability levels, respectively.

hand planter. This was higher than the 2.66 Mg ha^{-1} observed in the check plot. Shapiro and Wortmann (2006) observed a 4% yield increase with narrow **RS** and 24% increase with N rate of 84 kg ha^{-1}. A plant population of 65,359 seed ha^{-1} produced the highest grain yields compared to all other plant populations. Recent work by Harman et al. (2017) evaluated seven different planters and noted that the OSU Greenseeder hand planter had the highest mean grain yield at 4.83 Mg ha^{-1} with the highest number of ears per stalk near 0.93.

The forage weight recorded at Perkins in 2017 showed that narrow **RS** resulted in higher forage yields compared to wider **RS**. The highest forage yield (8.17 kg) was recorded from the combination of narrow **RS**, and narrow **PPS** with the OSU hand planter. Alternatively, the lowest forage weight (3.72 kg) was recorded from the combination of wide **RS**, and wide **PPS** with the farmer's practice.

Lake Carl Blackwell, OK (2018)

Results showed a significant effect of treatments on maize ear counts. A non-orthogonal single-degree-of-freedom-contrast (**RS** 0.51 vs. 0.76 m, Table 2) showed a significantly higher ear count with reduced **RS** compared to wider **RS**. In addition, the ear counts for narrow and wide **PPS** (contrast 0.30 vs 0.15 m) was significantly different ($p < .01$) (Table 2). Narrow **PPS** (0.15 m) resulted in higher ear counts compared to wide **PPS** (0.30 m). Likewise, the hand planter produced higher ear counts compared to the farmer's practice at ($p < .01$) (Table 2). The N rates of 60 and 120 kg ha^{-1} did not significantly influence ear counts. A plant population of 65,359 seeds ha^{-1} produced the highest ear counts compared to all other treatments. The highest number of ears was recorded from narrow **PPS**, and narrow **RS** using the OSU hand planter at 120 kg N ha^{-1}. Alternatively, the lowest ear count was recorded from the combination of wide **RS**, narrow **PPS**, and no N applied with the farmer's practice (Table 2).

Also, analysis of variance showed a significant difference in grain yield due to treatments applied ($p < .05$) (Table 3). The highest yield was obtained with a combination of narrow **RS** (0.51 cm), wide **PPS** (0.3 cm), and an N rate of 60 kg ha^{-1}. While the lowest yield was recorded from the combination of wide **RS**, narrow **PPS**, with the farmer's practice of 2.53 Mg ha^{-1}. The hand planter resulted in higher yields compared to the farmer's practice. This was because of better plant stand homogeneity with the hand planter compared to the traditional farmer's practice. Similarly, Cox and Cherney (2001) reported that narrow **RS** increased yields by 7.5%. Also, Widdicombe and Thelen (2002) analyzed different planting population densities (56,000, 65,000, 73,000, 81,000 and 90,000 plants per ha) and **RS** (0.38 m, 0.56 m, and 0.76 m) of maize at different locations. Widdicombe and Thelen (2002) noted that maize grain yield increased by 2 and 4% when **RS** was reduced from 0.76 m to 0.56 m and 0.38 m, respectively. Also, the highest plant density (90,000) had the highest grain yield.

Efaw, OK (2018)

Analysis of variance showed that ear counts were significantly affected by the treatments evaluated ($p < .05$). The highest number of ears were recorded from narrow **PPS** (0.15 m), narrow **RS** (0.51 m) using the hand planter at 120 kg N ha^{-1}. On the other hand, the lowest ear count was recorded from the combination of wide **RS** (0.76 m), narrow **PPS** (0.15 m), and 60 kg N ha^{-1} and with the farmer's practice (Table 2). Furthermore, a non-orthogonal single-degree-of-freedom-contrast (**RS** 0.51 vs. 0.76 m, Table 2) showed a significantly higher ear count with reduced **RS** (0.51 m) compared to wider **RS** (0.76 m). In addition, narrow and wide **PPS** (contrast 0.30 vs 0.15 m) was significant at ($p < .01$) (Table 2). Narrow **PPS** (0.15 m) resulted in higher ear counts compared to wide **PPS** (0.30 m). Likewise, the hand planter produced higher ear counts compared to the farmer's practice ($p < .01$) (Table 2). The N rate of 120 kg N ha^{-1} resulted in higher ear counts compared to 60 kg N ha^{-1}. A plant population of 65359 seeds/ha produced higher ear counts compared to all other plant populations.

Also, analysis of variance showed that grain yield was significant influenced by the treatments applied ($p < .01$) (Table 3). The highest yield was recorded at the narrow **RS** (0.51 m), wider **PPS** (0.30 m), and N rate of 120 kg ha^{-1} using the OSU hand planter (10.84 Mg ha^{-1}). The lowest yield was recorded from the check plot (1.76 Mg ha^{-1}, Table 3).

Treatment comparisons showed a significant difference between narrow **RS** and wider **RS** at ($p < .01$) (Table 3). Narrow **RS** resulted in higher grain yields compared to wider **RS**. Similarly, Testo, Reyneri., and Blandino (2017) reported that narrow **RS** significantly increased maize grain yields. Furthermore, wide **PPS** produced a higher grain yield than narrow **PPS**. Likewise, the hand planter resulted in higher grain yield compared to the farmer's practice. Finally, an N rate of 120 kg ha^{-1} produced significantly higher yields than 60 kg N ha^{-1}

The 60 kg N ha^{-1} rate accounted for the highest yield but was not significantly different from 120 kg N ha^{-1}. However, 60 kg N ha^{-1} was significantly different from the check ($p < .01$) (Table 3).

Discussion

This study demonstrated that narrow **RS** (0.51 m) with wide (0.30 m) **PPS** at all locations resulted in higher maize grain yields compared to the wider **RS** (0.76 m). At Perkins and Lake Carl Blackwell 2017, narrow **RS** resulted in a yield increase of 32% and 34% respectively when compared to wider **RS**. Narrow **RS** increased maize grain yields by 44% and 50% respectively at Efaw and LCB. This result support the findings of Barbieri et al. (2012), who stated that narrow and wide **RS** resulted in yields of 5.51 and 4.49 Mg ha^{-1} respectively.

Also, a plant population of 65,359 seeds/ha produced the highest maize grain yields.

Also, wider **PPS** (0.30 m) resulted in yield increases at all locations when compared to narrow **PPS** (0.15 m). At Perkins and LCB 2017, wide **PPS** resulted in a yield increase of 12% and 17% respectively when compared to narrow **PPS**. While, at Efaw and LCB 2018, wider **PPS** increased yields by 44% and 26% respectively. Furthermore, at Perkins and LCB 2017, the N rate of 60 kg ha^{-1} increased yields by 23% and 60% respectively compared to the check while 120 kg N ha^{-1} increased yields by 13% and 48% respectively. At Efaw and LCB in 2018, the N rate of 60 kg ha^{-1} increased yields by 44% and 55% respectively versus the check, while 120 kg N ha^{-1} increased yields by 8.47 Mg ha^{-1} and 11.9 Mg ha^{-1} respectively. Also, the hand planter and the farmer's practice were not significantly different in 2017. However, at LCB the hand planter resulted in a yield increase of 20% over the farmer's practice. Finally, the combination of narrow **RS** and wide **PPS** produced the highest yields (6.26 Mg ha^{-1}, 14.25 Mg ha^{-1}) at both locations in 2017 and 2018 respectively.

Conclusion

Finding the optimum combination of row and **PPS** that produce maximum yield per unit area under different environments has been a major concern for agronomists. This study provides evidence suggesting that maize producers in developing countries could use narrow **RS** with wide **PPS** to increase grain yields. Row spacing is something that producers seek, especially as they traverse across the terrain. Plant to plant spacing can certainly be taught, but the **RS** for working in and around the plants both for weeding and finally harvesting is somewhat fixed. Also, the OSU hand planter can be used to increase maize grain yield through improved plant stand homogeneity. By simply changing the internal drum, the OSU hand planter has the added benefit of being able to apply mid-season fertilizer close to the plant, thus increasing N use efficiency.

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