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Performance evaluation of intermediate maturing maize hybrid variety under different nitrogen levels and plant population density in West Shewa and East Wellega zone of Oromia region, Ethiopia

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Abstract
The experiment was conducted from 2019 to 2021 year to identify an optimum plant population and rate of N on BH546 maize hybrid variety at Bako National Maize Research Center study site and Ilu Gelan District. The experiment has two factors: three N rate (134, 180 and 226 kg ha^{-1}) and four plant population density (62,500, 71428, 83,333 and 100,000 plants ha^{-1}). Totally 12 treatments were accommodated in the experiment. ANOVA indicated that at Bako and Ilu Gelan, plant and ear height were significantly (p<0.05) influenced by plant population density. While at Bako, plant and ear height were influenced by main factor of N rates. Grain yield was significantly influenced by the main factor of N rates at both Ilu Gelan and Bako. At Ilu Gelan, it was also significantly affected by the main effect of plant population and the interaction effect of N rates and plant population. At Ilu gelan, 100,000 plant ha^{-1} delayed days to 50% male flowering. At this plant population, the maximum lodging percentage was recorded. The maximum grain yield (6437 at Ilu Gelan) and (7926 at Bako kg ha^{-1}) was observed at N rate of 226 kg ha^{-1} followed by grain yield recoded at N of 180 kg ha^{-1} at both location. The maximum grain yield 6671 kg ha^{-1} was observed at N rate of 226 kg ha^{-1} with 83,333 plant ha^{-1}. Application of N at the rate of 226 kg ha^{-1} with combination of 83,333 plants ha^{-1} was the most profitable of all the treatments, followed by plant population of 71,428 plants ha^{-1} with 134 kg of N rate ha^{-1} and 62,500 plants ha^{-1} with 226 kg ha^{-1} N rate. Thus, BH546 at plant population of 71,428 plants ha^{-1} with 134 kg of N rate ha^{-1} was suggested for producers around study areas and other areas having similar agro ecologies as it is economically feasible and easily accessible than the rest all treatments. Further investigation on time of N application supported by tissue analysis is mandatory.

Keywords: Ear height, grain yield, harvest index, kernels ear 1, plant height

1. Introduction

Maize (*Zea mays* L.) is the predominant crop of the world. It was originated in Central America and was brought to West Africa in the early 1500s by the traders of Portuguese (Dowswell *et al*., 1996) [18]. Maize was introduced to Ethiopia meanwhile 1600s to 1700s (Haffangel, 1961) [25]. About 30% of the total world production is used for human consumption directly and input for industry; while 70% is used as feed for animals (Turrent-Fernandez and Serratos-Hernandez, 2004) [53].

Next to wheat and rice, maize is the third most essential grain crop in the world (CGIAR, 2016) [11]. In case of Ethiopia, it is the second widely produced grain cops and is grown under diverse agro-ecologies and socioeconomic conditions (Tsedeke *et al*., 2017) [52]. Predominantly, it is produced during the main season known as meher from May-September rainfall (Dawit *et al*., 2014) [15]; mostly between 50° latitude north and south of the equator and from sea level to 3000 M.A.S.L. (Dowswell *et al*., 1996) [18]. In Ethiopia, the mid and lowland sub-humid agro-ecologies are the high potential areas for maize production (Alemu *et al*., 2019) [4].

Maize is serving as a potential food security crop in South America, Africa and China. In Africa, maize is used for making of bread and as a starchy base in the form of grits, porridges, pastes and beer. Grain of green maize is eaten baked, parched, roasted or boiled and has an important role in combating the starvation after dry season. In sub-Saharan African countries, maize is a basic food for about 50% of the population and provides 50% calories (CGIAR, 2016) [11]. In case of Ethiopia, it constitutes about 60% of the caloric intake of household (Dawit *et al*., 2014) [15].

Maize cultivation is mostly by smallholder farmers; comprising of about 80% of Ethiopia's population and producing over 95% of the total maize. Indubitably, the crop has great importance in the livelihood of most Ethiopians population. In Ethiopia, cereal is the most widely produced grain crops which contributed about 88.36% (302.05 million quintals) of the grain production. Of cereals, maize holds the lion shares (30.88%) with 10.56 million tonnes annual production (CSA, 2021) [14]. Now, maize is produced on an area of about 2.52 million ha with average production of 10.56 million tonnes and national average yield of 4.18 t ha^{-1} (CSA, 2021) [14]; which is far below the world's average productivity which is 5.83 t ha^{-1} (FAOSTAT, 2019) [20].

The low yield from farming could be ascribed to disappointment of the farmers to implement good agricultural practices. However, crop production is encountered with various controllable dares like untimely planting, inappropriate plant spacing, wrong planting method, inappropriate sowing depth, weed infestation, insect pests and diseases problems, inappropriate use of fertilizers and untimely harvesting (Karaye *et al*., 2017 and Zhou *et al*., 2019) [29, 61]. Moreover, poor soil fertility, nutrient management and low yielding cultivars are some of the principal factors limiting maize productivity in Ethiopia (Aticho *et al*., 2011; Dawit *et al.*, 2014; Tena and Beyene, 2011) [8, 15, 48].

Optimum agronomic practices which help to boost production and productivity for released/cultivated varieties are very important, however, it varies with location, season and cultivars. So, to maximize maize productivity per unit area of land, location, season and cultivar based optimal crop management practices are too important. So far, Feyisa (2020) [21] recommended 100 kg ha^{-1} of NPS as an optimum rate and economically feasible in relatively uniform rainy seasons while, during erratic and heavy rainy seasons, 125 kg ha^{-1} of NPS could be used to obtain higher net benefit around Bako area for BH661 maize hybrid which is classified under late maturing maize group. Moreover, Begizew *et al.* (2019) found BH661 maize hybrid gave the highest yield at plant population of 53333 plants ha^{-1} with 115 kg N ha^{-1}. Also, Abebe and Feyisa (2017) [1] recommended 92 N kg ha^{-1} in split application half at 10–15, and the rest half at 35–40 days after planting for BH661 maize hybrid. While, in the case of erratic and heavy rainfall areas, application of 92N kg ha^{-1} at three rounds: 1/3 N at 10–15, 1/3 N at 35–40 and 55–60 days after planting were suggested to get maximum profit and acceptable marginal rate of return.

However, for all agricultural crops, optimal agronomic practices are varies with species (even varieties), soil and atmospheric factors and production season. This truly stands for maize, as the productivity of maize genotypes varies with location, year, soil types, rainfall (distribution and amount), fertilizer rates, plant population density and the others. Even within the maize hybrid and inbred lines, the optimal crop management practices are varies for late maturing and intermediate maturing maize groups. Thus, the study was focused on studying BH546 maize hybrid against different N rates and plant population densities. Thus, the objective of this research was to identify an optimum plant population density and N rate for BH546 which may gave the highest grain yield and maximum net benefit (acceptable marginal rate of return).

2. Materials and Methods

2.1 Description of Experimental Site

The experiment was undertaken at Ilu Gelan District West Shewa Zone and on Bako research station for three consecutive main cropping season (2015-2017). The study area has the following weather and geographic characters (Table 1)

Table 1: Study area's geographic and weather description

Zone	Wereda	Annual Rainfall (mm)	Temp. (^{0}C)	Altitude (masl)	Latitude (N)	Longitude (E)
East Wellega	Gobu seyo at BNMRC study site	830-1658	13 - 27	1556- 2580	9°01'01" - 9°20'33"	36°53'11" -37°03'06"
West Shewa	Ilu Gelan	1600-2290	27.3°	1665 - 1790	08°59'51"	37°19'49"

Source: (Gemechu *et al*., 2015; Eshetu *et al*., 2020; Urgessa and Fekadu, 2021)

2.2 Soil sampling and physicochemical properties analyzed

Soil sample was taken from both experimental area in diagonal pattern at 5 m interval. From each sampling spot, soil sample were taken at a depth of 20 cm by sampling auger. The collected soil samples were mixed thoroughly, then nearly 1 kg soil was taken from the composite sample for study at laboratory. The composite soil sample was air dried, grounded to pass through 2 mm sieve and analyzed for texture class, available Phosphorus (ppm), Organic Carbon (OC%), Total Nitrogen (N%), Cation exchange capacity (CEC cmol/100 g soil) and potential of hydrogen (pH). However, for the rest soil chemical properties, the chemicals were not available. The result of soil physiochemical properties tested/studied at BARC was is illustrated in (Table 2) for Bako experimental site and in (Table 3) for Ilu Gelan experimental area.

Soil textural class the experimental area were analyzed using hydrometer method. The result indicated that textural class of experimental area at Bako was sandy clay and that of Ilu Gelan was Clay. The total nitrogen was analyzed using Kjeldahl method by digestion of soil (copper sulphate-potassium sulphate catalyst). The pH was measured by Potentiometer in the ratio of 1:2.5 soil to water suspension. Available P was examined using Bray-II process and calorimetrically used vanadomolybedate acid as an indicator. CEC was determined by using NH_4 AC extraction ammonia distillation method. OC was measured by Walkley-Black wet oxidation method and converted to OM by multiplying the value of OC by 1.724.

Table 2: Soil physiochemical properties of experimental area at Bako (On research station)

Experimental area	Soil Chemical Properties						Soil physical properties		
	TN (%)	Av. P (ppm)	CEC (cmol/100g soil)	OC (%)	OM	pH	Clay (%)	Sand (%)	Silt (%)
Bako	0.11	7.15	24	1.25	2.15	4.88	42	51	7
Status	Low	Low	Low	Low	Low	moderatly acidic			
Textural class							Sandy Clay		

Av. Pppm = available phosphorus in parts per million, TN = total nitrogen, CEC (Cmolkg^{-1}) = cation exchange capacity in cent mole per hundred

gram of soil, pH= hydrogen power, OM = percent of organic matter, OC = percent of organic carbon
Source: Horneck, *et al*. (2011) [27]

Table 3: Soil physiochemical properties of experimental area at Ilu Gelan

Exper. area	Soil Chemical Properties						Soil physical properties		
	TN (%)	Aval. P (ppm)	CEC (cmol/100g soil)	OC (%)	OM (%)	pH	Clay (%)	Sand (%)	Silt (%)
Ilu Gelan	0.30	9.14	47	3.51	6.05	5.75	58	25	17
Status	Very low	Very Low	high	low	Very high	Moderately Acidic			
Textural class							Clay		

Source: [Horneck, *et al*. (2011); Ping *et al*. (2014) [27]]

2.3 Description of Experimental Materials
Maize hybrid variety BH546 which come from pedigree CML 395/CML202//BKL001 was used for this experiment. Urea (46% N) was used and a primary source of N. As a source of Phosphorus and sulfur NPS (19%N, 38% P2O5, and 7% S) fertilizers were used, also NPS used N source.

2.4 Treatments and Experimental Design
Two factors: three N rate: 134, 180 and 226 kg ha^{-1}) in the form of urea and four plant population levels: 62,500, 71428, 83,333 and 100,000 plants ha^{-1} planted at intra row spacing of 40, 35, 30 and 25 cm respectively. Meanwhile of the experiment, BH546 was planted at inter row spacing of 80 cm. uniformly, 100 kg ha^{-1} of NPS was applied at the time of planting.
The experiment was laid out in randomized complete block design (RCBD) in factorial arrangement (4*3) and each treatments was replicated three times. An experimental unit (a plot) has a length and width of 4m (16 m^2 plot area). Experimental units within a block received the treatments at random. Blocks and plots were separated by 2 m and 0.5 m wide space respectively.

2.5 Experimental Procedures
Experimental site was ploughed three times from March to May by using tractor plough. Inter row spacing (distance between one furrow to the next farrow) was manipulated at 80 cm distance. Maize seed sowing was done in the first week of June by placing three seeds per hole at a specified intra row spacing. Meanwhile of seeding, full dose of NPS was applied evenly to all experimental units at the depth of 2.5-5 cm around the seed with side-banding method. Before emergency, Primagram gold was applied to suppress weed emergency at the rate of 3l/ha. After almost all seeds germinated (two weeks after planting under normal condition), seedlings were thinned to two plant per hole by keeping a good stand seedlings. Half dose of N fertilizer was applied at 21-25 days after sowing and the remaining half dose was applied at 40-45 days after sowing. Once the specified rates of urea placed approximately 5-7 cm distance from the plant, it must be covered immediately with soil due to its volatility nature (www.extension.umn.edu).
All the necessary crop management practices were evenly applied to all experimental units as per the recommendation for maize. Finally, plants in the central rows were used for data collection and analysis.

2.6 Data Collected
In this experiment data were taken from five representative randomly selected plants for some parameters and from net plot areas for the rest parameters. Generally, growth, phonological and yield parameters data were collected.

Days to 50% tasseling
Number of kernels per ear: Days to 50% silking
Thousand kernels weight (g): Plant height (cm)
Grain yield (kg ha^{-1}): Ear height
Harvest index: Lodging

2.7 Data Analysis
The collected data were subjected to ANOVA using SAS software version 9.3 following a procedure appropriate to a randomized complete block design. Comparison of treatment means was done using the Fisher's least significant difference (LSD) test at 5% probability.

3. Results and Discussion
3.1 Maize Growth, Development and Yield Characters
3.1.1 Maize Plant and Ear Height (cm)
At both location, plant height and ear height were significantly (p<0.05) influenced by the main effect of plant population density. Also, the main factor of N rates exerted significant effect on plant and ear height only at Bako. N at a rate of 226 kg ha^{-1} gave the tallest plant height (267.4 cm) and ear height (138.3cm) at Bako which is significantly similar with plant and ear height recorded at 180 kg ha^{-1} N at the thame area. While, the shortest plant (257.5 cm) and ear height (131.5 cm) was recorded at 134 kg N ha^{-1}. From the result, as N rate increased, the plant and ear height of BH546 Maize hybrid increased in parallel. The tallest plant and ear height was observed at plant population of 100,000 plants ha^{-1} which is significantly similar with plant and ear height recorded at plant population of 83,333 plants ha^{-1}. While, the shortest plant and ear height was recorded at 62,500 plants ha^{-1} at both locations (Table 4). From the result, as plant population increased the plant and ear height of BH546 Maize hybrid increased linearly.
Similarly, Tekulu *et al.* (2019) [47] reported that plant height of maize was significantly influenced by NPSZnB levels in Laelay Adiyabo district but not in Medebay Zana district. Plant growth and development probably retarded if any of the nutrient is under its threshold value in the soil or not sufficiently balanced with other nutrient. High N and P nutrient elongates basal internode which in turn maximize the ear and plant height of maize (Rajkumara 2008) [42]. Moreover, increment in plant height is probably due to increase in cell elongation and greater vegetative growth at the return of different nutrient contained in NPSZnB fertilizer contribute for plant growth (Tekulu *et al.*, 2019) [47].
Higher plant population density lead to the weaker plants of more height (Chandiposha and Chivende, 2014) [12]. Similarly, Zhang *et al.* (2006) [59] report indicated as the taller plant resulted under the highest planting density. The greater plant density increases internode elongation and decreases the duration of rapid internode thickening, results in increased internode length and decrease in stalk diameter (Gou *et al*. 2007; Novacek *et al*. 2013; Xue *et al.*, 2016a) [24, 36, 58]. The length of internodes below the ear increases as plant density increases, causing ear and plant height to increase.

3.1.2 Days to 50% Male and Female Flowering

Population density of BH546 maize hybrid exerted significant effect ($p<0.01$) on days to 50% male flowering at Ilu gelan. However, at both Ilu gelan and Bako (On research station), days to male flowering (tasseling) was not ($p\geq0.05$) significantly affected by the main effect of N rates and the interaction of N rates and plant population densities. Days to 50% female flowering (silking) was significantly ($p<0.01$) affected by the main effect of N rates and plant population density at Ilu Gelan District. But, at Bako research station site, days to 50% female flowering was not statistically significantly affected by the main effect of N rates and plant population density. At both location, both days to 50% male and female flowering was not significantly affected by the interaction effect of plant population density and N rates (Table 4). At Ilu gelan, 100,000 plant population ha^{-1} delayed days to 50% male flowering up to 81.26 days from planting ((Table 4). From the result, not only the above ones but also environmental factors influence the appearance stage of phonological characters.

In line with current finding, Amanullah *et al.* (2009) [5]; Ashraf *et al.* (2016) [7] found that, all the phenological characters (tasseling, silking, and maturity), were significantly affected by plant population density. Also, the number of days to silking was affected by plant population density where by the days to tasseling under 55555 plants ha^{-1} was significantly lower (49.0 days) than that obtained under 83333 plants ha^{-1} (Shrestha *et al*., 2018) [45]. Light is critical to measure day length and phenology of plants. Competition for light and water delayed silk emergence and results in anthesis silking interval problem [Smith *et al*. (1982) [46]; Westgate (1994) [55]]. This indicate that in case of high plant density, there is extreme competition for light which result elongated plant height and delay the appearance of tasseling and silking stage.

Table 4: Main effect of nitrogen levels and plant population density on phonological and growth characters of BH546 maize hybrid at Bako (On research station) and Ilu Gelan District from 2019 to 2021 production season

N kg ha^{-1}	MF		FF		PH		EH	
	IG	Bako	IG	Bako	IG	Bako	IG	Bako
134	80.69	82.69	84.11	86.33	283.2	257.5^{b}	149.5	131.5^{b}
180	80.42	82.86	83.72	86.58	282.0	263.3^{a}	147.6	136.1^{a}
226	80.03	82.14	82.89	85.64	283.0	267.4^{a}	151.8	138.3^{a}
LSD $_{(5\%)}$	NS	NS	1.493	NS	NS	11.33	NS	8.54
F-test			**			*		**
PD/ha								
62500	79.37^{b}	81.89	82.44^{b}	85.19	273.6^{b}	256.3^{b}	141.9^{b}	127.0^{c}
71428	79.74^{b}	82.41	82.85^{b}	85.67	278.3^{b}	265.2^{a}	143.1^{b}	135.5^{b}
83333	81.15^{a}	82.96	84.26^{a}	86.78	288.9^{a}	264.1^{a}	154.9^{a}	137.5^{ab}
100000	81.26^{a}	83.00	84.74^{a}	87.11	290.1^{a}	265.3^{a}	158.6^{a}	141.3^{a}
LSD $_{(5\%)}$	1.47	ns	1.49	ns	15.83	11.33	12.71	8.54
F test	**		**		**	**	**	**
N*PD	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	2.0	4.1	1.9	6.0	6.0	4.6	9.1	6.7

N Kg ha-¬1 = Nitrogen level in kg ha 1, PD ha-1 = plant population density per hectare, MF = days to 50% male flowering, FF= days to 50% female flowering, PH=Plant height in cm, EH = ear height in cm, IG = Ilu Gelan, N*PD = Interaction of nitrogen rate and plant population density
Means within columns followed by different letter (s) for each variable are significantly different at ($p<0.05$)
*, and **, statistically significant at $P\leq0.05$, $p\leq0.01$ probability levels respectively; ns= not significant

3.1.3 Stalk Lodging (%)

Plant population density exerted significant effect on lodging percentage of BH546 Maize hybrid. While, lodging percentage was not significantly ($p\geq0.05$) influenced by main effect of N rates and the interaction of N rates and plant population density (Table 5). Lodging percentage was high (19.82) at highest plant population density (100, 000 plants ha^{-1}) which is significantly the same with lodging percentage recorded at plant population density of 83, 333 and 71, 428 plants ha^{-1}. While, at low plant population, the lodging percentage was also significantly low (Table 5).

The lowest stalk lodging was noted at lowest plant population density (44444 plants/ha). Greater plant population's results weaker plants of more size which prone to lodging and disease (Chandiposha and Chivende, 2014) [12]. In fact, as plant population density increases the plant height, internode length and ear height also increased. The Pickett *et al.* (1969) [39] reported that maize stalk lodging is associated with plant height, number of internodes above the ear, ear height, stalk diameter, and length of internodes below the ear. Stalk lodging is positively associated with basal internode length (Esechie 1985) [19], but negatively associated with basal internode diameter (Martin and Russell 1984; Novacek *et al*. 2013) [34, 36]. High plant population density limits light intensity reaching the canopy of maize, consequently hindering the light destruction (photo destruction) of auxin. More auxin rises the rate of internode elongation, results longest internodes (Tetio-Kagho and Gardner 1988) [49]. Xue *et al*. (2016a) [58] found that high plant density increases the rate of quick internode elongation and declines the duration of rapid internode thickening, resulting internodes to increase in length and decrease in diameter.

3.1.4 Thousand Kernels Weight (g) and Number of Kernels per Ear

Thousand kernel (seed) weight was not significantly ($p\geq0.05$) affected by the main effect of N rates, plant population density and their interaction at both Ilu gelan and Bako on research site. The number of kernels ear^{-1} were significantly ($p<0.05$) affected by the main effect of N rates at Ilu Gelan, but not at Bako. To the reverse, the number of kernels ear^{-1} were significantly ($p<0.05$) influenced the main effect of plant population density at Bako, but not at Ilu Gelan (Table 5).

Significantly, the maximum number of kernels ear^{-1} (494.1) were recorded at N rate of 180 kg ha^{-1} which significantly similar with kernels number recorded at N rate of 226 kg ha^{-1}. While, the lowest number of kernels ear^{-1} was noted at N rate of 134 kg ha^{-1}. The result obtained at Bako national maize research Center study site indicated that: at low planting density (62,000), the number of kernels ear^{-1} was high (578.5) which is significantly the same with number of kernels ear^{-1} recorded at plant density of 71, 428 and 83, 333 plants ha^{-1}. The lowest number of kernels ear^{-1} was recorded at planting density of 100,000 plants ha^{-1} (Table 5). Besides of plant population density and N rates, number of kernels per ear were also influenced by environment.

Maize ear length and yield components decreased with the increasing plant population. Kernels per ear significantly varied with plant density and ranged from 447 to 675 in 2019 and from 375 to 0712 in 2020 (Djaman *et al.* 2021) [17]. Westgate *et al.* (2017) [54] reported that in densely sown crops plants produced smaller ears, fewer kernels per ear and less grain weight per ear. Moreover, Prior and Russell (2019) revealed an increased kernel weight with planting density up to 51,000 plants ha^{-1}, followed by kernel weight decreasing with rises of plant population up to 72,000 plants ha^{-1}.

Furthermore, Lemcoff and Loomis (1994) [31] and Tollenaar and Wu (1999) [50] suggested that the use of higher plant density reduced grain size, number of grains per row and per plant. They also advocated that high plant population beyond optimal leads to severe interplant competition for photo assimilate, soil water and nutrients of soil. The increased plant population density causes extended time interval between anthesis and silking which reduces kernel number per ear, enhances barren plant number and caused kernel abortion [Lemcoff and Loomis and (1986); Hashemi-Dezfouli and Herbert (1992) [32, 26]].

3.1.5 Harvest Index (HI)

The result indicated that harvest index (HI) of BH546 maize hybrid was not statistically significantly ($p \geq 0.05$) affected by the plant population density, N rate and the interaction of both factors at Ilu Gelan. However, it was statistically significantly ($p<0.05$) influenced by both the main effect of plant population densities and N rates at Bako on study site. Although, not by the interaction of the main effects (Table 5). N at the rate of 226 kg ha^{-1} gave the maximum HI (0.68), While, the lowest HI (0.59) was recoded at 134 kg ha^{-1} N rate. In the case of plant population density, the maximum HI (0.68) was noted at less dense plant population (62,500 plants ha^{-1}), while, the rest HI was significantly the same and considered as the lowest (Table 5). From the result HI was decreased in parallel with increasing plant population density, to the reverse, it was increased with increasing N rate at Bako.

3.1.6 Grain Yield (kg ha^{-1})

Grain yield was significantly ($p<0.05$) influenced by the main factor of N rates at both Ilu Gelan and Bako. At Ilu Gelan, it was also statistically significantly influenced by the main effect of plant population density and the interaction effect of N rates and plant population density. In the contrary, grain yield was not significantly affected by the main effect of plant density at Bako (Table 5). Accordingly, significantly the highest grain yield (6437 at Ilu Gelan) and (7926 at Bako kg ha^{-1}) was recorded at N rate of 226 kg ha^{-1} which is significantly at par with grain yield recoded at 180 N kg ha^{-1} at both location. While, the lowest grain yield was recorded at 134 kg ha^{-1} of N (Table 5). The result indicated that grain was ranged from 4674 kg ha^{-1} to 6671 kg ha^{-1} at Ilu Gelan. Significantly the maximum grain yield (6671 kg ha^{-1}) was recorded at N rate of 226 kg ha^{-1} in combination with 83,333 plant ha^{-1}. However, it is not significantly differed from grain yield recorded at N rate of 226 kg ha^{-1} in combination with all levels of plant population density, 180 and 134 N rate in combination with all plant population density except at 62,500 plant population ha^{-1} (Table 6). However, the result was not consistent across the environment, thus, grain yield is greatly affected by environment.

The highest grain Yield of BH546 maize hybrid was noted at higher plant population density (66666 plants ha^{-1}) in combination with application of 161 kg N ha^{-1} at Bako. Dias *et al.* (2019) [16] reported an optimum plant population density of 78,500 plants ha^{-1} for maize hybrid DKB390 and 71,000 plants ha^{-1} for BG7049YH maize hybrid from different plant population densities ranging from 60,000 to 90,000 pph in Brazil. At Laelay Adiyabo district maize grain yield was significantly influenced by NPSZnB fertilizer rates whereby unfertilized plots gave lower yield as compared to 150, 200, 250, 300 and 350 rates of NPSZnB kg ha^{-1} (Tekulu *et al*. 2019) [47].

Akbar *et al.* (2016) [3] reported that optimum plant population density gave greater yield due to soil nutrients utilization more powerfully. The author also found lower grain yield with highest plant population density as of smaller ear size, less number of ear plant^{-1} due to more competition for factors important for growth. Moreover, some scholars have an opinion that maize grain yield normally revealed a quadratic response to plant density; while a gradual decreased yield rate increase relative to density increase, and lastly a yield plateau at some relatively high plant population density [Ottman and Welch (1989); Novacek *et al*. (2013) [38, 36]]. This might be due to the rational that higher plant population increases plant sterility and extends the interval between male and female flowering, and resulted decreased the number of grain ear^{-1} [Sangoi *et al.* (2002); Liu *et al.* (2004) [43, 33]].

Table 5: Main effect of nitrogen rate and plant density on yield and yield characters of BH546 at Bako (On research station) and Ilu Gelan District from 2019 to 2021 production season

N kg ha^{-1}	L	TSW		KPE		HI		GY Kg ha^{-1}	
	Bako	IG	Bako	IG	Bako	IG	Bako	IG	Bako
134	15.51	337.7	319.7	452.0^{b}	568.7	0.54	0.59^{c}	5356^{b}	6721^{b}
180	17.53	342.2	321.0	494.1^{a}	537.2	0.56	0.63^{b}	5785^{ab}	7295^{ab}
226	15.80	349.8	331.3	484.3^{ab}	522.8	0.55	0.68^{a}	6437^{a}	7926^{a}
LSD (5%)	NS	NS	NS	73.56	NS	NS	0.037	717.35	1568.39
F-test				*			**	*	*
PD/ha									
62500	11.36^{b}	349.9	322.2	471.0	578.5^{a}	0.57	0.68^{a}	5304	7029
71428	16.84^{ab}	348.0	327.7	483.7	570.3^{a}	0.59	0.63^{b}	6072	7079
83333	17.12^{ab}	345.1	328.2	490.7	556.0^{a}	0.54	0.62^{b}	6114	7381
100000	19.82^{a}	330.0	318.0	461.8	466.9^{b}	0.51	0.60^{b}	5947	7768
LSD (5%)	6.39	NS	NS	NS	82.25	NS	0.043	NS	NS
F test	*				*		*		
N*PD	NS	NS	NS	NS	NS	NS	NS	*	NS

CV (%)	16.3	15.1	8.3	16.5	15.5	23.2	12.7	14.5	22.9

L= Lodging percentage, TSW = thousand seed weight in gram, KPE = number of kernels ear 1, HI = Harvest Index, GY (kg ha¬-1) = grain yield in kilogram hectare, IG = Ilu Gelan, N*PD = Interaction of Nitrogen grate and Plant population density

Means within columns followed by different letter (s) for each variable are significantly different at ($p<0.05$) *, and **, significant at $p\leq0.05$, $p\leq0.01$ probability levels respectively; ns= not significant

Table 6: Interaction effect of nitrogen rate and plant density on grain yield of BH546 at Ilu Gelan District (2019-2021 production season)

N rates kg ha^{-1}	Plant Population density			
	62500	**71428**	**83333**	**100000**
134	4674^{c}	6162^{ab}	5347^{abc}	5241^{abc}
180	4800^{bc}	5896^{abc}	6324^{a}	6118^{ab}
226	6438^{a}	6157^{ab}	6671^{a}	6483^{a}
LSD $_{(0.05)}$ 1434.69				
CV (%) 14.5				
F- test *				

Means shared different letter (s) are significantly different at ($p<0.05$)

3.2 Partial Budget Analysis
3.2.1 Net Benefit and Marginal Rate of Return Analysis
From net benefit analysis, planting of BH546 at plant population of 83,333 plants ha^{-1} in combination of N rate of 226 kg ha^{-1} gave the maximum net benefit (25595.49 ETBr.), sequentially followed by net benefit obtained at plant population density of 71,428 plants ha^{-1} in combination with 134 kg of N rate ha^{-1} and 62,500 plants ha^{-1} with 226 kg ha^{-1} N rate with respective net benefit of 25, 265.89 and 24240.29 ETBr. As indicated in (Table 7).

From net benefit analysis, planting of BH546 at plant population of 83,333 plants ha^{-1} in combination with N rate of 226 kg ha^{-1} gave the maximum net benefit (25595.49 ETBr.), sequentially followed by net benefit obtained at plant population density of 71,428 plants ha^{-1} with 134 kg of N rate ha^{-1} and 62,500 plants ha^{-1} with 226 kg ha^{-1} N rate with respective net benefit of 25, 265.89 ETBr. and 24240.29 ETBr.

From the result, N at a rate of 226 kg ha^{-1} with combination of 83,333 plants ha^{-1} was the most profitable of all the treatments, followed by net benefit obtained at plant population density of 71,428 plants ha^{-1} in combination with 134 kg of N rate ha^{-1} and 62,500 plants ha^{-1} with 226 kg ha^{-1} N rate. However, in average, farmers are not using more than 90 kg ha^{-1} of N. Furthermore, the second most profitable treatment: 71,428 plants ha^{-1} in combination with 134 kg of N rate ha^{-1} on which the maximum marginal rate of return (20.42) recorded was economically feasible and easily accessible than the rest all treatments (Table 7).

In most cases, growers prefer the highest profit (low cost and high income) (Boughton *et al*., 1990; CIMMYT, 1988) [10, 13]. Thus, using plant population of 71,428 plants ha^{-1} with 134 kg of N rate ha^{-1} is advisable than using 62,500 plants ha^{-1} with 226 kg ha^{-1} of N rate and 83,333 plants ha^{-1} with N rate of 226 kg ha^{-1} as 226 kg ha^{-1} of N may not be applicable with almost all farmers.

Table 7: Net benefit, Dominance and marginal rate of return analysis for BH546 maize hybrid under different plant population and N rates at Ilu Gelan from 2019-2021 production year

Treatments		GY	AGY	TC (ETBr.)	GFB (ETBr.)	NB (ETBr.)	MRR%	Rank
N kg ha^{-1}	PP ha^{-1}							
134	62000	4674	4206.6	62466.91	67305.60	4838.69		
134	71428	6162	5545.8	63466.91	88732.80	25265.89	20.4272	1
134	83333	5347	4812.3	64466.91	76996.80	12529.89D		
180	62000	4800	4320	65466.91	69120.00	3653.09D		
134	100000	5241	4716.9	65966.91	75470.40	9503.49	11.7008	
180	71428	5896	5306.4	66466.91	84902.40	18435.49	17.864	
180	83333	6324	5691.6	67466.91	91065.60	23598.69	5.1632	
226	62000	6438	5794.2	68466.91	92707.20	24240.29	0.6416	
180	100000	6118	5506.2	68966.91	88099.20	19132.29D		
226	71428	6157	5541.3	69466.91	88660.80	19193.89	0.1232	
226	83333	6671	6003.9	70466.91	96062.40	25595.49	6.4016	
226	100000	6483	5834.7	71966.91	93355.20	21388.29D		

D = Dominance, N = nitrogen in kg per hectare, pp = plant population hectare 1, GY = Grain yield in kg per hectare, AGY = Adjusted grain yield in kg per hectare, TC = Total cost, GFB =Gross field benefit, NB =Net benefit, MRR = Marginal rate of return in percent.

4. Conclusions
From the result, most of the growth, developmental and yield traits were significantly affected by the main effect of plant population density at both location. Also the main factor of N rates exerted significant effect of some growth, phonological and yield characters. However, the result was not consistent across the location.

The result indicated, N at the rate of 226 kg ha^{-1} gave the tallest plant height (267.4 cm) and ear height (138.3 cm) at Bako. The tallest plant and ear height was recorded at plant population of 100,000 plants ha^{-1}. At Ilu gelan, 100,000 plant ha^{-1} delayed days to 50% male flowering. At this plant population, the maximum lodging percentage was recorded. The highest grain yield (6437 at Ilu Gelan) and (7926 at Bako kg ha^{-1}) was recorded at N rate of 226 kg ha–1 followed by grain yield recoded at 180 N kg ha^{-1} at both location. The maximum grain yield 6671 kg ha^{-1} was recorded at N rate of 226 kg ha^{-1} in combination with 83,333 plant ha^{-1}.

Generally, application of N at the rate of 226 kg ha^{-1} with plant population of 83,333 plants ha^{-1} gave the highest net benefit of all the treatments, followed by plant population of 71,428 plants ha^{-1} with 134 kg of N rate ha^{-1} and 62,500 plants ha^{-1} with 226 kg ha^{-1} N rate. However, in average farmers are not using more than 90 kg ha^{-1} of N. Thus, BH546 at plant population of 71,428 plants ha^{-1} with 134 kg of N rate ha^{-1} was recommended for growers as it is economically feasible and easily accessible than the rest all treatments. Further it's better to study on time of N application supported by tissue analysis is mandatory.

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