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Effect of Plant Density and Nitrogen Fertilizer Rate on Grain Yield of Late Maturing Maize Hybrid BH661

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The yield potential of maize continuously shifted with modification of plant density and nitrogen level because of high mobile nature of available nitrogen and continues releasing of new hybrid with high nitrogen requirements. Thus modification of these factors to optimum level significantly increases the grain yield of the crop. Based on this concept, a field experiment was conducted at four locations for three consecutive years (2016-2018) to determine the optimum plant density and nitrogen level for late maturing maize hybrid. The experiment was laid out in a Randomized Complete Block Design in factorial arrangement with three replications. Four plant density viz., 44444, 53333, 62500 and 66666 with five nitrogen levels viz. 69, 92, 115, 138 and 161 kg ha^{-1} were combined by factorial combinations and tested in the experimental plots to select the optimum level for high yield. The result indicated that increasing in plant density produced tall plants with weak stalk strength ultimately resulted high lodging under highest plant density. The maximum grain yield (7838.1kilo gram per hectare) obtained under optimum plant density (53333 plants per hectare with application of 115 kilo gram nitrogen per hectare). This result showed 29% and 24.4% yield advantages compared to the standard check and satellite check respectively. Similarly application of 115 kg N /ha under 53333 plant densities was the most profitable compared to other combinations. Thus the previous recommended plant density, 44444 plants/ ha with application of 92 kg N /ha is insufficient for hybrid BH661 cultivation. Slightly higher plant density and nitrogen level, 53333 plants per hectare with application of 115 kg N ha^{-1} are suitable for the high yield of hybrid maize BH-661 during main seasons.

Keywords: BH-661, Nitrogen Fertilizer Rate, Plant Density, Grain Yield

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INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal crops on which millions of people depend for their livelihood. It is one of the most versatile emerging crops having wider adaptability under varied agro-climatic conditions and successful cultivation in diverse seasons and ecologies for various purposes. Globally, maize is known as “Queen” of cereals because it has the highest genetic yield potential among the cereals. In Ethiopia, maize stands first of all other cereal crops in annual production and productivity, although it is second in area coverage next to *tef* (CSA, 2018). Currently in Ethiopia maize is cultivated by 10.6 million households on 2.1 million hectares and produced 8.4 million tones as compared to 5.2 million tons of teff (CSA, 2018). Maize contributes 28 % to the total national grain production and 22% of the daily calorie needs. During the last ten years the productivity of maize increased from 2.1 tones/ha to 3.9 tones/ha. The popularity of maize in Ethiopia is partly because of its high value as a food crop as well as the growing demand for the Stover as animal fodder and source of fuel for rural families. (Abdirazak and Bereket, 2018). Approximately 88 % of maize produced in Ethiopia is consumed as food, both as green and dry grain (Abate *et al.,* 2015). In such a way maize plays an important role in the food security of the country. In order to improve the productivity of maize many breeding researches were carried out over the past several years. With this effort local varieties become replacing with input-responsive, stable and high yielding modern varieties (Abate *et al*, 2015). Key planting factors influencing maize grain yield include spacing of seed and rate of fertilizer application among others. According to the GTP II, the productivity of maize will increase to 5.0 tones/ha with total productivity of 10.9 million tones by the year 2020. This requires intensive supply of inputs mainly fertilizer and improved seeds of modern and superior hybrid varieties with their appropriate plant density.

BH661 maize hybrid is among the most high yielding late maturing modern varieties which is highly sensitive to plant density and N fertilizer level as its performance and yield potential is highly affect by these factors. Under high plant density and high nitrogen rate the height of plant increase vertically with decreasing stalk strength resulting high lodging (Qian *et al*., 2010). Due to the lodging effect 44,444 plants per hectare with 92 kg N/ha is still the recommended amount for late maturing maize hybrids in Ethiopia (www. eiar.gov.et). However under this low plant density and low nitrogen rate the utilization and conversion of available resources like solar radiation, nutrient and water in to dry matter production decrease (Shrestha, 2013; Farnia *et al.,* 2015). In such situation little modification of such important factors (density and N rate) in to the optimum brings about great change in grain yield as such modern hybrid has high yield potential.

Thus to exploit the full potential and achieve maximum grain yield of BH661 maize variety, modification of spacing or plant density and rate of Nitrogen fertilizer is needed. Keeping this fact in view this study was initiated with the objective to evaluate the effect of plant population and Nitrogen fertilizer level on grain yield potential of late maturing maize hybrid BH661 under main season conditions.

MATERIALS AND METHODS

Description of Experimental Sites

The experiment was conducted at Bako (on-station & on-farm) and Jimma (on-station) for three consecutive years during main seasons of 2016, 2017 and 2018. Bako National Maize Research Center is located in East Wellega Zone of the Oromia Regional State, Western Ethiopia at an altitude of 1650 m above sea level (masl). It lies between 9°06' North latitude and 37°09' East longitude in the mid-altitude sub-humid agro-ecology of the country 260 km west of Addis Ababa. During the experimental season, the rainy season covered the period from May to October and maximum rainfall was received in the months of July and August and the average annual rainfall was 1237.9 mm. The mean minimum, mean maximum and average air temperatures are 13.3, 28.1 and 20.6°C, respectively. The mean soil temperature at 0, 5, 10, 20, 50, and 100 cm depths are 25.4^{0}C, 25.3^{0}C, 23.8^{0}C, 23.4^{0}C, 23.2^{0}C and 24.1^{0}C, respectively. Sixty percent of the soil is reddish brown in color and clay loam in texture (Negassa, 2001). According to USDA soil classification, the soil is classified under the Nitosol order.

Jima Agricultural Research Center is located in Jima Zone of the Oromia Regional State, South Western part of Ethiopia at an altitude of 1750 m above sea level (masl). It lies between 7°46' North latitude and 36°00' East longitude in the mid-altitude sub-humid agro-ecology of the country. During the experimental season, the average annual rainfall is 1536 mm. The mean minimum and mean maximum temperature are 11.2°C and 25.9°C respectively.

Soil Characterization

A representative soil samples were taken at 0 to 30 cm depth using an auger in a diagonal pattern among each 5 m interval before planting from Bako on-station and on-farm in each experimental year. The soil samples were then analyzed at Bako Agricultural Research Center soil laboratory for chemical properties (Soil pH, Organic carbon, Organic matter, Total N, Available phosphorus and Cations exchange capacity) using standard laboratory procedures and classified according to Landon (1984).

Soil water reaction determined by glass electrode method indicated that the pH (water) was strongly acid in the range of 5.0 to 5.9 which can result in satisfactory growth but with drop in yield. The pH range of 5.0 to 5.9 is below 6.6 to 7.3 considered neutral and optimum for crop growth and yield. Organic carbon determined using the Walkley and Black method was in the range of 1.6 to 2.6 % generally classified as medium. The highest organic carbon was recorded in 2017 on-station site with value of 2.68 %. The percentage organic matter recorded was highest in 2017 on-station with value of 4.62 % classified as medium. The percentage total N measured using Kjeldahl method was in the range of 0.14 to 0.23 % and therefore considered medium. The available phosphorus (P) determined calorimetrically using

Table 1. Results of soil chemical properties before planting

Year	Site	PH (1:2.5) H_2O	%OC	%OM	%TN	Avail. P (ppm)	CEC (Cmol kg^{-1})	Base saturation % (Ca^{2+}, Mg^{2+})
2018	Bako (on-farm Tibe)	5.41	2.00	3.45	0.17	13.08	10	30
2018	Bako (on station)	5.19	1.71	2.94	0.15	14.08	5	10
2017	Bako (on-farm Tibe)	5.40	2.39	4.12	0.21	13.08	10	25
2017	Bako (on station)	5.26	2.68	4.62	0.23	13.08	5	10
2016	Bako (on Station)	5.78	1.61	2.77	0.14	23.08	15	25
Critical values and classification		(5.0-5.9) Strongly acid	(1.6-2.5) Medium	(2.1-4.2) Medium	(0.125-0.225) Medium	(<20) Low	(5-12) Low	(<40) Low
Overall		Low inherent fertility soil						

ultraviolet and visible spectrophotometer (UVS) was <20 ppm in 2017 and 2018 at both on-station and on-farm sites and considered as low, but the highest (23.08 ppm) available phosphorus was measured in 2016 on-station, which is considered as medium. Cation exchange capacity (CEC) determined by ammonium saturation method ranged from 5.0 cmol kg^{-1} to 15.0 cmol kg^{-1} which indicates low nutrient availability. In general the soil is of low inherent fertility, as its CEC value is less than 15 cmol kg^{-1} and base saturation less than 30 % (Table 1) (Landon, 1984).

Experimental Materials:

The experimental materials for this study consisted of one hybrid maize variety, nitrogen and phosphorus fertilizers. Hybrid maize variety BH661 was used for the study. BH661is late maturing variety released in 2011, performing well in agro-ecological range of 1600-2200 meter above sea level with rainfall range of 1,000–1,500mm. It can give 9500–12000 and 6500–8500 kg ha^{-1} grain yield on research farm and on-farmers farm experiments, respectively. It matures at about 160 days with plant height of 255-290 cm. Nitrogen fertilizer in the form of urea (46% N) and Phosphorus fertilizer in the form NPS (19 %N, 38% P2O5, and 7 % S) were used as a source of nitrogen and Phosphorus respectively. Nitrogen fertilizer (urea) was used for the experiment. It was applied at different rates to each treatment.

Treatments and Experimental Design

The hybrids BH661 was treated under five rates of nitrogen (69N kg/ha, 92N/ha, 115 N kg/ha, 138 N kg/ha and 161 N kg/ha) and four plant population densities (44444, 53333, 62500 and 66666 plants per hectare). The treatment set up that contains 44,444 plants ha^{-1} with application of 92 kg N ha^{-1} was used as a standard check. One satellite check plot having plant densities of 62, 500 with 150 kg NPSBZn blended fertilizer application was added as a second check.

The experiment was laid out as a randomized complete block design (RCBD) in factorial arrangement with three replications. The gross plot size was 4.8 m × 6 m (28.8 m^2) with row length of 4.8 m, but the net plot size 4.8m × 4.5m (21.6 m^2) was used for harvesting to minimize the border effects. The treatments were randomly assigned to the experimental unit within a block. The blocks were separated by 2 m wide space.

Agronomic Management

Land preparation was done three times from March to May in each location by using tractor plough at on-stations and by using oxen plough at on-farm locations. Planting time was varied from location to location and from year to year but all planting times were done in between May 28 to June15. Planting was done with one additional seed per hole and seedlings were thinned to required plant per plot two weeks after planting to keep a good stand seedling for each treatment.

Full dose of phosphate fertilizer in the form of NPS at the national recommended rate of 69 kg P_2O_5 ha^{-1} was applied uniformly to all plots at the time of sowing. Half dose of nitrogen fertilizer as per the treatments was applied at sowing time and half dose of nitrogen fertilizer was applied four weeks after sowing and immediately covered with soil. In order to ensure a healthy crop, all other agronomic practices including weeding, hoeing, field pest control and other practices were done as per research recommendation for maize. Finally, maize plants in the central net plot area were harvested at harvesting maturity stage for data collection.

Data Collection:

Data for plant height (cm) and ear height (cm) were recorded from ten randomly taken samples per plot. But stalk lodging (%), root lodging (%) and grain yield (kg/ha) data were taken from the net plot area at harvesting. Plants of middle rows on 21.6 m^2 area in the center of the plot avoiding border rows of each plot were harvested and weighted. The cobs were then shelled, dried in the bright sunshine and their moisture content measured. The grain yield of each plot was then calculated and converted to kg ha^{-1}.

Statistical Analysis:

Data analyses were conducted according to the principles of analysis of variance, using the general linear model (GLM) in SAS version 9.3 (SAS Institute, 2004). Significant differences among means were determined by the least significant difference (LSD) test at 5% probability.

Economic Analysis:

Economic analysis was performed to investigate the economic feasibility of the treatments. The price of maize that farmers received from sale was calculated based on current market price of maize. The total variable costs including the cost of fertilizers, improved seed and labors were also calculated based on the current price. The net return was calculated by subtracting total variable cost from the total return The total return was calculated with that grain yield (kg ha^{-1}) and stalk yield multiplied by field price that is money gained from sale of the grain and stalk. Finally to assess the cost and benefit associated with different treatments, the partial budget analysis was done following the method suggested by CIMMYT (1988).

RESULTS

Plant Height and Ear Height

The combination analysis of variance revealed that a highly significant ($P<0.01$) effects of years, locations, treatments and interaction among them on plant height of maize.

Maximum plant height (328.47cm) was recorded under highest plant density (66666 plants/hectare) with application of 138 kg N /ha. However statistically similar plant height was also obtained under application of 92, 115 and 161 kg N/ha on the same density. Similarly application of either 138 or 161 kg N/ha under 53333 plants per hectare produced statistically similar plant height (Table 2). The shortest plants were obtained under 44444 and 62500 plants per hectare.

Ear Height

Like that of the plant height, the combination analysis of variance revealed that a highly significant ($P<0.01$) effects of years, locations, treatments and interaction among them on ear height of maize.

Maximum ear height (191.53cm) was recorded under highest plant density (66666 plants/hectare) with application of 138 kg N /ha. However statistically similar ear height were also obtained under application of either of N rate, except 69 kg N/ha, on the same density. Similarly application of either 138 or 161 kg N/ha under 53333 plants /hectare produced statistically similar ear height (Table 3). The shortest ear height (171.73) obtained under lowest density (44444 plants/hectare) with application of either 69 or 115 kg N/ha and under 62500 plants /hectare with application of 69 kg N/ha, though statistically similar results were obtained under application of either of N rate on 44444 and 62500 plants /hectare and with application of lowest N rate on either of each density (Table 3). This increase in ear height has related to increase in plant height to obtained sufficient sun light.

Stalk Lodging

The combination analysis of variance showed that a highly significant ($P<0.01$) effects of years, locations and treatments on stalk lodging of maize. But these factors were not significantly interacted to affect stalk lodging.

Maximum stalk lodging (26.5%) was recorded under highest plant density (66666 plants/hectare) with application of highest N rate (161 kg N/ha) followed by application of 138 kg N/ha under similar population (Table 4). The minimum stalk lodging was recorded under lowest plant density (44444 plants/ha) with application of medium (optimum) N rate, 115 kg N/ha.

Table 2. Effect N level and plant density on plant height of maize (2016-2018)

N kg/ ha)	Density (plants/ ha)	Mean Plant Height (cm)			
		Bako	Tibe	Jimma	Combined
69	66,666	302.11bcde	318.50e	276.67ab	308.67ef
92	66,666	314.11ab	332.83bcd	280.50a	321.60abcd
115	66,666	308.44abcd	334.50abcd	271.00abcd	318.87abcde
138	66,666	322.44a	337.50abc	271.67abcd	328.47a
161	66,666	307.56abcd	345.50a	273.33abcd	322.73abc
69	53,333	302.78bcde	327.00cde	269.33abcd	312.47cdef
92	53,333	299.00bcde	328.17cde	276.17ab	310.67ef
115	53,333	302.67bcde	329.00cde	267.67abcd	313.20bcdef
138	53,333	314.11ab	343.00ab	256.00d	325.67a
161	53,333	313.44abc	337.67abc	257.83cd	323.13ab
69	444,444	299.00bcde	322.67de	275.00abc	308.47ef
92	444,444	297.44de	326.50cde	266.17abcd	309.07ef
115	44,444	290.78e	331.00bcd	269.83abcd	306.87f
138	44,444	296.56de	324.83de	265.17abcd	307.87f
161	44,444	298.22cde	327.67cde	268.17abcd	310.00ef
69	62,500	293.78de	324.17de	267.83abcd	305.93f
92	62,500	301.89bcde	324.83de	259.83bcd	311.07def
115	62,500	297.78cde	329.50cde	261.50bcd	310.47ef
138	62,500	302.89bcde	324.50de	270.17abcd	311.53def
161	62,500	301.00bcde	326.50cde	267.17abcd	311.20def
150NPSBZn	62500	304.33bcde	324.50de	…..	312.40cdef
LSD		15.83	12.21	17.55	10.58
CV		5.59	3.21	5.66	4.68

Means followed by the same letter within column are not significantly different (P<0.05)

Table 3. Effect N level and plant density on Ear height of maize (2016-2018)

N kg /ha)	Density (plants/ ha)	Mean Ear Height			
		Bako	Tibe	Jimma	Combined
69	66666	172.33abcdef	184.00g	148.00abc	177.00e
92	66,666	178.56ab	197.50abcdef	139.00cd	186.13abc
115	66,666	176.44abcd	200.33abcd	139.67bcd	186.00abc
138	66,666	183.89a	203.00abc	143.33abcd	191.53a
161	66,666	177.33abc	208.00a	139.00cd	189.60a
69	53,333	166.00cdefg	196.33abcdefg	145.67abcd	178.13bcde
92	53,333	171.11bcdefg	190.67cdefg	147.67abcd	178.93bcde
115	53,333	169.33bcdefg	194.17bcdefg	148.33ab	179.27bcde
138	53,333	174.89abcdef	203.67ab	149.67a	186.40ab
161	53,333	176.11abcde	200.00abcde	149.00a	185.67abcd
69	444,444	163.56fg	184.00g	138.67d	171.73e
92	444,444	168.78bcdefg	188.17defg	139.67bcd	176.53e
115	44,444	160.00g	193.33bcdefg	145.00abcd	173.33e
138	44,444	165.22defg	189.17defg	145.67abcd	174.80e
161	44,444	169.56bcdefg	193.00bcdefg	147.00abcd	178.93bcde
69	62,500	164.44efg	186.67fg	139.67bcd	173.33e
92	62,500	167.33bcdefg	188.00defg	150.00a	175.60e
115	62,500	167.89bcdefg	191.33bcdefg	142.33abcd	177.27de
138	62,500	168.44bcdefg	187.67efg	141.33abcd	176.13e
161	62,500	167.44bcdefg	193.33bcdefg	145.33abcd	177.80cde
150NPSBZn	62500	170.56bcdefg	192.33bcdefg	….	179.27bcde
LSD		11.79	12.65	9.13	8.49
CV		7.4	5.66	3.72	6.56

Means followed by the same letter within column are not significantly different (P<0.05)

Table 4. Effect N level and plant density on stalk lodging of maize (2016-2018)

N kg/ ha)	Density (plants /ha)	Mean Stalk Lodging					
		Bako	Tibe	Kersa	G/Washimo	Jimma	Combined
69	66666	172.33abcdef	184.00g	148.00abc	177.00e	172.33abcdef	184.00g
92	66,666	178.56ab	197.50abcdef	139.00cd	186.13abc	178.56ab	197.50abcdef
115	66,666	176.44abcd	200.33abcd	139.67bcd	186.00abc	176.44abcd	200.33abcd
138	66,666	183.89a	203.00abc	143.33abcd	191.53a	183.89a	203.00abc
161	66,666	177.33abc	208.00a	139.00cd	189.60a	177.33abc	208.00a
69	53,333	166.00cdefg	196.33abcdefg	145.67abcd	178.13bcde	166.00cdefg	196.33abcdefg
92	53,333	171.11bcdefg	190.67cdefg	147.67abcd	178.93bcde	171.11bcdefg	190.67cdefg
115	53,333	169.33bcdefg	194.17bcdefg	148.33ab	179.27bcde	169.33bcdefg	194.17bcdefg
138	53,333	174.89abcdef	203.67ab	149.67a	186.40ab	174.89abcdef	203.67ab
161	53,333	176.11abcde	200.00abcde	149.00a	185.67abcd	176.11abcde	200.00abcde
69	444,444	163.56fg	184.00g	138.67d	171.73e	163.56fg	184.00g
92	444,444	168.78bcdefg	188.17defg	139.67bcd	176.53e	168.78bcdefg	188.17defg
115	44,444	160.00g	193.33bcdefg	145.00abcd	173.33e	160.00g	193.33bcdefg
138	44,444	165.22defg	189.17defg	145.67abcd	174.80e	165.22defg	189.17defg
161	44,444	169.56bcdefg	193.00bcdefg	147.00abcd	178.93bcde	169.56bcdefg	193.00bcdefg
69	62,500	164.44efg	186.67fg	139.67bcd	173.33e	164.44efg	186.67fg
92	62,500	167.33bcdefg	188.00defg	150.00a	175.60e	167.33bcdefg	188.00defg
115	62,500	167.89bcdefg	191.33bcdefg	142.33abcd	177.27de	167.89bcdefg	191.33bcdefg
138	62,500	168.44bcdefg	187.67efg	141.33abcd	176.13e	168.44bcdefg	187.67efg
161	62,500	167.44bcdefg	193.33bcdefg	145.33abcd	177.80cde	167.44bcdefg	193.33bcdefg
150NPSBZn	62500	170.56bcdefg	192.33bcdefg	….	179.27bcde	170.56bcdefg	192.33bcdefg
LSD		3.78	12.59	9.14	11.24	6.03	5.2
CV		66.85	42.94	70.66	76.73	42.48	56.97

Means followed by the same letter within column are not significantly different (P<0.05)

Root Lodging

The combination analysis of variance revealed that a highly significant (P<0.01) effects of years, locations, treatments and interaction among them on root lodging of maize.

Maximum root lodging (11.00%) was recorded under highest plant density (66666 plants/hectare) with application of lowest N rate (69 kg N /ha). However statistically similar results were also obtained under 53333, 62500 and 66666 plants per hectare with various N rate (Table 5). The minimum stalk lodging was recorded under lowest plant density (44444 plants/ha) with application of medium (optimum) N rate, 138 kg N/ha.

Table 5. Effect N level and plant density on root lodging of maize (2016-2018)

N kg ha-1	Density (plants/ha)	Mean Root Lodging					
		Bako	Tibe	Kersa	G/Washimo	Jimma	Combined
69	66666	9.44a	10.78bcd	15.67a	11.67a	1.33bc	11.00a
92	66,666	7.33ab	10.78bcd	7.67bc	3.67bc	1.67abc	8.21bcde
115	66,666	8.00ab	13.22abc	6.67bcd	3.33bc	2.00abc	9.21abc
138	66,666	7.11ab	12.89abc	9.33ab	4.00bc	3.33abc	9.17abcd
161	66,666	7.00ab	10.44bcd	10.00ab	3.67bc	4.33ab	8.25bcde
69	53,333	7.67ab	10.67bcd	7.33bcd	11.67a	2.00abc	9.25abc
92	53,333	6.22ab	13.67abc	2.67cd	6.67b	3.67abc	8.63abcde
115	53,333	7.22ab	9.00cd	5.00bcd	3.67bc	3.67abc	7.17cdef
138	53,333	7.44ab	9.00cd	7.00bcd	3.00bc	3.00abc	7.42cdef
161	53,333	5.00b	8.56cd	7.67bc	4.33bc	3.00abc	6.58def
69	444,444	4.89b	11.33bcd	2.67cd	6.00bc	2.67abc	7.17cdef
92	444,444	5.78ab	10.67bcd	1.00cd	6.67b	3.33abc	7.13cdef
115	44,444	6.44ab	9.22cd	1.33cd	2.00c	2.00abc	6.29ef
138	44,444	4.44b	6.78d	2.00cd	3.00bc	2.6abc	4.83f
161	44,444	6.78ab	10.67bcd	2.67cd	6.00bc	5.33a	7.63cde
69	62,500	5.89ab	17.22a	3.67bcd	12.00a	0.67bc	10.61ab
92	62,500	6.78ab	15.22ab	5.67bcd	11.00a	0.33c	10.33ab
115	62,500	5.33b	13.22abc	4.00bcd	6.00bc	1.00bc	8.21bcde
138	62,500	6.78ab	10.67bcd	6.33bcd	5.67bc	1.33bc	8.04bcde
161	62,500	7.00ab	13.44abc	5.00bcd	4.00bc	2.33abc	8.79abcde
150NPSBZn	62500	6.00ab	10.89bcd	4.33bcd	5.00bc	….	7.50cde
LSD		4	4	5.2	6.62	4.06	3.87
CV		64.54	64.54	49.06	69.817	40.89	91.56

Means followed by the same letter within column are not significantly different (P<0.05)

Maize Grain Yield

The combined results of analysis showed that highly significant (P<0.01) effect of year, location, block, entry, interaction between year and entry and interaction among year location and entry on the grain yield. Maximum grain yield ha^{-1} (7835.1 kg) was obtained at the plant density of 53,333 plants/ha with the application of 115 kg N ha^{-1}. However Application of 115, 138 and 161 kg N/ha on 53,333 and 66,666 plants/ha produced similar grain yield (Table 6). The minimum yield (5506 kg/ha) was recorded under 62,500 plants/ha with application of 69 kg N/ha.

Similarly there was a highly significantly difference among treatments, replication, blocks and years in all locations. But the interaction between year and entry was shown in significant effect on grain yield at Bako, and significant effect in the rest locations. Maximum grain yield 8995 kg ha^{-1} was recorded at higher plant density (66,666 plants ha^{-1}) with application of 138 kg N ha^{-1} at Bako (Table 6). But statistically similar grain yield was recorded under application of 161 kg N ha^{-1} in the same plant densities, and with application of 115 kg N ha^{-1}, 138 kg N ha^{-1} 161 kg N ha^{-1} under 53,333 plants ha^{-1}. In case of Tibe maximum grain yield 7545 kg ha^{-1} was recorded

Table 6. Effect of N fertilizer rate and plant density on grain yield of BH661 at Bako, Tibe, Kersa, Goba Washamo, Jimma and combination effect in three consecutive years (2016-2018)

Treatment		Grain Yield (kg/ha)					
N kg ha-1	**Density (plants/ha)**	**Bako**	**Tibe**	**Kersa**	**Goba Washmo**	**Jimma**	**Combined**
69	66,666	7480bcde	5999fghij	5537bcde	5664ef	5071hi	6455def
92	66,666	7612bcd	6101efghi	5548bcde	5872def	5391fghi	6570def
115	66,666	7617bcd	7045abcd	7276ab	6609bcde	5803bcdef	7234abc
138	66,666	8995a	7006abcde	5716bcde	6320cdef	6356abc	7505ab
161	66,666	8053ab	6840abcdef	6732abcd	6626bcde	6302abcd	7254abc
69	53,333	7201bcde	6258defghi	4021e	5351f	4904i	6219efg
92	53,333	7381bcde	6272cdefghi	4344e	6916abc	5761bcdefg	6527def
115	53,333	7874ab	7545a	8507a	7920a	5529efghi	7835a
138	53,333	8074ab	7181abc	7173abc	7454ab	6089abcde	7549a
161	53,333	8227ab	7375ab	7941a	7924a	6566a	7834a
69	44,444	6452de	5695ghij	4326e	5818def	5494efghi	5823gh
92	44,444	6650cde	5746ghij	5075de	6035cdef	5621efgh	6037efgh
115	44,444	6452de	6257efghi	5299de	6618bcde	5673defgh	6256efg
138	44,444	7358bcde	6501bcdefgh	5021de	6585bcde	5836bcdef	6648cde
161	44,444	7672bc	6584bcdefg	5746bcde	6757bcd	5804bcdef	6909bcd
69	62,500	6293e	5127j	4205e	5547f	54.76efghi	5506h
92	62,500	7168bcde	5447ij	4596e	5664ef	5982abcdef	6013fgh
115	62,500	7099bcde	5828ghij	5029de	5830def	6421ab	6205efg
138	62,500	7555bcd	5966fghij	5820bcde	5985cdef	5117ghi	6546def
161	62,500	7591bcd	5836ghij	5423bcde	5978cdef	5708cdefgh	6460def
150NPSBZn	62,500	7454bcde	5612hij	5372cde	5797def	….	6296defg
LSD		12.02	9.18.06	18.74	10.17	6.67	6.28
CV		17.29	15.6	19.58	9.47	6.9	16.63
Sig level		**	**	**	**	**	**

at 53,333 plants ha^{-1} with application of 115 kg N ha^{-1}. But statistically similar grain yield was also recorded under 66,666 and 53,333 plants ha^{-1} with application of either 138 kg N ha^{-1}or 161 kg N per hectare (Table 6). Similarly at Kersa and Goba-washmo maximum grain yield was recorded at 53,333 plants ha^{-1} with application of 115 kg N $ha^{-1.}$ But statistically similar grain yield was also obtained with application of 138 and 161 kg N ha^{-1} under similar plant densities (53,333 plants per hectare). While in the fifth site (Jimma) maximum grain yield was recorded under application of maximum nitrogen level on 53,333 plants per hectare.

Economics

The economic benefits of improved agronomic practices (spacing and fertilizer level) are largely derived from increased grain yield and ultimately achieved a better price. The highest net profit (Birr 37,767.20) was obtained with a plant population of 53,333 plants ha-1 with

Table 7. Partial budget analysis of nitrogen fertilizer rates and plant densities on BH661 maize hybrid during 2016-2018 cropping season

N kg ha-1	Density (plants/ha)	GY (Quintal/ha)	SY (Tonne/ha)	TR (Birr)	NR (Birr)
69	66,666	64.55	5.808	35783.0	31981.3
92	66,666	65.70	5.91	36486.0	32073.3
115	66,666	72.34	6.51	39460.5	34436.8
138	66,666	75.05	6.750	40977.7	35343.0
161	66,666	72.54	6.52	39424.3	33178.5
69	53,333	62.19	5.59	34377.1	30969.1
92	53,333	65.27	5.87	36081.6	32062.6
115	53,333	78.35	7.04	42397.2	37767.2
138	53,333	75.49	6.78	41107.5	35866.5
161	53,333	78.34	7.04	42418.1	36566.1
69	444,444	58.23	5.23	32379.5	29234.0
92	444,444	60.37	5.42	33719.0	29962.5
115	44,444	62.56	5.62	34160.2	29792.7
138	44,444	66.48	5.97	36258.6	31280.1
161	44,444	69.09	6.20	37944.2	32354.7
69	62,500	55.02	4.94	30499.5	26827.0
92	62,500	60.13	5.40	32983.2	28699.7
115	62,500	62.05	5.57	33593.0	28698.5
138	62,500	65.46	5.87	35781.3	30275.8
161	62,500	64.61	5.79	35610	29493.5
150NPSBZn	62,500	62.96	5.65	34471.2	30756.7

GY =Grain yield; SY = Stalk yield; TR = Total return; NR = Net return

application of 115 kg N ha^{-1} followed by plant population of 53,333 plants ha-1 with application of 161 kg N ha^{-1} which resulted in net return of Birr 36,566.10 (Table 7). Ameta and Dhakur (2000) reported higher monetary return and B:C ratio of maize with narrow row spacing (60 cm) when compared to wider row spacing (75 cm). Chandankar *et al*. (2005) observed that cultivating maize at 60 cm x20 cm spacing resulted in higher net return and BCR (Rs. 19, 268 ha-1 and 2.62). Sankaran *et al*. (2005) opined that enhancement in fertilizer application to the tune of 25-50 per cent above the recommended level increased the gross, net and B: C ratio. Raskar *et al.* (2013) from Vadodara reported the highest BCR with the application of 160 kg N ha-1 than lower levels of N (80 and 120 kg ha-1) on sandy loam soil.

DISCUSSIONS

The plant height and ear height increased with increasing in plant density and N rate. The increase in the plant height at crowded plant population may be due to strong competition among the plants for sun light, while increase in plant height with increase in the rate of nitrogen application could be attributed to positive effect of N on plant growth and inter-nodal extension due to more availability of N throughout the growing period. These results are in line with the findings of Khan *et al.* (2017). Similarly Al-Naggar and Atta (2017) found that highest ear height under higher plant density and higher nitrogen rate. Plant height increased with decreases in intra-row spacing up to 13.5 cm (100,000 plant ha-1) and further decreased in intra row spacing reduced plant height (Abuzer *et al.,* 2011). Woldesenbet and Haileyesus (2016) reported that the height of maize plant increased with increasing in nitrogen rates.

Stalk lodging increase with increase in N rate and plant density. Maximum stalk lodging recorded under highest N rate and highest plant density. Increasing in plant density can aggravate competition for natural resource like nutrient, air, water and light that produced tall and week stalks which are susceptible for lodging. At the same time increasing in N rate under dense population increase vertical growth towards light or towards free space that resulted susceptible stalks for lodging. This result agreed with those of Shi *et al.* (2016) who observed higher percent of lodging at higher N rate and higher plant density.

In contrast to stalk lodging, root lodging increased with decreasing N rate. The maximum root lodging recorded under lowest N rate and highest plant density (Table 5). Nitrogen is the most important nutrient for plant growth and development. Thus plants with nitrogen starvation can produce week and short root system which are not strong enough to anchor the plant with soil when the above ground plant parts become increased and increased. Dense planting increases competition for space and nutrients among individual plant roots, which subsequently reduces root matter (Chen *et al*. 2012). The number and average diameter of aerial roots decrease with increasing plant density (Liu *et al*. 2012)

The grain yield of maize increased with increasing plant density up to optimum. Maximum grain yield was obtained under 53,333 plants per hectare at all locations except Bako. Similarly, Grain yield was also increased with increasing nitrogen rate up to optimum. The combined analysis showed that maximum grain yield (7835 kg ha^{-1}) was recorded under 53,333 plant densities with application of 115 kg N ha^{-1}.

Compared to the standard control of 44,444 plants ha^{-1} with the application of 92 kg N ha^{-1}, the mean grain yield was increased by 29 % when the maize hybrid sown at 53,333 plants ha^{-1} with application of 115kg N ha^{-1}. Similarly the results surpassed the satellite check plot by 24% (Table 2).

In general, the grain yield ha^{-1} was increased with the increase plant density and nitrogen rate, although, economically faceable grain yield was achieved under 53,333 plants per hectare with application of 115 kg N ha^{-1}. However increased maize plant density above optimum can increased lodging that resulted reduction in grain yield

The positive relationship between grain yield and plant density was due to the high number of plants per unit area. The increased in maize grain yield under high plant density might be due to efficient utilization of available resources like nutrient, water, air and solar radiation. Maize hybrids can be grown up to 76,500 plants ha^{-1} with no adverse effect on yield or grain quality (Gözübenli, 2010). Leaf area index and light interception increased with increasing in planting density (Shakarami and Rafiee, 2009). Farnia *et al.,* (2015) reported that plant shortage per unit area prevents maximum usage of production parameters while over density can increase the competition and decrease the yield. Higher grains yield at higher nitrogen levels might be due to the lower competition for nutrient and positive effect of N on plant growth, leaf area expansion and thus increase solar radiation use efficiency which indirectly increases dry matter production for grain filling that ultimately increases in grain yield (Golla *et al*, 2018). This result is in line with many workers (Gözübenli, 2010; Shrestha, 2013; Golla *et al,* 2018).

SUMMARY AND CONCLUSION

The grain yield of BH661 maize hybrid tends to increase with increasing plant population and N fertilizer level up to optimum. Maximum grain yield ha^{-1} (7835 kg) was obtained under plant densities of 53,333 plants ha^{-1} with the application of 115 kg N ha^{-1}. This grain yield result exceed by 29% and 24% compared to the grain yield of standard check and satellite check respectively. Similarly application of 115 kg N ha^{-1} under 53,333 plant densities was economically the most profitable compared to other combinations. Thus this hybrid should be sown with 53,333 plants ha^{-1} (75 cm x 20 cm spacing) with application of 115 kg N ha^{-1} to ascend its production by 20% from current production status.

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