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The impact of different nitrogen fertilizer levels on maize hybrids performance in a humid environment

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Abstract

Fertility and its management are critical issues in sustainable agriculture for crops such as maize. The objective of this research was to compare maize hybrids (H) and nitrogen (N) rates, growth, yield, and yield components. We hypothesized that increasing supplemental levels of N would increase yield and yield components. A field experiment was conducted at NARC Islamabad using in a split plot design with three replications in 2017 and 2018, with the following levels of N (kg ha^{-1}: 100 (N1), 175 (N2), N3 (250), N4 (325), and N5 (400) using three different hybrids (H), H1 (P-3939), H2 (30-T-60), and H3 (30-Y-87). Data were analyzed using the MIXED procedures of SAS. The statistical models included the individual effects of N levels and H, the interactions between N and H and random effect of the year. Orthogonal polynomial contrasts were constructed to determine the optimum level of N. Yield and yield components were improved at 325kg N ha^{-1} with significant effects on maximum plant height, number of grains cob^{-1}, number of grains per m^2 and grain yield. The results revealed that growth, yield and yield components were maximized at (P < 0.000) for NARC Islamabad at the N4 level without having an interaction with the H of maize crop. It was concluded that the selection of best H at 325kg N ha^{-1} can be used to enhance the efficiency of maize yield in autumn season.

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Introduction

Maize is the world's most widely grown cereal and one of the most important and highest yielding staple food crop in many developing countries after wheat and rice crop (FAO, 2010). It is important both for human consumption and as animal feed (Danish *et al.*, 2019). Starch is the main component of maize (Masood *et al.*, 2011; Eltelib *et al.*, 2006). It contains valuable unsaturated fatty acids and in Pakistan and various other countries it is also one of the main sources for edible oil (Khan *et al.*, 2013). Worldwide, maize starch is also used for the production of biofuel such as ethanol after fermentation (Ahmad *et al.*, 2007). Research is needed to enhance maize yield to find the most promising hybrids of maize under stress environments and to evaluate their agronomic performance (Mubeen *et al.*, 2013; 2016).

Nitrogen (N) is a crucial plant nutrient and the major yield determining factor that is required for plant growth, development, and ultimately impacts final yield. It plays a major role in many physiological processes such as chlorophyll development and it is a principal component of various enzymes, proteins and nucleic acids. Consequently, N deficiency or an excess decreases yield (Sharifi and Taghizadeh, 2009; Khan *et al.*, 2014). An Enhancing the levels of N in the soil has been a major management strategy to attain high grain yield (Zhu *et al.*, 2016). N fertilizer is costly but is frequently required for maximizing yield, so optimum levels of N are important for maximizing returns. However, N demand changes radically from year to year and at different locations, making it challenging to determine optimum levels of N at the peak crop demand. (Shanahan *et al.*, 2008). Best management practices of N reduce losses of N and enhance availability of N for crops, which in turn improve nitrogen use efficiency and reduce the potential negative impact of N on the environment (Havlin *et al.*, 2009).

N is required in larger amounts than other nutrients and increasing levels of N have been shown to have a significant impact on grain yield (Khaliq *et al.*, 2008). A study by Abbas *et al.* (2005) found that an application of N enhanced the cob number, the plant stand, 1000-grain weight and grain number. Crop yield and seed yield also tend to increase with increasing N rates (Shrestha 2013; Dahmardeh 2011; Sharifi and Namvar 2016). A study by Khan *et al.* (2012) found that an application of N provided sufficient nutritional requirements for maize crop to grow rapidly and it promoted grain production. An optimal rate of N is required for maximum yield and grain weight (Wajid *et al.*, 2007).

The N requirement for maize crop depends on soil type, crop rotation pattern, and weather conditions (Blackmer, *et al.*, 2009; Bundy, *et al.*, 2011). The mismanagement of plant nutrition leads to low productivity (Bakht *et al.*, 2006). Information on frequency and quantity of irrigation water and N fertilizer for optimum maize growth and yield have not been well described for arid environments that are characterized by high temperatures and low rainfall (Hammad *et al.*, 2011; 2018). Developing high yielding maize cultivars that have relatively high grain protein content under low N stress is critical to ensure food and nutrition security (Arisede *et al.*, 2020). In Pakistan, the national average maize yield is extremely low compared to developed countries, and an imbalanced supply of nutrients is considered one of the major causes for the limitations in yield (Fahad *et al.*, 2014b, Khan *et al.*, 2014). Although a number of experiments have been conducted in Pakistan to determine the optimum amount of N for maize, insufficient research has been conducted to simultaneously determine the impact of N on maize hybrids by splitting doses, times and methods of application. The objective of this study was, therefore, to determine the impact of five different levels of N on yield and yield components of different autumn maize hybrids at two different environments.

Materials and methods

Site

A field study was conducted at the research farm of NARC Islamabad Lat 33.68 and Long 73.04 during 2017 and 2018. NARC Islamabad has humid subtropical climate. Most soils are deficient in nitrogen. The soil at the experimental site of NARC Islamabad site was loamy soil. Composite soil samples to a depth of 30cm were obtained from the experimental site using a soil auger prior to sowing. Soil analysis showed that all two sites had a pH near 8.0 and were rated as deficient in the main elements, N, P and K.

Weather

Standard weather data, including daily maximum and minimum air temperature (ºC), rainfall (mm) and daily sunshine (hours) were recorded for each year by a nearby weather station of the Meteorological station NARC Islamabad, Lat 33.68 and Long 73.04.

Cultural practices

The experiment was laid out in a randomized complete block design (RCBD) with a split plots and three replications; the net plot size was 6 m x 3 m. Nitrogen levels were randomized in the main plots and maize hybrids in the sub plots. The experiment was comprised of five levels of nitrogen (N_1= 100kg N ha^{-1}, N_2= 175kg N ha^{-1}, N_3 = 250kg N ha^{-1}, N_4= 325kg N ha^{-1} and N_5 = 400kg N ha^{-1}) and three different maize hybrids (H_1= P-3939, H_2 = 30 T 60, and H_3= 30 Y 87). The soil was analyzed before sowing and after harvesting. Crops were sown in 2017 and 2018 in autumn season on 60cm spaced ridges with a plant-to-plant distance of 20cm. Phosphorus (P) was applied as DAP at a rate of 115kg ha^{-1}; potassium (K) was applied as SOP (K_2SO_4) at a rate of 75kg ha^{-1} at the time of sowing. One third of nitrogen was applied at the time of sowing, while the remaining two-thirds of N were applied in two splits, the first at 15 days after sowing and the second at flowering. A total of eight irrigations were applied during the growing season such as first furrow irrigation 100 mm and another 7 furrow irrigations of 75 mm. All other cultural practices, such as hoeing, weeding, and plant protection measures were kept uniform for all individual plots.

Data Sampling

The data were collected according to standard procedures. The crop was harvested manually at full maturity. Each sub plot area was 6m x 3m. Data on plant height (cm) at physiological maturity was recorded from base to the tip of tassel with the help of meter rod by selecting ten plants randomly from each plot and then averaged were worked out. For the cobs length randomly selected 10 plants were removed and their lengths were measured with the help of measuring tape incm and then averaged. Cobs from randomly selected 10 plants were removed and their girth (cm) with the help of Vernier Caliper were measured incm and then averaged. Number of grain rows per cob were calculated of ten randomly selected cobs from each plot and were averaged. Grains per cob was calculated on ten randomly selected cobs from each plot and were threshed and was averaged. In each plot selected the total number of cobs in m^{-2} area were collected and threshed and grains per m^{-2} were calculated and was averaged. After threshing, Grain weight of randomly 1000 grains were taken from seed lot of each plot and was weighted with the help of electronic balance so 1,000 grain weight (g) were recorded. Three central rows of each treatment were harvested, dried, threshed and weighted and then was converted into grain yield (kg ha^{-1}).

$$\text{Grain yield} = \frac{\text{Grain yield per three rows}}{\text{No. of rows} \times \text{row length} \times \text{R-R distance}} \times 10000$$

Statistical Analysis

Data were analyzed using the MIXED procedures of SAS (version 9.4, SAS/STAT, SAS Institute Inc., Cary, NC). Normality of the data on growth and characteristics of yield were tested based on the distribution of the residuals using Shapiro-Wilk and homogeneity of variance. A pooled analysis was carried out within the location across years/seasons (Gomes & Gomes, 1984). The statistical models included the following parameters: the fixed effects of levels of nitrogen, hybrid, interactions between nitrogen and hybrid, and the random effect of year. The Kenward-Roger method was used to calculate the approximate denominator degrees of freedom to compute F-tests in the statistical models. The Tukey adjustment was applied to account for multiple comparisons. In all analyses, single degrees of freedom of orthogonal polynomial contrasts of interest using contrast statement including the linear and quadratic effects of levels of nitrogen were also evaluated. The mixed models were computed to generate least squares means ± standard error of the mean (LSM ± SEM) of the response variables. Figures and tables were developed according to the LSM ± SEM generated from the mixed models based on the fixed and random effects of the models. Statistical significance was considered at $P \leq 0.05$, and a tendency was considered at $0.05 < P \leq 0.10$.

Results and discussion

Plant Height

The year effect on plant height was significant, and the maximum plant height was observed in 2018, 3% (182cm) as compared to 2017 (177cm) (Table 2). Significant differences in plant height were found among the hybrids, with the maximum plant height observed in 30-Y-87 (181cm) which is at par with hybrid P-3939, (179cm). The difference in plant height are due to the genetic nature of different hybrids. The N rate had a significant effect on plant height. The plots fertilized with N4 had the greatest plant height was recorded (187cm which is followed by N3 185cm) while the minimum height of plant (169cm) were observed in plots fertilized at rates of N1, respectively (Table 2). Imran *et al.* (2015) also reported that an increase in the rate of N resulted in an increase in plant height, the main parameter that helps in the determination of growth during the growing season. The increase in plant height is due to the increasing levels of N. An interaction between levels of N and H tended to be non-significant ($p<0.2776$). The plant height (187cm) was maximized ($P < 0.001$) at N4 level in maize crop.

Table 1. Soil physical and chemical characteristics of the experimental site.

Soil Characteristics	Soil sample depth					
	15cm		20cm		30cm	
	2017	2018	2017	2018	2017	2018
Soil pH	7.85	7.8	7.82	7.9	8.0	8.1
Organic matter %	1.21	1.25	0.92	0.94	0.62	0.63
Total Soil N (%)	0.071	0.071	0.054	0.071	0.044	0.049
Available P (mgkg-1)	6.4	6.5	5.5	5.5	4.8	4.9
Available K (mgkg-1)	82	86	71	73	66	67
Texture	loam	loam	loam	loam	loam	loam

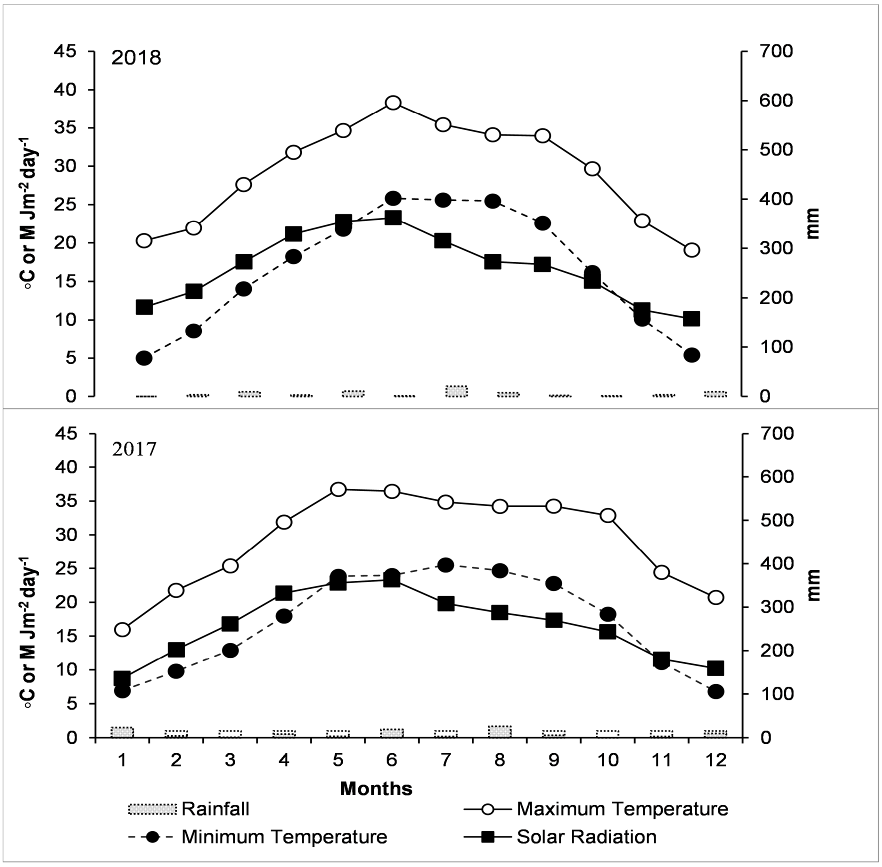

Fig 1. Monthly total rainfall, average solar radiation, and maximum and minimum air temperature at the experimental site during 2017 and 2018.

Cob Length

The year effect on cob length was statistically highly significant, with a maximum length of 16.3cm was recorded in 2018 as compared to 2017 15.2cm (Table 2). Table 2 shows that significant effect for hybrids, the maximum cob length was found for H3 (16.01cm) which is at par with H1 (15.8cm).

Findings for cob length showed that the effects of N levels on cob length were highly significant, and the greatest cob length was obtained at N4 (16.7cm) which was statistically followed by N3 (16.5cm). The interactive effect between H and N levels was found to be statistically non-significant. These results agree with those observed by Seadh *et al.* (2015) and Matusso and Materusse (2016), in which they concluded that N added to maize plants can enhance cob length.

Cob Girth

The results from this study indicate that the year effect on cob girth was statistically highly significant, with maximum cob girth attained during 2018 (4.33cm) as compared to 2017 (3.73cm). Differences were found to be significant among the H, with H3, 30-Y-87 and H1, P-3939 having maximum cob girth 4.07cm and 4.02cm, respectively, while minimum cob girth was recorded in 30-T-60 (4cm), as shown in Table 2. Differences for N levels were also highly significant, with maximum cob girth obtained at N4 (4.18cm) which was statistically at par with N3 (4.14cm). The minimum girth was obtained at N1 (3.8) (Table 2). These results are in accordance with those reported by Seadh *et al.* (2015) and Matusso and Materusse (2016) who found that supplemental N enhanced the cob girth of maize with increasing levels of N.

Grain rows per cob

Grain rows per cob is a vital yield component trait and increases the total number of grains per cob. The maximum number of grain rows per cob was higher during 2018 (13.98) as compared to 2017 (12.9). There was a significant difference among the hybrids, with the maximum number of grain rows per cob observed in H3, 30-Y-87 (13.9), which was at par with H1, P-3939 (13.4), while the minimum was found for H2, 30-T-60 (12.9) (Table 2). N application rates were also found to be significant. The highest number of grain rows per cob was obtained at N4 (14.7), (Table 2). Thus, N added to maize enhances the cob girth which in turn increases the number of grain rows per cob. These results agree with those observed by Seadh *et al.* (2015) and Matusso and Materusse (2016).

Table 2. Effect of different N fertilizer levels on yield and yield components of maize hybrids.

Treatment	Plant height (cm)	Cob length (cm)	Cob Girth (cm)	Grain Rows /Cob	Grains No/cob	Grains No/m²	1000 Grain wt (g)	Yield (kg/ha)
A) Year								
2017	177 b	15.29 b	3.73 b	12.94 b	408 b	3431 b	240 b	6352 b
2018	182 a	16.34 a	4.33 a	13.98 a	437 a	3546 a	269 a	6808 a
Tukey HSD	2.02	1.5	0.08	3.34	13.2	69	1.13	4.1
Significance	**	**	**	**	*	*	**	**
B) Nitrogen Levels								
N1	169 d	14.63 c	3.85 c	12.16 d	378 d	3154 c	241 d	5728 d
N2	175 c	15.3 bc	3.98 b	13.02 c	410 c	3405 b	247 c	6157 cd
N3	185 a	16.59 a	4.14 a	14.04 b	445 a	3688 a	263 ab	6999 b
N4	187 a	16.76 a	4.18 a	14.76 a	453 a	3732 a	265 a	7485 a
N5	180 b	15.8 b	4.01 b	13.33 c	428 b	3461 b	258 b	6534 c
Tukey HSD	4.18	0.73	0.1	0.58	16.7	193.8	5.7	464.6
Significance	**	**	**	**	**	**	**	**
C) Hybrids								
Autumn season hybrids								
H1 = P-3939	179 ab	15.85 ab	4.02 ab	13.49 ab	424 ab	3480 ab	256 a	6574 ab
H2 = 30-T-60	179 b	15.59 b	4.00 b	12.96 b	417 b	3432 b	251 b	6397 b
H3 = 30-Y-87	181 a	16.01 a	4.07 a	13.94 a	427 a	3553 a	256 a	6770 a
Tukey HSD	1.91	0.29	0.06	0.6	9.7	76.8	3.8	250.4
Significance	*	**	*	**	*	**	**	**
Mean	179.4	15.81	4.03	13.46	422.7	3488	254.6	6580
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

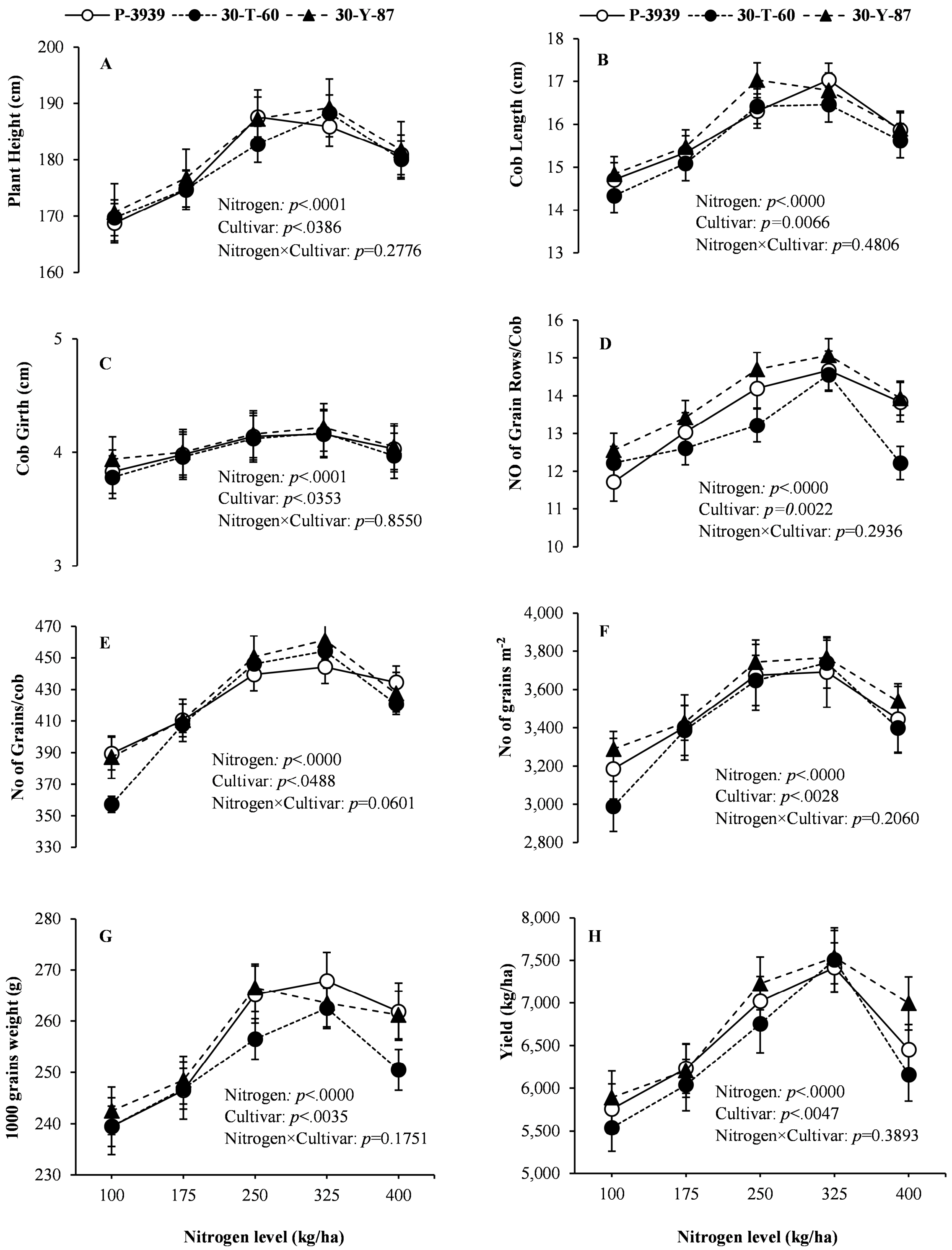

Fig 2. Fertilizer response for two years for different hybrids with HSD at 5%. A) Plant height: Linear ($P<0.0001$), and quadratic ($P<0.0386$) effects of levels of nitrogen, B) Cob length: Linear ($P<0.0000$), and quadratic ($P<0.0066$) effects of levels of nitrogen C) Cob girth: Linear ($P<0.0001$), and quadratic ($P<0.0353$) effects of levels of nitrogen. D) No of grain rows per cob: Linear ($P<0.0000$), and quadratic ($P<0.0022$) effects of levels of nitrogen. E) No of grains per cob: Linear ($P<0.0000$), and quadratic ($P<0.0488$) effects of levels of nitrogen. F) No of grains m^{-2}: Linear ($P<0.0000$), and quadratic ($P<0.0028$) effects of levels of nitrogen. G) 1000 grain weight: Linear ($P<0.0000$), and quadratic ($P<0.0035$) effects of levels of nitrogen. H) Grain yield: Linear ($P<0.0000$), and quadratic ($P<0.0047$) effects of levels of nitrogen.

Number of Grains Per Cob

The number of grains per cob is a contributing factor in the number of grains m^{-2}. The year effect on the number grains per cob was greater in 2018 (437) than 2017 (408), (Table 2). The impact of the hybrids on the number of grains per cob was significant. The H 30-Y-87 had the highest maximum number of grains per cob for H3 (427) which was statistically at par with H1 (424). The statistical analysis showed that the N application rates were found to be highly significant.

The highest number of grains per cob was found at N4 (453) which is followed by N3 (445), and the lowest number of grains per cob (378) occurred at N1. These results are in agreement with the findings of Selassie (2015), Woldesentbet and Haileyesus (2016), and Achiri *et al.* (2017) who concluded that enhancing the N levels increased the number of grains per cob. The interaction between H and levels of N was not statistically significant. The number of grains per cob was highest (453) ($p < 0.0000$) at N4 level followed by N3 (445) without having an interaction with the H of maize crop (Fig. 2E).

Total Number of Grains m^{-2}

The number of grains per cob and the number of grains per are essential parameter that contributes towards final yield of maize. The year effect on the total number of grains m^{-2} was, with the maximum number of grains (3546 m^{-2}) for 2018 as compared to 2017 (3431m^{-2}). The highest number of grains m^{-2} was found for hybrid 30-Y-87 (3553 m^{-2}) and the lowest number of grains was found for hybrid 30-T-60 (3432 m^{-2}).

With respect to nitrogen fertilizer, the highest number of grains was found for the treatment N4 (3732m^{-2} followed by N3 3688m^{-2}), while the lowest number of grains was observed for N1 (3154 m^{-2}) (Table 2). These results are in line with the findings of Qian *et al.* (2016) who concluded that N application significantly enhanced the number of grains m^{-2}. The total number of grains (3732m^{-2}) was highest ($P < 0.000$) at N4 level without having an interaction with the H of maize crop (Fig. 2F).

1000 Grain Weight

The weight of 1,000 grains is also an essential yield component parameter. In this study, the year effect on the 1,000 grain weight was statistically significant, with a higher 1,000 grain weight during 2018, 11% (269 vs 240g) compared to 2017 (Table 2). The highest 1,000 grain weight (256g) was found for both hybrids 30-Y-87 and P-3939 (Table 2). With respect to nitrogen, the highest 1,000 grain weight recorded at N4 (265g) followed by N3 (263g) (Table 2). El-Shahed *et al.* (2017) observed similar responses regarding the effect of N on vegetative growth, which in turn favored metabolic processes and increased growth and yield attributes of maize. Seadh *et al.* (2015) and Matusso and Materusse (2016) found that the addition of N increased grain rows per cob, the number of grains per cob and 1,000 grain weight. The 1,000 grain weight (265g) was highest ($P < 0.0035$) at N4 level without having an interaction with the H of maize crop (Fig. 2G).

Grain Yield

Ultimately final grain yield is most important. The results from this study showed that the year effect on grain yield of maize H were statistically highly significant, as one would expect because of the interaction between environmental parameter, crop management, and genetics. The grain yield was recorded 7% (6352 vs 6808kg ha^{-1}) more in 2018 as compared to 2017 (Table 2).

It was mainly attributed to more number of grains during 2018 at these experimental site. Differences in yield between years ascribed due to different daily variations in maximum and minimum temperatures resulting in different daily leaf temperature across the year, different patterns of rainfall and relative humidity over the two years and other temporal variations in the environment.

Hybrid differences in grain yield were highly significant with similar trend, the results indicated that highest grain yield was found for hybrid 30-Y-87 (6,770kg ha^{-1} followed by H1 producing 6,574kg ha^{-1}), while H 30-T-60 produced the lowest grain yield (6,397kg ha^{-1}).

The differences for the different N application rates were highly significant. The highest grain yield (7,485kg ha^{-1}) was observed for the N4 application rate, while the lowest grain yield (5,728kg ha^{-1}) was obtained N1 application rate, These results substantiate the findings of Selassie (2015), Woldesentbet and Haileyesus (2016) and Achiri *et al.* (2017) who observed similar effects of N levels on yield in maize, as well as Qian *et al.* (2016), who found that N fertilization increased grain yield significantly for different maize hybrids. The grain yield (7,485kg ha^{-1}) was highest ($P < 0.000$) at N4 level without having an interaction with the H of maize crop (Fig. 2H).

Conclusion

The results obtained in this experiment shows that in autumn season under irrigated conditions the highest yield and yield components for different maize hybrids were achieved for a N fertilizer rate of 325kg N ha^{-1} when one-third of a dose of N was applied at the time of sowing and the remaining two-thirds were applied in two splits, the first at 15 days after sowing and the second at flowering. Hence, N4 (325kg N ha^{-1}) is recommended under irrigated conditions.

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Declaration of interests

All authors do not have any conflicts of interest.

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