Communications in Soil Science and Plant Analysis

ISSN: 0010-3624 (Print) 1532-2416 (Online) Journal homepage: https://www.tandfonline.com/loi/lcss20

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To cite this article: Fikayo B. Oyebiyi, Lawrence Aula, Peter Omara, Eva Nambi, Jagmandeep S. Dhillon & William R. Raun (2019) Maize (*Zea mays* L.) Grain Yield Response to Methods of Nitrogen Fertilization, Communications in Soil Science and Plant Analysis, 50:21, 2694-2700, DOI: 10.1080/00103624.2019.1670837

To link to this article: https://doi.org/10.1080/00103624.2019.1670837

Published online: 09 Oct 2019.

COMMUNICATIONS IN SOIL SCIENCE AND PLANT ANALYSIS
2019, VOL. 50, NO. 21, 2694–2700
https://doi.org/10.1080/00103624.2019.1670837

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Maize (*Zea mays* L.) Grain Yield Response to Methods of Nitrogen Fertilization

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ABSTRACT

In the developing world, fertilizer application is commonly achieved by broadcasting nutrients to the soil surface without incorporation. A commonly used nitrogen (N) source is urea and if not incorporated, can sustain N losses via ammonia volatilization and lower crop yields. This study evaluated the effect of planting, N rate and application methods on maize (*Zea mays* L.) grain yield. An experiment with a randomized complete block design (nine treatments and three replications) was established in 2013 and 2018 in Oklahoma. The planting methods included; farmer practice (FP), Oklahoma State University hand planter (OSU-HP), and John Deere (JD) mechanical planter. Side-dress N application methods included; dribble surface band (DSB), broadcast (BR), and OSU-HP. Nitrogen was applied at the rate of 30 and 60 kg ha^{-1} as urea and UAN at V8 growth stage. On average, planting and applying N at 60 kg ha^{-1} using OSU-HP resulted in the highest yield (11.4 Mg ha^{-1}). This exceeded check plot yield (5.59 Mg ha^{-1}) by 104%. Nitrogen application improved grain yield by over 57% when compared to the 0-N check (8.77 Mg ha^{-1}). Mid-season N placement below the soil surface using OSU-HP makes it a suitable alternative to improve grain yield.

ARTICLE HISTORY
Received 9 September 2019
Accepted 17 September 2019

KEYWORDS
Plant spacing; method of nitrogen placement; OSU hand planter; maize yield; developing countries; subsistence farmers

Introduction

Maize (*Zea mays L.*) production in the world exceeded 1 billion metric tons in 2013 (FAO 2014). At present, 29 M ha of maize are planted by hand, and where average grain yields hover near 1.8 Mg ha^{-1} (FAO 2014). In conjunction with rice and wheat, maize supplies at least 30% of the food calories to more than 4.5 billion people in 94 developing countries across the globe (Shiferaw et al. 2011). Presently, maize is produced on 100 million hectares in 125 developing countries (FAO 2014). About 67% of maize produced in the developing world comes from the low middle-income countries; thus, maize is significant in the livelihoods of farmers. It is estimated that by 2020, world population will be around 7.7 billion and by 2050, it will be approximately 9.3 billion, denoting that the demand for maize in the developing world is expected to double (Rosegrant et al. 2009).

Maize is, not only known to be a staple food across the globe but also, is an important ingredient in animal feed. Additionally, the demand for livestock feed has also surged due to the increase in the demand for poultry and livestock products in the more affluent countries of the world (Delgado 2003). However, since the world population will likely increase to 9.3 billion in 2050, it is important to address domestic production of staple food crops especially maize. This will help to reduce the food insecurity burden on developing nation economies. Furthermore, by increasing the imports of maize from the 7% demand that exists today, to about 24% in 2050, the resulting value of this product will be near 30 billion USD (Rosegrant et al. 2009).

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However, the majority of maize production in the developing world is planted and managed completely by hand, including harvest. This in turn leads to yields of about 1.8 Mg ha^{-1} (FAO 2014). Also, maize farming in the developing world is accomplished on a small scale (0.1 to 2 ha) by smallholder farmers (Ibeawuchi et al. 2009). Planting takes place with various traditional agricultural implements like, hand hoes, stick planters, and dibble sticks which in general demand high labor and create health challenges (Adjei et al. 2003; Dhillon et al. 2018).

Researchers and government agencies have aimed to improve food production needs by 2050. Oklahoma State University (OSU) has assisted in this regard via the development of the Greenseeder hand planter (OSU-HP). The OSU-HP targets placing one seed at a time per planting hole/depression, achieving up to 80% singulation efficiency and 20% multiple seed delivery depending on seed sizes (Omara et al. 2016). The OSU-HP is made up of polyvinyl chloride round pipe (PVC) with a diameter of 5.8 cm attached to a metering delivery system. This metering system consists of aluminum, internal plastic housing, catchment drum, spring, and brush. On the end of the metering system is a metal tip/shovel, which can dig into the soil (5 to 10 cm depth) depending on the force applied by the operator. The OSU-HP helps with the removal of chemically treated seeds from farmers' hands, decreases soil erosion due to improved homogeneity of plant stands and further offers a means for accurate mid-season fertilizer application (Dhillon et al. 2017).

Fertilizer application in the developing world is commonly achieved by broadcasting before planting and/or mid-season. A conventional source of nitrogen (N) is urea which when placed on the soil surface results in N loss via ammonia volatilization. This results in lower N use efficiency (NUE). Furthermore, broadcast applications can cause leaf damage when applied mid-season (leaf burn). In order to properly improve plant yields, terrain-specific methods of planting and fertilization need to be developed. Therefore, it is vital to further examine OSU-HP against traditional planting and N application methods as a mechanism to improve yield in developing countries. The objective of this experiment was to evaluate the effect of methods of planting and N application on maize grain yield using conventional methods, and an OSU-HP engineered and agronomically improved planter.

Materials and methods

Field experiments were conducted at Efaw, Perkins, and Lake Carl Blackwell (LCB) in Oklahoma (OK). Efaw is located on the north side of Stillwater, and Perkins is located 10 miles south of Oklahoma State University (OSU) Stillwater campus. The Lake Carl Blackwell site is located 14 miles west of Stillwater. The soil classification at each site was; ashport silty loam (fine-silty, mixed, super active, thermic fluventic Haplustolls) at Efaw; Port silt loam (fine silty, mixed, thermic cumulic Haplustolls), at Lake Carl Blackwell; and fine, mixed thermic udertic Paleustolls at Perkins OK. In 2013 planting season, Efaw and Perkins received 702 mm and 599 mm total rainfall, respectively, with an average temperature of 20°C at both sites. In 2018, Efaw and LCB received in total, 633 mm and 664 mm of rainfall, respectively, with an average temperature of 21° C at both sites.

A total of four trials were carried out for this study. Two of the trials were conducted in 2013 at Efaw and Perkins. The other two trials were set up in 2018 at Efaw and LCB. Field activities for all sites in each year are included in Table 1. Maize was planted in the summer of 2013 and 2018 using a John Deere 2-row MaxEmerge planter (JD), OSU-HP and a simulated (FP).

A randomized complete block design with three replications and a total of nine treatments per replication were evaluated at each site. The plant population of 74,000 seeds ha^{-1} was obtained by planting maize on a 76 cm row spacing and 18 cm plant-to-plant spacing. The plot sizes measured 3.0 m x 6.0 m with an alley of 1.5 m. A marked string (18 cm spacing) was used to attain uniformity in planting for FP and OSU-HP treatments.

In the FP treatments, a scenario was simulated where maize was planted using a long wooden stick with a metal tip, and a hole was made and two to three seeds were dropped per hole/depression.

Table 1. Field activities for each location, 2013 and 2018, Efaw and Perkins, OK.

Year	2013		2018	
Location	Efaw	Perkins	Perkins	LCB
Planting	5/25/2013	3/29/2013	04/19/2018	04/09/2018
Sidedress N	06/21/2013	06/24/2013	06/22/2018	06/22/2018
Harvest	08/29/2013	08/29/2013	08/29/2018	08/30/2018

In order to achieve the projected plant population, 34 strikes were made per row at a distance of 76 cm. One treatment (check) was planted using a JD vacuum planter at 3.2 km hr^{-1}. The JD planter was adjusted to deliver 18 cm plant spacing.

Two treatments each were planted with the OSU-HP and stick planter. Methods of N application were side-dress (OSU-HP), dribble surface band (DSB) and broadcast. For both planting years (2013 and 2018) N was applied at 50, and 100 kg N ha^{-1}. Aside from the check treatments in 2013 that were planted using a JD planter, other treatments were planted, fertilized, and harvested by hand. The middle two rows of each plot were harvested and total grain weight determined and converted to grain yield per hectare (Mg ha^{-1}). The data obtained were analyzed using SAS software (SAS Institute, 2012), "PROC GLM" and mean separation was achieved using "LSMeans" statements. Single degree of freedom contrast analyses was accomplished, to compare the effect of different treatments on grain yield.

Results

LCB 2018

Analysis of variance showed that there were significant grain yield differences due to treatment effect (p = .01) (Table 2). The highest yield was achieved when N was applied using the OSU-HP at a rate of 60 kg N ha^{-1}. The unfertilized check plots resulted in the lowest grain yield (4.71 Mg ha^{-1}). Grain yields ranged from 4.71 in the unfertilized check plot to 11.16 Mg ha^{-1} when using OSU-HP at 60 kg ha^{-1} (Table 3). The second lowest yield was observed when urea and UAN were DSB applied at a rate of 60 kg N ha^{-1} using a JD (Table 3). The FP where urea was broadcast applied at N rates of 30 and 60 kg ha^{-1} yielded at least 62.6% higher than the unfertilized plot. Grain yield using the FP at 30 kg N ha^{-1} resulted in a 0.3 Mg ha^{-1} yield increase when compared to FP at 60 kg ha^{-1}. Also, the OSU-HP with an N rate of 30 kg ha^{-1} yielded similar to 60 kg N ha^{-1}. The effect of planting method and N application rates were both significant for yield (Table 3).

Apart from broadcasting as a method of N application, OSU-HP method yielded greater than other N methods (Broadcast-urea, DSB-urea, DSB-UAN). Averaged across methods and rates of N application, OSU-HP planting method yielded higher than FP, and JD by 34.5% and 42.6% respectively. There was a significant difference between average grain yield for fertilized and unfertilized treatments when averaged across planting and N application methods (p = .001). However, there was no significant difference between grain yield at 30 and 60 kg ha^{-1} (p = .621) (Table 3). This suggests that there was sufficient N supply from the soil to meet crop demands with

Table 2. Analysis of variance for the main effect of treatment on maize grain yield as influenced by planting method, N rate and method of application.

	Mean Square Error			
Location	Error ab	Treatment ab	F	PR > F
Efaw 2018	0.9	6.9	7.7	<0.01
Efaw 2013	2.0	6.8	3.4	0.03
LCB 2018	1.9	9.4	5.1	0.01
Perkins 2013	3.2	20.2	6.4	0.01

a source of variation. PR>F – Probability level at 0.05

b Error and treatment degrees of freedom for all treatments were 12 and 8, respectively.

Table 3. Maize (Zea mays L.) grain yield as influenced by N application methods and planter, Perkins and Efaw 2013, LCB and Efaw 2018.

				Grain yield (Mg ha^{-1})			
				2013		2018	
Treatment	Planter	N application method	N rate (kg ha^{-1})	Perkins	EFAW	LCB	EFAW
1	Check	NA	0	5.33	6.22	4.71	6.09
2	OSU-HP	OSU-HP, Urea	30	11.22	10.30	9.87	10.82
3	OSU-HP	OSU-HP, Urea	60	13.32	10.07	11.16	11.01
4	FP	Broadcast, Urea	30	5.97	7.32	7.98	7.87
5	FP	Broadcast, Urea	60	5.23	7.03	7.66	7.66
6	JD	DSB-urea	30	5.82	6.35	7.06	8.23
7	JD	DSB-urea	60	11.76	6.68	7.59	10.09
8	JD	DSB-UAN	30	12.44	6.68	7.65	8.35
9	JD	DSB-UAN	60	11.76	8.89	7.20	9.45
MSE				3.15	2.01	1.87	0.90
SED				2.10	1.34	1.25	0.60
CV, %				18.38	18.9	16.9	10.89
Contrasts for N application methods/Planting methods				PR>F			
OSU-HP vs Broadcast (FP)				0.0004	0.0049	0.0652	0.0003
OSU-HP vs DSB-urea (JD)				0.5309	0.0012	0.0065	0.0163
OSU-HP vs DSB-UAN (JD)				0.8915	0.0178	0.0049	0.0065
OSU-HP vs Check				0.0016	0.0057	0.0001	<.0001
Broadcast (FP) vs DSB-urea (JD)				0.0013	0.4927	0.1738	0.0541
Broadcast (FP) vs DSB-UAN (JD)				0.0008	0.5212	0.1738	0.1026
Contrasts for N rates							
0 vs average of N30 and N60				0.0047	0.1424	0.0010	0.0001
N30 vs N60				0.6142	0.4398	0.6209	0.1317
Contrasts for N source							
Urea vs UAN				0.0605	0.8174	0.0770	0.4461

SED – standard error of the difference between two equally replicated means, CV – coefficient of variation, %, MSE – mean square error from analysis of variance, JD – John Deere planter (all check planted using JD), FP – farmer practice (entire plot planted by hand using stick planter), DSB – Dribble Surface Band, N – Nitrogen.

addition of 30 kg N ha^{-1} and that doubling the N rate could not create a yield difference. Additionally, yields were not significantly different when urea was applied either as broadcast or DSB (p = .174). Also, fertilizer sources (UAN and urea) were not significantly different (p = .077). However, OSU-HP at 60 and 30 kg N ha^{-1} produced the highest yields compared to other treatments. This may be because OSU-HP placed N below the soil surface, reduced volatilization losses which might have occurred with other treatments (broadcast and DSB) where N was surface applied.

EFAW 2018

There were significant differences in maize grain yield due to the effect of different treatments at the EFAW experimental site (p < .01) (Table 2). The OSU-HP produced the highest grain yield (11.01 Mg ha^{-1}) when N was applied at a rate of 60 kg ha^{-1} (Table 3). This yield was 7.6% higher than the yield of the nearest treatment which was also OSU-HP at 30 kg N ha^{-1}. The lowest grain yield (6.09 Mg ha^{-1}) was recorded in the unfertilized check plot treatment. This grain yield in the unfertilized check plot was 80.8% lower than the highest yield observed with OSU-HP at 60 kg ha^{-1}. In addition to the check treatment, yield for FP at both N rates of 30 and 60 kg ha^{-1} (broadcast applied) was lower when compared to others (Table 3). Grain yields ranged from 6.1 to 11.0 Mg ha^{-1} in the unfertilized check and OSU-HP at 60 kg N ha^{-1}, respectively (Table 3). Furthermore, OSU-HP with an N rate of 30 kg ha^{-1} produced similar yield levels to that observed when the N rate was doubled to 60 N, kg ha^{-1}. Single degree of freedom contrasts showed that both planting methods and N rates had a significant effect on maize grain yield (Table 3). When grain yield was averaged across all planting methods and N rates, OSU-HP method of N application yielded significantly greater than broadcast method (FP) ($p < .0001$). Nitrogen application using OSU-HP resulted in yield that exceeded the broadcast method (FP) by 40.6%. Similarly, yield achieved with OSU-HP N application method was 19.2% and 22.6% greater than for DSB urea and DSB UAN methods, respectively (Table 3).

There was no significant difference in grain yield due to the N source used (Urea and UAN). Nevertheless, yield obtained with Urea was 4.3% higher than yield achieved with UAN ($p = .450$). Also, there was no difference between grain yield for N rate at 30 and 60 kg ha^{-1} ($p = .132$). Overall, N applied at a rate of 60 kg ha^{-1} produced 8.3% more yield than 30 kg N ha$^{-1.}$ This is because the OSU-HP on average yielded 52% higher than other planting and N application methods, N placement below the soil surface might have lowered volatilization. This possibly led to higher yields with OSU-HP compared to other methods where N was surface applied through broadcast and DSB.

EFAW 2013

Results from analysis of variance showed that grain yield was significantly influenced by the main effect of treatments ($p = .03$) (Table 2). Grain yields were higher when N was applied using the OSU-HP at a rate of 30 kg N ha^{-1} and lower in the unfertilized check plot (Table 3). Grain yield using OSU-HP at 30 kg N ha^{-1} exceeded that of the unfertilized check plot by 65.6%. Famer practice (FP) where urea was broadcast had a yield that was at least 13% higher than the one attained in the unfertilized check plot. Contrast analysis revealed that the effects of both planting and N rate application methods on maize grain yield were significant (Table 3). However, broadcast versus DSB method of N application did not result in a substantial yield difference. Applying N with the OSU-HP resulted in a 41.9% higher yield than when broadcast ($p = .005$). Similarly, applying N with OSU-HP significantly increased grain yield by 56.3% relative to the DSB with urea ($p = .001$). A similar result was also found when OSU-HP was compared to DSB with UAN ($p = .018$) (Table 3). However, there were no significant differences in yield when N was broadcast applied versus DSB methods with either urea ($p = .493$) or UAN ($p = .521$). Results also indicated no significant difference between grain yield in the unfertilized check plots, and average grain yield in the fertilized plots ($p = .142$). Further analysis did not find a substantial grain yield difference between N rates of 30 and 60 kg ha^{-1} ($p = .440$). A similar pattern was also seen for the sources of N (urea and UAN) with no significant differences ($p = .817$) (Table 3). Incorporating urea into the soil could be the possible reason why OSU-HP yielded higher than other methods of N application.

PERKINS 2013

Analysis of variance showed that treatments were significantly different when analyzing maize grain yield ($p = .01$) (Table 2). Maize grain yield was highest when OSU-HP was used at a rate of 60 kg N ha^{-1} (Table 3). Furthermore, this exceeded the yield in the unfertilized check plot by 49.9%. Grain yield was lowest when planting was accomplished using FP and N was broadcast applied at a rate of 60 kg ha^{-1}. For this treatment, yield was less than that of the unfertilized check plot (5.3 Mg ha^{-1}) by 1.9%. The second highest yield was obtained using JD and N was DSB applied at a rate of 30 kg ha$^{-1.}$ Grain yield in this treatment was 33.3% higher than the unfertilized check plot yield.

Single degree of freedom contrast analysis showed that when yield was averaged across all N rates and planting methods, grain yield obtained with OSU-HP method of N application was significantly higher than that achieved by broadcasting Urea. Nitrogen applied using OSU-HP had 119.1% more yield than N applied by broadcasting on the soil surface ($p < .0001$). However, yield attained using OSU-HP as a method of N application was similar to yield associated with DSB application methods (Table 3). The DSB application of N as either Urea or UAN resulted in at least 57% higher grain yield than the surface applied urea using FP. Outcomes also indicated that application of N led to an average grain yield that exceeded the unfertilized check plot by 81.8% ($p = .005$). There were, however, no significant differences between grain yield attained at N rates of 30 and 60 kg ha^{-1} (p = .614). Similarly, N sources (Urea or UAN) did not result in significant grain yield differences (p = .061) (Table 3).

Discussion

Maize grain yield was influenced by the treatments evaluated in this study. Overall, use of OSU-HP to plant and apply N at a rate of 60 kg ha^{-1} resulted in the highest grain yield across years and sites. Furthermore, planting maize and applying N (30 kg ha^{-1}) using OSU-HP achieved, on average, higher grain yields than JD and DSB or FP and broadcast application combinations. The high yield associated with OSU-HP suggests that N placement below the soil surface may reduce volatilization. Rees et al. (1996) observed that below the surface (point) placement of N resulted in 18% higher N recovery than surface applied N. Ciampitti and Vyn (2011) observed an increase in maize grain yield per unit area when N was side-dress applied compared to when N was not side-dressed. A report by Bouwman, Boumans, and Batjes (2002) that reviewed 148 research papers indicated that ammonia volatilization from incorporated N was 50% lower than the surface applied N sources. Also, Carter and Rennie (1984), concluded from their study that N placed beneath the soil at a close proximity to plants resulted in maximum N utilization and efficiency, on both conventional and no-tillage system. In this study, incorporating Urea beneath the soil was possible using the OSU-HP, and that makes this device desirable for by-plant, and mid-season N applications.

Generally, DSB application of Urea did not result in a substantially higher grain yield when compared to surface broadcast applications (broadcast). Nonetheless, yield was on average higher for DSB N application method. Halvorson and Del Grosso (2013) reported no significant yield difference between broadcast and band applied N in irrigated maize. Subsurface banding of N also may be more effective at reducing N loss than broadcast incorporated N (Maddux et al. 1991). Furthermore, Sweeney, Ruiz-Diaz, and Jardine (2018) reported some inconsistent findings between banded application and broadcast methods under ridge-till and no-till, respectively, at different growth stages. Results from plots where Urea or UAN was DSB applied compared with broadcast Urea application, further suggests that placement of N next to the plant improves N uptake and grain yield, a possible reason for yield improvement with OSU-HP.

By and large, at all sites, check plots (Zero-N) yielded significantly lower compared with plots with N (DSB, broadcast, and OSU-HP), this is evidence of the importance of N and that was clearly deficient at all sites and years.

Conclusions

In this study, yields were higher with the OSU hand planter compared to the conventional methods. This is because the OSU hand planter takes into account inter-plant variability and accommodates accurate placement of fertilizer, next to each plant giving it better N proximity. However, with apparent challenges of low maize grain yield because of poor planting method, the OSU-HP could mitigate this by improving seed placement and incorporating N below the soil, which makes the OSU-HP a desirable device for mid-season N applications. Results from this study may help subsistence farmers globally, to adopt the OSU-HP as a prospective implement that can ultimately increase yield and reduce N losses via the placement of N beneath the soil surface and close to the actual growing plant.

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