**Grain Yield Response of Hybrid Maize to Plant Population and Nitrogen Rate in Northwestern Ethiopia**

\*Agegnehu Shibabaw, Bitwoded Derebe, Yechale Mengie, Oumer Beshir, Wudu Getahun, Sefie Wale, Alemayehu Assefa and Anteneh Abewa

Amhara Region Agricultural Research Institute

Adet Agricultural Research Center

P. O. Box 08, Bahir Dar, Ethiopia  
\*Corresponding author e-mail: [agegnahus@yahoo.com](mailto:agegnahus@yahoo.com)

## Abstract

Field experiments were conducted to determine optimal planting density and nitrogen rate on hybrid maize in northwestern Ethiopia. Experiments were conducted in the Jabitehinan district using late maturing hybrid maize variety (BH-661) and in the Mecha and south Achefer districts using the medium-maturing hybrid maize variety (BH-546) in the 2021/2022 main rainy season. The treatments consisted of factorial combinations of five plant populations and four nitrogen rates. In the case of late maturing variety plant populations of 44,444 plants ha-1 (75 cm\*30 cm), 60606 plants ha-1 (55 cm\*30 cm), 76923 plants ha-1 (65 cm\*20 cm), 90909 plants ha-1 (55 cm\*20 cm), and 55,555 plants ha-1 (80 cm\*45 cm), which were two plants per hill as check and four nitrogen rates (128, 197, 266 and 335 kg ha-1) for late maturing varieties. The same treatment setup up used for the medium maturing variety except for the change on a double hill, i.e.,62,500 plants ha-1 (80 cm\*40 cm), which was two plants per hill as checked. Data on plant height, cob length, cob diameter, stover, and grain yield were collected and analyzed through SAS system. The results showed that plant height, cob length, cob diameter, stover, and grain yield were significantly *(P<0.01)* affected by the main effects of planting density and nitrogen fertilizer rates in both locations and maize varieties. Maximum grain yields of 10764 and13156 kg ha-1 were recorded for medium and late maturing hybrid maize varieties, respectively, at the interaction effect of 90909 plants ha-1 population density (55 cm\*20 cm) and 266 kg ha-1 of nitrogen rate. The partial budget analysis also indicated that the combination of planting density of 90909 plants ha-1 (55 cm\*20 cm) with 266 kg ha-1 of nitrogen rate was found economically feasible with the highest net benefit of 220140.2 ETB ha-1 and MRR of 650% for medium maturing maize variety in Mecha and south Achefer districts.  However, for late maturing maize variety in Jabitenan district, the combined effect of planting density 76923 plant ha-1 (65 cm\*20 cm) with an N rate of 197 kg ha-1 was found to be economic optimum with a net benefit of 260223.7 ETB ha-1 and MRR of 2350%.

**Keywords**: Economically optimum; fertilizer; planting density; spacing

## INTRODUCTION

Maize (*Zea mays L.)* is one of the most important crops in terms of area coverage and productivity in northwest Amhara, Ethiopia. Maize has been used as human food and in the production of many alcoholic beverages for centuries in Ethiopia. According to CSA ([2021](https://quillbot.com/grammar-check#_ENREF_4)), maize was grown on an area of over 2.5 million hectares with a total production and productivity of over 105.5 million quintals and 41.79 q ha-1, respectively. It stands second next to Teff in area coverage and first in total production of all crops in the country. The general trend of maize in area coverage and production showed an increasing tendency from year to year ([Cochrane & Bekele, 2018](https://quillbot.com/grammar-check#_ENREF_3)). The growing demand for food self-sufficiency, increased awareness about the food value of maize, and the introduction of high-yielding varieties are the main reasons why the area coverage of maize production is increasing ([Tesfay Alemu, 2001](https://quillbot.com/grammar-check" \l "_ENREF_19)). However, the productivity of the crop at the regional level is too low, about 39.83 q ha-1, though the yield potential of the crop is over 80 q ha-1 on the research station (CSA, 2018).

Inappropriate plant spacing, declining soil fertility, inadequately improved varieties, drought, pests, and diseases are the contributing factors to the lowest yield of maize in the region and Ethiopia as well (Zerssa*[et al.](https://quillbot.com/grammar-check" \l "_ENREF_23)*[, 2021](https://quillbot.com/grammar-check" \l "_ENREF_23)). Good agronomic practices, particularly plant density and nitrogen fertilization, tremendously influence the grain yield of maize ([Worku](https://quillbot.com/grammar-check" \l "_ENREF_21) *[et al.](https://quillbot.com/grammar-check" \l "_ENREF_21)*[, 2020](https://quillbot.com/grammar-check" \l "_ENREF_21)). Maize is produced for a longer period with a planting density of 44,444 plants ha-1 and a variable nitrogen fertilizer rate depending on local soil and climatic conditions in the Amhara region. Fertilizer rates of 128 and 92 kg ha-1 of N and P2O5, respectively, with a plant population density of 44444 plants ha-1have been commonlyemployed as blanket applications for maize production in the region (Tadesse *et al.,* 2007). However, different scholars suggested that a higher plant population with an increasing nitrogen fertilizer rate gave an extra higher yield in maize ([Mandic](https://quillbot.com/grammar-check" \l "_ENREF_9) *[et al](https://quillbot.com/grammar-check" \l "_ENREF_9)*[., 2015](https://quillbot.com/grammar-check" \l "_ENREF_9)). Likewise, [Worku *et al.* (2020)](https://quillbot.com/grammar-check#_ENREF_21) confirmed that maximum grain yield was recorded at 240 kg ha−1 N and 90,900 plants ha−1 plant population densities. In other similar studies, late-maturing hybrid maize varieties produced greater yields at the plant population density of 67,000 plants ha-1 and a high nitrogen fertilizer rate in better rainfall areas ([Mandic](https://quillbot.com/grammar-check" \l "_ENREF_9) *[et al.,](https://quillbot.com/grammar-check" \l "_ENREF_9)* [2015](https://quillbot.com/grammar-check" \l "_ENREF_9)). In the same way, [Zeleke, Alemayehu, & Yihenew (2018)](https://quillbot.com/grammar-check#_ENREF_22) concluded that the planting density of 88888 plants ha-1 with 161 kg ha-1 of nitrogen fertilizer was found to be superior both agronomically and economically for maize production in Achefer District. Concurrently, [Quevedo *et al.* (2018)](https://quillbot.com/grammar-check#_ENREF_14) showed that 87,500 plants gave an extra yield of 9.916 t ha-1. In the same way, [Mandic *et al.* (2015)](https://quillbot.com/grammar-check#_ENREF_9) showed that the crop density of 71429 plants ha-1 was optimal for growing in the Srem region of India. On the other hand, [Mekuannet (2019)](https://quillbot.com/grammar-check#_ENREF_10) showed that a plant density of 66,666 plants ha-1 (75 x 20 cm) was taken as optimal density and recommended for the production of maize in the Buno Bedele district of southwest Ethiopia.

In another unpublished report, ATA (Agricultural Transformation Agency) and BOA (Bureau of Agriculture) criticize the existing seed and fertilizer rates as too low to achieve maximum yield on maize in Northwest Amhara. Instead, BOA recommends 80 cm\*40 cm with double hill and fertilizer rates of 200 and 200 kg ha-1 of urea and NPS fertilizer for medium maturing varieties. ATA also advocated plant-to-plant spacing of 80 cm\*45 cm with a double hill (55,555 plants ha-1) and 300 kg ha-1 of UREA and 200 kg ha-1 of NPS for late-maturing varieties in Ethiopia. Hence, revising the existing plant population densities and nitrogen fertilizer rate was critically essential in the major maize-growing area of northwest Amhara. With this background, an experiment was initiated to determine the optimal plant population and nitrogen fertilizer rate for maximal yield of maize in northwestern Ethiopia soil and climatic conditions

## MATERIALS AND METHODS

## Description of the Study Area

The experiment was carried out at Jabitehinan, Mecha, and north Achefer districts of northwestern Amhara, Ethiopia, in the 2021/22 G.C. main rainy season. The number of sites was two per district. Jabitehinan district is located within 10° 42' 33" to 10° 42' 06 "north latitude and 35° 07' 03" to 35° 25' 02̎ "east longitude (fig. 1). The district constitutes two agro-ecological zones, viz., Woina Dega and Kola. Jabitehinan district has a monomodal RF pattern with a mean annual rainfall of 1500 mm. According to the Woreda Office of Agriculture, the topography is classified as 65% plain, 15% mountainous, 15% undulating, and 10% valley. The temperature of the district ranges between 14°C and 32°C, with an average annual temperature of 22°C. The altitude of the district ranges from 1500 to 1800 meters above sea level.

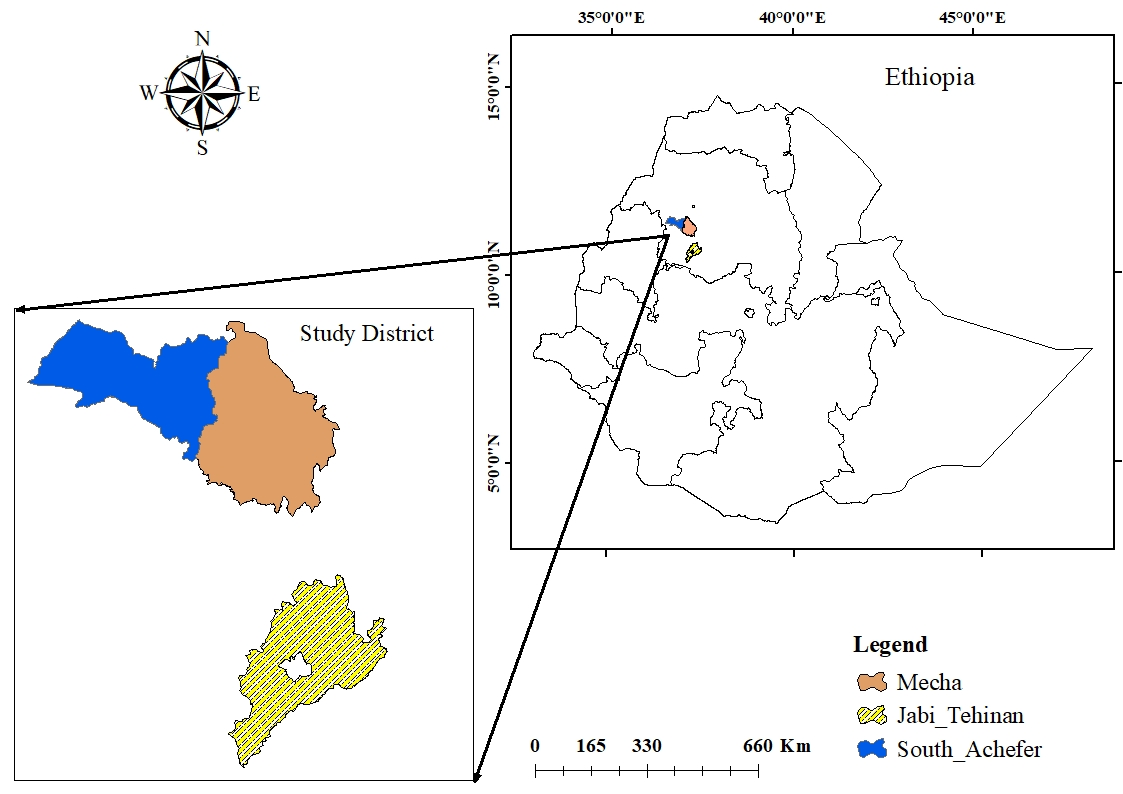


Figure 1. Map of the study areas

Achefer and Mecha district is positioned within 11°24'12'' to 11°9'12’’north latitude and 36°51'12’’ to 37°24' 12’’east longitudes, with an altitude ranging from 1700 to 2300 meters above sea level. The average annual rainfall is 1400 mm. The mean maximum and minimum temperatures are 26.8 °C and 9.7 °C, respectively. In all districts, maximum rainfall is received in June, July, August, and September. Maize, finger millet, tef, and pepper are the main crops produced in the districts.

***Experimental Setup***

## Two sets of experiments were conducted: Set-I: Jabitehinan was selected for the late-maturing hybrid maize variety (BH-661), while Mecha and South Achefer were selected for the medium-maturing hybrid maize variety (BH-546) as Set-II. Four planting densities P1 (44,444 plant ha-1), P2 (60606 plant ha-1), P3 (76923 plant ha-1), P4 (90909 plant ha-1) and P5 (55555 plant ha-1) with a corresponding plant spacing of 75 × 30, 55× 30, 65x20, 55 × 20 cm, and 80x45 (two plants per hill), respectively, and four nitrogen fertilizer rates (F1 = 128 kg ha-1, F2 = 197 kg ha-1, F3 = 266 kg ha-1, and F4 = 335 kg ha-1) were combined in factorial RCBD with three replications for the late maturing variety at Jabitehinan. The same treatment setup was used for the medium maturing variety at Mecha and South Achefer except with a modification of P5 = 62,500 plants ha-1 (80x40 cm using two plants per hill).  ATA recommended plant population densities of 55555 and 62,500 plants per hectare, using two plants per hill as a check for the late and medium maturing varieties of maize, respectively. The number of rows per plot varied depending on inter-row spacing, with 5 rows for 75 cm, 7 rows for 55 cm, 6 rows for 65 cm, and 5 rows for 80 cm inter-row spacing.  The net plots were 2.25m\*2.4m (5.4m2) for 75\*30 cm, 2.75m\*2.60m (7.15m2) for 55\*20 cm, and 2.6m \*2.6m (6.76m2) for 65\*20, 2.4m\*2.20m (5.28m2) for 80\*40, and 2.75m\*2.40m (6.6m2) for 55\*30 cm row spacing. The distance between blocks was 1.5 m, while the distance between each plot was 1 meter. For one plant per hill, two seeds were sown and later thinned to one plant twenty days after planting. Four seeds were sown for the double-hill planting method (80x40 and 80x45 cm spacing) and later thinned into two plants per hill. All P2O5 (138 kg ha-1) and 1/3 N were applied at sowing time, and the remaining 2/3 N was applied at the knee-height crop stage. The field was plowed four times before planting using the traditional oxen plow method. The field was weeded twice per season, with the first weeding done 25 days after sowing and the second weeding done 45 days after planting. No insecticide or fungicide was applied since there was no outbreak of insects or diseases. Sowing was in the first week of June, and harvesting was at the end of November.

## Data Collection, Measurement and Analysis

## Ten representative maize plants were chosen randomly and tagged to measure plant height, cob height, and seeds per cob, cob length, chlorophyll content, and 1000 seed weight. However, grain and stover yield was measured from the entire plot, excluding the border rows, and later changed to hectare bases. Plant height was measured from the soil's surface to the base of the tassel. Chlorophyll content was measured using a spade meter at the tasseling stage. The number of grains per cob was recorded by counting the number of seeds from each cob. Grain yield was measured after air-drying, and adjusted to a moisture content of 12.5 percent. All agronomic data were subjected to analysis of variance using the SAS system (Gomez, 1984). The homogeneity of error of variance was analyzed by dividing the larger mean square of error by the smaller mean square of error as suggested by (Gomez (1984). Combined analysis of variance over years done to obtain stable recommendation despite year variation.

## Measuring of Chlorophyll Content Using SPAD Meter

## Initially, ten randomly selected maize plants were tagged to measure the leaf chlorophyll index. The leaf chlorophyll index was measured using the SPAD meter at the tasselling stage in all sites and varieties. SPAD meter scanning determines the chlorophyll concentration by measuring the leaf absorbance in red and near-infrared regions. The reading values are proportional to the amount of chlorophyll present in the leaf. The collected data were finally averaged and analyzed using the SAS system.

## Partial Budget Analysis

## Partial budget analysis was determined using the CIMMYT manual (CIMMYT, 1988). Only costs that differed between treatments, including labor, seed, and fertilizer, were considered as variable costs. Total variable costs, gross benefit, net benefit, and marginal rate of return were calculated. Gross benefit is calculated as the sum of the price of grain and stover products. The difference between the gross benefit and the variable costs is the net benefit for each treatment. The ratio of the change of the net benefit to the change of variable costs is the marginal rate of return. Grain yield was adjusted down by 10% to calculate the partial budget analysis. The cost of UREA, hybrid maize seed, and price of maize grain were 14, 170, and 22 ETB per kilogram, respectively. The cost of labor was 100 ETB per day, while the price of the stover was 1000 ETB per ton.

## *Soil Sample Collection and Analysis*

Immediately before planting, soil samples were collected using an auger at a plow depth of 0–20 cm for assessing essential soil nutrients. The hydrometer method was used to determine the particle size distribution of the soil sample (Bouyoucos, 1962). The pH of the soil was analyzed using a glass electrode PH meter (Murphy, 1968). According to Jackson (1973), the Micro-Kjeldahl method was used to quantify total nitrogen, while the Olsen methods were used to determine phosphorus (Olsen, 1982). The organic carbon was measured through a volumetric approach (Walkley & Black, 1934).

## RESULT AND DISCUSSION

*Testing sites soil properties*

The findings of soil analyses indicated that in all locations the soil type was clay loam with a particle size distribution ranging from 50-60% clay, 23-29% silt, and 19-26% sand (Table 1). The pH of the soil was strongly to weakly acidic in Mecha and weakly acidic in Achefer and Jabitehinan (Tekalign, 1991). The organic carbon of the soil was low at Mecha and Achefer and medium in Jabitehinan (Walkley & Black, 1934). The nitrogen content was found medium to low (Horneck, Sullivan, Owen, & Hart, 2011). According to Olsen et al. (1982), available phosphorus was low to medium in Mecha and Achefer and medium in Jabitehinan. In general, the soil analysis result clearly showed that the districts had depleted soil nutrients.

Table 1. Soil physic-chemical properties of testing sites

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Testing district | | | Interpretation | Reference |
| Soil Parameter | Mecha | Achefer | Jabitenan | Status |  |
| Sand% | 20-23 | 19-26 | 20-24 |  |  |
| Silt% | 23-26 | 24-28 | 24-29 |  |  |
| Clay% | 53-60 | 53-56 | 50-55 |  |  |
| PH | 5.4-5.9 | 5.5-6.0 | 3.5-5.9 | weak acidic | ([Tekalign, 1991](#_ENREF_18)) |
| Organic carbon % | 1.9-2.3 | 1.8-2.3 | 2.0-2.5 | medium | ([Walkley & Black, 1934](#_ENREF_20)) |
| Total nitrogen % | 0.10-0.14 | 0.10-0.12 | 0.11-0.14 | medium | (Horneck, 2011) |
| Available P (mg kg-1) | 9-12 | 9-12 | 10-13 | medium | ([Olsen, Sommers, & Page, 1982](#_ENREF_12)) |

pH = potential of hydrogen

## Field Performance of Medium Maturing Hybrid Maize Variety in South Achefer and Mecha

The combined analysis of variance (ANOVA) showed that the growth and yield of medium-maturing hybrid maize varieties were significantly (P<0.01) influenced by the application of different planting densities and nitrogen fertilizer rates (Table 2). Planting density highly significantly (P<0.01) affected plant height and cob length, while grain and stover yield were significant (P<0.05). Concurrently, nitrogen fertilizer rates were highly significant (P<0.01) and affected the plant height, cob length, and diameter, seed number per cob, grain yield, and stover yield, while chlorophyll content was significant (P<0.05). The interactions of planting density and nitrogen fertilizer rate did not significantly (P > 0.05) affects any of the growth and yield parameters of maize (Table 2).

Table Mean squares of analysis of variance for different sources of variations on growth and grain yield medium maturing (BH-546) hybrid maize varieties

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Source of variation | DF | PH  (cm) | CL  (cm) | SN  (cm) | CD  (cm) | GY  (kg ha-1) | STY  (t ha-1) | CHL  (µmol per mm2) |
| Planting density (PPD) | 4 | 1926\*\* | 66\*\* | 4393.0ns | 2ns | 504554\* | 574.9\* | 27ns |
| Nitrogen (N) | 3 | 212\*\* | 37\*\* | 14438\*\* | 0.8\*\* | 13883575\*\* | 239\*\* | 238\* |
| Replication (Rep) | 2 | 24.9ns | 11ns | 44330ns | 0.1ns | 1967191.3ns | 10.3ns | 4.1ns |
| N\*PPD | 12 | 210.4ns | 33.3ns | 3332.7ns | 0.9ns | 937425.7ns | 38.4ns | 58.5ns |

\*\*highly significant at P<0.01; \*significant at P<0.05; ns=not significant at P≥0.05; DF=Degree of freedom; PH= Plant height; SN=seed number; CD=Cob diameter; GY= grain yield; STY=stover yield; CHL=Chlorophyll content

The plant height of maize increased as plant density increased. The tallest plant height (253.55 cm) was recorded at the highest plant population densities of 900909 plants ha-1, while the shortest plant height (238.07 cm) was recorded at the sparsely populated planting density (Table 3). The increases in plant height as well as the increases in planting densities were due to the stimulation of the stem as plants competed with each other for light. The result is in line with Shye et al. (2016), who showed stimulated stem elongation in dense planting densities rather than sparsely populated planting densities. As opposed to plant height, cob length (19.41 cm), seed number per cob (538.26), and cob diameter (4.92 cm) were the largest at the lowest plant population density of 44444 plants ha-1. Maximum planting density of 900909 plants ha-1 revealed the lowest cob length (17.95 cm), seed number per cob (513.56), and cob diameter (4.63 cm) of the BH-546 hybrid maize variety (Table 3). The increase in individual plant performance at lower planting density may be due to the decrease in competition for the same nutrient resources. The competition for water, nutrients, and light stiffened at dense planting densities and decreased individual plants's performance. The result is in line with Postma et al. (2021), who showed decreases in the size of the yield component of plants as planting density increases per unit area.

Table 3 Effects of plant population density and nitrogen fertilizer rate on growth and yield of medium maturing maize hybrid variety at Mecha and south Achefer

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Plant population  densities  (plants ha-1) | Plant height  (cm) | Cob  length  (cm) | Seed number  cob-1 | Cob diameter  (cm) |
| 44444 | 238.07c | 19.41a | 538.26a | 4.92a |
| 60606 | 241.16c | 18.90a | 528.38ab | 4.77b |
| 76923 | 247.10b | 18.17bc | 521.53ab | 4.75b |
| 90909 | 253.55a | 17.95c | 513.56b | 4.63c |
| 62500 | 239.94c | 18.82ab | 532.21ab | 4.83ab |
| N level (kg ha-1) | \* | \*\* | \* | \* |
| 128 | 241.34 | 18.07b | 507.28c | 4.71b |
| 197 | 243.86 | 18.56ab | 523.75c | 4.74b |
| 266 | 245.20 | 18.83a | 531.78a | 4.83a |
| 335 | 245.45 | 19.14a | 544.32a | 4.85a |
| Sig. | ns | \* | \* | \* |
| CV% | 4.9 | 9.5 | 9.4 | 4.2 |

\*\*highly significant at P<0.01; \*significant at P<0.05; ns=not significant at P≥0.05; CV=coefficient of variation; means followed with the same letter are not significantly different

The highest cob length (19.14 cm), seed number per cob (544.3), and cob diameter (4.85 cm) were recorded at 335 kg ha-1 nitrogen fertilizer rate. In terms of statistics, the nitrogen fertilizer rate of 266 kg ha-1 was comparable to N 335 kg ha-1 and revealed the heights of cob length (18.83 cm), seed number per cob (531.78), and cob diameter (4.83 cm) (Table 3).

Grain and stover yield increased as planting density increased (Table 4). The highest grain yield (10121.51 kg ha-1) and stover yield (24.03 t ha-1) were recorded at maximum plant population densities of 90909 plants ha-1. The lowest grain yield (7707 kg ha-1) and stover yield (14.76 t ha-1) were recorded at the lowest plant density of 44,444 plants ha-1. The general scenario showed that grain and stover yield constantly increased as planting density increased from 44,444 to 90,909 plants per hectare. The result aligns with Mak et al. (2021), who showed yield increment as plant population increases to 97400 plants per hectare. Similarly,  Worku et al. (2020) recorded the highest grain yield from the combination of the 360 kg ha-1 N level and plant population density of  90,900 plants ha−1. The effect of plant population on maize's chlorophyll concentration was minimal and insignificant. However, chlorophyll content was maximum (54.76 µmol per m2) at sparsely plant population density (44444 plants ha-1) than the chlorophyll content (52.84 µmol per m2) recorded at maximum plant population densities of 90909 plants ha-1. According to Postma et al. (2021), leaf chemistry is affected by decreased total non-structural carbohydrate concentrations in the leaves of the dense canopies. It decreases nitrate levels and demonstrates lower chlorophyll content at maximum plant population density.

The nitrogen fertilizer rate of 266 kg ha-1 produced the highest grain yield (9202.2 kg ha-1), whereas the highest stover yield (21.61 t ha-1) and chlorophyll content (55.84 µmol per mm2) were recorded at the highest N rate of 335 kg ha-1. Minimum grain yield (8105 kg ha-1), stover yield (16.95 t ha-1), and chlorophyll content (51.02 µmol per mm2) were recorded at a minimum nitrogen fertilizer rate of 128 kg ha-1. The result is in line with Worku et al. (2020), who recorded the highest grain yield from the combination of the highest N level (360 kg ha-1) and the highest planting density of 90,900 plants ha-1. Similarly, Mak et al. (2021) showed maximum grain yield (10.13 t ha-1) at 97400 plants ha-1.

Table 4 Effect of plant population density and nitrogen fertilizer rate on growth and yield of medium maturing hybrid maize variety

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Plant population  density  (plants ha-1) | Row  Cob -1 | Grain  yield  (kg ha-1) | Stover  Yield (t ha-1) | Chlorophyll  Content  (µmol per mm2) |
| 44444 | 14.50 | 7707.20d | 14.76d | 54.76 |
| 60606 | 14.36 | 8655.01c | 18.40c | 53.73 |
| 76923 | 14.45 | 9555.40b | 21.16b | 53.51 |
| 90909 | 14.33 | 10121.51a | 24.03a | 52.84 |
| 62500 | 14.52 | 7979.91d | 18.36c | 54.52 |
| N level (kg ha-1) | ns | \* | \*\* | ns |
| 128 | 14.27c | 8105.00b | 16.95c | 51.02c |
| 197 | 14.33c | 8921.60a | 18.65bc | 53.79b |
| 266 | 14.53ab | 9202.20a | 20.13ab | 54.85ab |
| 335 | 14.63a | 8986.40a | 21.61a | 55.84a |
| Sig. | \*\* | \* | \*\* | \*\* |
| CV% | 4.8 | 11.8 | 17.5 | 8.9 |

\*\*highly significant at P<0.01; \*significant at P<0.05; ns=not significant at P≥0.05; CV=coefficient of variation and means followed with the same letter are not significantly different

## Field Performance of Late Maturing Hybrid Maize Variety at Jabitenan

Mean squire analysis of variance (ANOVA) showed that the growth and yield of late-maturing maize hybrid varieties (BH-661) showed highly significant (P<0.01) differences in response to varying planting density and nitrogen fertilizer rates (Table 5). Planting densities were highly significantly (P<0.01) affected seed per cob, and significantly (P<0.05) affected cob length, rows per cob, grain, and stover yield of the BH-661 maize hybrid variety. Similarly, the main effect of nitrogen fertilizer rate was significantly (P<0.05) affected plant height and seed number per cob and highly significantly (P<0.01) affected cob length, grain yield, and Stover yield. The nitrogen fertilizer rates also significantly (P<0.01) affected the chlorophyll content of maize. The cob length and seed number per cob were significantly (P<0.05) impacted by the interactions of planting densities and nitrogen fertilizer rate.

Table 5. Mean squares of analysis of variance for different sources of variations on growth and grain yield of late maturing hybrid maize variety BH-661

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Source of variation | DF | PH (cm) | CL (cm) | SN  (cm) | CD  (cm) |  | GY  (kg ha-1) | STY  (t ha-1) | CHL  (µmol per mm2) |
| Planting density (PPD) | 4 | 166.4 | 35.6\* | 29321.0\*\* | 0.74 |  | 22253277.1\* | 186.3\* | 101.9 |
| Nitrogen (N) | 3 | 3068.0\* | 13.5\*\* | 15359.6\* | 0.30 |  | 12569247.0\*\* | 72.9\*\* | 334.5\* |
| Replication (Rep) | 2 | 144.2 | 24.3\* | 5172.3 | 0.01 |  | 928912.0 | 15.5 | 33.1 |
| N\*PPD | 12 | 353.0 | 4.9\* | 1998.1\* | 0.14 |  | 2642485.1 | 15.6 | 36.8 |

\*\*highly significant at P<0.01; \*significant at P<0.05; ns=not significant at P≥0.05; DF=Degree of freedom; PH= Plant height; SN=seed number; CD=Cob diameter; GY= grain yield; STY=stover yield; CHL=Chlorophyll content

Planting density and nitrogen fertilizer rates had a significant (P<0.001) impact on cob length, seed number, and other growth metrics of the late-maturing (BH-661) hybrid maize variety. The growth metrics were inversely related to the increasing rate of planting density (table 6). The highest cob length (18.47 cm), seed number per cob (537.2), and cob diameter (4.51 cm) were recorded at the smallest plant population density of 44444 plants ha-1. While not statistically significant, the planting density of 55555 plants per hectare revealed the longest cob length (17.97 cm)  and cob diameter (4.45 cm), following the lowest planting densities of 44444 plants ha-1. The smallest cob length (15.43 cm), seed number per cob (455.5 cm), and cob diameter (4.07 cm) were recorded at maximum plant population densities of 90909 plants ha-1. In general, cob length and diameter often decrease with increasing planting density. This might be due to stiff competition of nutrients, radiation, and water for the growing plant at maximum plant population densities.  The result is in line with Zeleke et al. (2018), who showed cob length, cob number per plant, and thousand-grain weight decreased with increasing planting density from 53,333 to 90,900 plants ha-1.

Growth parameters correspondingly improved with increases in nitrogen fertilizer rate (Table 6). The tallest plant height (286.9 cm) was recorded at the maximum nitrogen fertilizer rate (335 kg ha-1), whereas the shortest plant height (264.6 cm) was recorded at 128 kg ha-1 nitrogen fertilizer rates. The nitrogen fertilizer rate of 335 kg ha-1 showed the maximum cob length (17.72 cm), seed number per cob (507), and cob diameter (4.49 cm). In terms of statistics, the nitrogen fertilizer rate of 266 kg ha-1 was comparable to N 335 kg ha-1 and revealed the height of the cob length (17.45 cm), seed number per cob (503.5), and cob diameter (4.36 cm).

Table 6 response of plant population density and nitrogen fertilizer rate on growth and grain yield of late maturing hybrid maize variety

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Plant population  Density  (plants ha-1) | Plant height  (cm) | Cob  length  (cm) | Seed  number  cob-1 | Cob diameter  (cm) |
| 744444 | 282.3 | 18.47a | 537.2a | 4.51a |
| 60606 | 279.2 | 17.02b | 471.7c | 4.43ab |
| 76923 | 277.4 | 16.36b | 458.7c | 4.29b |
| 90909 | 276.6 | 15.43c | 455.5c | 4.07c |
| 55555 | 282.1 | 17.97a | 505.7b | 4.45ab |
| N level (kg ha-1) | ns | \* | \* | \*\* |
| 128 | 264.6b | 16.22c | 464.1b | 4.27b |
| 197 | 282.6a | 16.81cb | 468.4b | 4.28b |
| 266 | 284.0a | 17.45ab | 503.5a | 4.36ab |
| 335 | 286.9a | 17.72a | 507a | 4.49a |
| Sig. | \* | \* | \*\* | \* |
| CV% | 4.8 | 8.2 | 10.7 | 7.4 |

\*\*highly significant at P<0.01; \*significant at P<0.05; ns=not significant at P≥0.05; CV=coefficient of variation and means followed with the same letter are not significantly different

Planting density and nitrogen fertilizer rates had a significant (P<0.001) impact on cob length, seed number, and other growth metrics of the late-maturing (BH-661) hybrid maize variety. The growth metrics were inversely related to the increasing rate of planting density (table 6). The highest cob length (18.47 cm), seed number per cob (537.2), and cob diameter (4.51 cm) were recorded at the smallest plant population density of 44444 plants ha-1. While not statistically significant, the planting density of 55555 plants per hectare revealed the longest cob length (17.97 cm) and cob diameter (4.45 cm), following the lowest planting densities of 44444 plants ha-1. The smallest cob length (15.43 cm), seed number per cob (455.5 cm), and cob diameter (4.07 cm) were recorded at maximum plant population densities of 90909 plants ha-1. In general, cob length and diameter often decrease with increasing planting density. This might be due to stiff competition of nutrients, radiation, and water for the growing plant at maximum plant population densities.  The result is in line with Zeleke et al. (2018), who showed cob length, cob number per plant, and thousand-grain weight decreased with increasing planting density from 53,333 to 90,900 plants ha-1.

Growth parameters correspondingly improved with increases in nitrogen fertilizer rate (Table 6). The tallest plant height (286.9 cm) was recorded at the maximum nitrogen fertilizer rate (335 kg ha-1), whereas the shortest plant height (264.6 cm) was recorded at 128 kg ha-1 nitrogen fertilizer rates. The nitrogen fertilizer rate of 335 kg ha-1 showed the maximum cob length (17.72 cm), seed number per cob (507), and cob diameter (4.49 cm). In terms of statistics, the nitrogen fertilizer rate of 266 kg ha-1 was comparable to N 335 kg ha-1 and revealed the height of the cob length (17.45 cm), seed number per cob (503.5), and cob diameter (4.36 cm).

Table 7 response of plant population density and nitrogen fertilizer rate on growth and grain yield of late maturing hybrid maize variety in Jabitenan district

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Plant population  density  (plants ha-1) | Row  Cob -1 | Grain  yield  (kg ha-1) | Stover  (t ha-1) | Chlorophyll  Content  (µmol per mm2) |
| 44444 | 13.56a | 8158.0e | 13.65d | 51.51a |
| 60606 | 13.01b | 9723.2c | 16.52c | 50.71a |
| 76923 | 12.87bc | 10998.4b | 18.08b | 47.88ab |
| 90909 | 12.54c | 11856.1a | 21.86a | 47.10b |
| 55555 | 13.10b | 8421.2d | 15.70d | 51.32a |
| N level (kg ha-1) |  |  |  |  |
| 128 | 12.62b | 9432.4b | 14.28c | 45.52c |
| 197 | 12.69b | 9925.2ab | 17.56b | 48.68bc |
| 266 | 13.21a | 10219.3a | 17.95ab | 51.49ab |
| 335 | 13.55a | 9748.6ab | 18.86a | 53.13a |
| Sig. | \* | \*\* | \* | \* |
| CV% | 5.6 | 6.8 | 9.9 | 13.52 |

\*\*highly significant at P<0.01; \*significant at P<0.05; ns=not significant at P≥0.05; CV=coefficient of variation; and means followed with the same letter are not significantly different

## *Economic analysis*

In Mecha and Achefer districts, the largest net benefit (220140.2 ETB ha-1) was recorded at the plant population density of 90900 plants ha-1 and 266 kg N ha-1 rates, followed by the same plant population and 197 kg N ha-1 rates (tables 8 and 9). In contrast, the lowest net benefit (143955.5 ETB ha-1) was recorded at 44,444 plant population density and 128 N ha-1 rates. According to CIMMYT (1988), an increase in output will always result in increased profits as long as the marginal rate of return is greater than the minimum rate of return, which is 100%. In Mecha and Achefer districts, more than six treatment combinations showed more than 100 percent marginal rate of return. As per one unit of investment, the net benefit ranged from 2.6 to 77.3 units (Table 8). As a rule of thumb, when the margin is above the minimum acceptable rate of return, a treatment combination with the highest net benefit could be selected for recommendation (CIMMYT, 1988). As a result, plant population density of 90900 plants ha-1 (55\*20 cm) and 266 kg N ha-1 fertilizer rates yielded the largest net benefit of 220140.2 ETB ha-1 and an acceptable MRR of 644.5 percent than other treatment combinations. This means one Ethiopian birr expenditure for planting density and N fertilizer application, and farmers can expect to get 6.45 ETB. As a result, it is possible to suggest 90900 plants ha-1 (55\*20 cm) and 266 kg ha-1 of N fertilizer rates for the production of BH-546 in the Achefer and Mecha districts.

Table 8 Gross income and net profit of medium maturing hybrid maize variety in Mecha and south Achefer districts as affected by the interactions of plant population density and nitrogen fertilizer rate

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Population  density  (plants ha-1) | N rate  (kg ha-1) | Grain yield  (kg ha-1) | AGY  (kg ha-1) | ASY  (t ha-1) | UC  (ETB ha-1) | Labor Cost (ETB ha-1) | Seed Cost  (ETB ha-1) | TVC  (ETB ha-1) | Grain Price (ETB ha-1) | Stover Price (ETB ha-1) | Gross Befit (ETB ha-1) | Net Befit  (ETB ha-1) |
| 44444 | 128 | 7040.22 | 6400.2 | 12.2 | 3895.7 | 3000 | 3525 | 10420.7 | 140804.2 | 13572 | 154376.2 | 143955.5 |
| 62500 | 128 | 7248.01 | 6589.1 | 14.1 | 3895.7 | 3600 | 4406.3 | 11901.9 | 144959.6 | 15704.6 | 160664.2 | 148762.3 |
| 76923 | 128 | 8707.38 | 7915.8 | 16.3 | 3895.7 | 3600 | 4806.9 | 12302.5 | 174147.3 | 18058.3 | 192205.6 | 179903.1 |
| 44444 | 197 | 7791.85 | 7083.5 | 12.6 | 5995.7 | 3000 | 3525 | 12520.7 | 155835.9 | 13956.6 | 169792.5 | 157271.9 D |
| 62500 | 197 | 8285.86 | 7532.6 | 16.4 | 5995.7 | 3600 | 4406.3 | 14001.9 | 165717.1 | 18216.8 | 183933.9 | 169932 D |
| 60606 | 128 | 8184.77 | 7440.7 | 15.7 | 3895.7 | 4200 | 6101 | 14196.7 | 163696.4 | 17455.5 | 181151.9 | 166955.2 D |
| 76923 | 197 | 9596.73 | 8724.3 | 18.4 | 5995.7 | 3600 | 4806.9 | 14402.5 | 191933.8 | 20456.2 | 212390 | 197987.4 |
| 44444 | 266 | 8122.84 | 7384.4 | 14.6 | 8095.7 | 3000 | 3525 | 14620.7 | 162456.9 | 16267.8 | 178724.6 | 164104 D |
| 90909 | 128 | 8939.59 | 8126.9 | 18 | 3895.7 | 4200 | 7210.3 | 15305.9 | 178792.2 | 19962.5 | 198754.7 | 183448.8 D |
| 62500 | 266 | 8153.53 | 7412.3 | 17.8 | 8095.7 | 3600 | 4406.3 | 16101.9 | 163071.4 | 19820.3 | 182891.7 | 166789.8 D |
| 60606 | 197 | 8362.31 | 7602.1 | 17.2 | 5995.7 | 4200 | 6101 | 16296.7 | 167247.1 | 19155 | 186402.1 | 170105.5 D |
| 76923 | 266 | 9881.3 | 8983 | 20.1 | 8095.7 | 3600 | 4806.9 | 16502.5 | 197626.7 | 22377.5 | 220004.2 | 203501.7 |
| 44444 | 335 | 7565.69 | 6877.9 | 13.7 | 10195.7 | 3000 | 3525 | 16720.7 | 151314.8 | 15274 | 166588.8 | 149868.2 D |
| 90909 | 197 | 10125.39 | 9204.9 | 19.3 | 5995.7 | 4200 | 7210.3 | 17405.9 | 202507.3 | 21480.4 | 223987.6 | 206581.7 |
| 62500 | 335 | 7913.07 | 7193.7 | 17.8 | 10195.7 | 3600 | 4406.3 | 18201.9 | 158262 | 19735.3 | 177997.3 | 159795.4 D |
| 60606 | 266 | 8628.18 | 7843.8 | 16.1 | 8095.7 | 4200 | 6101 | 18396.7 | 172564.1 | 17879.6 | 190443.7 | 172047.1 D |
| 76923 | 335 | 9653.82 | 8776.2 | 21.2 | 10195.7 | 3600 | 4806.9 | 18602.5 | 193076.6 | 23573.4 | 216650 | 198047.5 D |
| 90909 | 266 | 10764.82 | 9786.2 | 21.9 | 8095.7 | 4200 | 7210.3 | 19505.9 | 215296.9 | 24349.2 | 239646.1 | 220140.2 |
| 60606 | 335 | 9098.43 | 8271.3 | 17.2 | 10195.7 | 4200 | 6101 | 20496.7 | 181969.4 | 19134.3 | 201103.8 | 180607.1D |
| 90909 | 335 | 10251.45 | 9319.5 | 27.3 | 10195.7 | 4200 | 7210.3 | 21605.9 | 205027.9 | 30343.6 | 235371.5 | 213765.6 D |

\* AGY=Adjusted Grain Yield; ASY= Adjusted Stover Yield; UC= Urea cost; TVC=total variable cost

Table 9. Marginal rate of return for plant population density and nitrogen rate interactions effect on medium maturing hybrid maize variety in Mecha and south Achefer districts

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Population  density  (plants ha-1) | N rate  (kg ha-1) | TVC  (ETB ha-1) | Net benefit  ((ETB ha-1) | MRR  100% |
| 44444 | 128 | 10420.7 | 143955.5 | - |
| 62500 | 128 | 11901.9 | 148762.3 | 3.2 |
| 76923 | 128 | 12302.5 | 179903.1 | 77.7 |
| 76923 | 197 | 14402.5 | 197987.4 | 8.6 |
| 76923 | 266 | 16502.5 | 203501.7 | 2.6 |
| 90909 | 197 | 17405.9 | 206581.7 | 3.4 |
| 90909 | 266 | 19505.9 | 220140.2 | 6.5 |

\*Urea cost=14 ETB, grain cost=22 ETB, labor cost 100 ETB, stover cost 1000 ETB/t and hybrid seed cost=170 ETB

In Jabitenan district, the largest net benefit (264326.785 ETB ha-1) was recorded at the plant population density of 90900 plants ha-1 and 266 kg N ha-1 rates, followed by the same plant population and 197 kg N ha-1 rates. On the contrary, the lowest net benefit (164846.0 ETB ha-1) was recorded at 44,444 plant population density and 128 N ha-1 rates (tables 10 & 11). In Jabitehinan, three treatment combinations showed an above-100 percent marginal rate of return. The marginal rate of return ranged from 0.8 to 24.8 units. Among these, the largest net benefit with an acceptable level of MRR could be selected for recommendation. Therefore, the planting density of 76923 plants ha-1 and nitrogen fertilizer rates of 197 kg ha-1 yielded the largest net benefit of 260223.7 ETB ha-1 and an acceptable MRR of 2350%. This means one Ethiopian birr expenditure for planting density and nitrogen fertilizer application, farmers can expect to get 23.5 Ethiopian birr.  As a result, it is possible to recommend a planting density of 76923 plants ha-1 (65\*20 cm) and 197 kg ha-1 nitrogen fertilizer rates for the production of BH-661 in the Jabitenan district.

Table 10 Gross income and net profit of late maturing hybrid maize variety at Jabitenan as affected by the interaction of plant population density and nitrogen fertilizer rate

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Plant population  density  (plants ha-1) | N  (kg ha-1) | Grain yield  (kg ha-1) | AGY  (kg ha-1) | ASY  (t ha-1) | UC  (ETB ha-1) | Labor Cost (ETB ha-1) | Seed Cost  (ETB ha-1) | TVC  (ETB ha-1) | Grain Price (ETB ha-1) | Stover Price (ETB ha-1) | Gross Befit (ETB ha-1) | Net Befit (ETB ha-1) |
| 44444 | 128 | 8237.778 | 7488.889 | 10.51111 | 3895.652 | 3000 | 3525 | 10420.65 | 164755.6 | 10511.11 | 175266.7 | 164846.015 |
| 55555 | 128 | 10144.92 | 9222.656 | 10.55859 | 3895.652 | 3600 | 4406.25 | 11901.9 | 202898.4 | 10558.59 | 213457 | 201555.128 |
| 76923 | 128 | 9747.857 | 8861.688 | 16.06154 | 3895.652 | 3600 | 4806.86 | 12302.51 | 194957.1 | 16061.54 | 211018.7 | 198716.17 D |
| 44444 | 197 | 8350.222 | 7591.111 | 12.26222 | 5995.652 | 3000 | 3525 | 12520.65 | 167004.4 | 12262.22 | 179266.7 | 166746.015D |
| 55555 | 197 | 7717.188 | 7015.625 | 13.44063 | 5995.652 | 3600 | 4406.25 | 14001.9 | 154343.8 | 13440.63 | 167784.4 | 153782.473D |
| 60606 | 128 | 8192 | 7447.273 | 11.73455 | 3895.652 | 4200 | 6101.01 | 14196.66 | 163840 | 11734.55 | 175574.5 | 161377.884D |
| 76923 | 197 | 12842.27 | 11674.79 | 17.78077 | 5995.652 | 3600 | 4806.86 | 14402.51 | 256845.4 | 17780.77 | 274626.2 | 260223.705 |
| 44444 | 266 | 8389.334 | 7626.667 | 12.53333 | 8095.652 | 3000 | 3525 | 14620.65 | 167786.7 | 12533.33 | 180320 | 165699.348D |
| 90900 | 128 | 10368 | 9425.455 | 15.42 | 3895.652 | 4200 | 7210.29 | 15305.94 | 207360 | 15420 | 222780 | 207474.058D |
| 55555 | 266 | 8116.797 | 7378.906 | 15.51484 | 8095.652 | 3600 | 4406.25 | 16101.9 | 162335.9 | 15514.84 | 177850.8 | 161748.879D |
| 60606 | 197 | 9536 | 8669.091 | 14.60364 | 5995.652 | 4200 | 6101.01 | 16296.66 | 190720 | 14603.64 | 205323.6 | 189026.974D |
| 76923 | 266 | 10331.54 | 9392.308 | 15.99231 | 8095.652 | 3600 | 4806.86 | 16502.51 | 206630.8 | 15992.31 | 222623.1 | 206120.564D |
| 44444 | 335 | 7328.444 | 6662.222 | 13.86444 | 10195.65 | 3000 | 3525 | 16720.65 | 146568.9 | 13864.44 | 160433.3 | 143712.68D |
| 90900 | 197 | 10684 | 9712.727 | 20.96909 | 5995.652 | 4200 | 7210.29 | 17405.94 | 213680 | 20969.09 | 234649.1 | 217243.149D |
| 55555 | 335 | 7369.141 | 6699.219 | 17.03828 | 10195.65 | 3600 | 4406.25 | 18201.9 | 147382.8 | 17038.28 | 164421.1 | 146219.192D |
| 60606 | 266 | 10592 | 9629.091 | 16.04364 | 8095.652 | 4200 | 6101.01 | 18396.66 | 211840 | 16043.64 | 227883.6 | 209486.974D |
| 76923 | 335 | 10631.92 | 9665.385 | 15.28077 | 10195.65 | 3600 | 4806.86 | 18602.51 | 212638.5 | 15280.77 | 227919.2 | 209316.718D |
| 90900 | 266 | 13156 | 11960 | 20.71273 | 8095.652 | 4200 | 7210.29 | 19505.94 | 263120 | 20712.73 | 283832.7 | 264326.785 |
| 60606 | 335 | 10184 | 9258.182 | 17.1 | 10195.65 | 4200 | 6101.01 | 20496.66 | 203680 | 17100 | 220780 | 200283.338D |
| 90900 | 335 | 12742 | 11583.64 | 21.60727 | 10195.65 | 4200 | 7210.29 | 21605.94 | 254840 | 21607.27 | 276447.3 | 254841.331D |

AGY=Adjusted Grain Yield; ASY= Adjusted Stover Yield; UC= Urea cost; TVC=total variable cost

Table 11. Marginal rate of return for the interaction effect of plant population density and nitrogen rate on late maturing hybrid maize variety at Jabitenan district

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Plant population  density  (plants ha-1) | N rate  (kg ha-1) | TVC  (ETB ha-1) | Net benefit  ((ETB ha-1) | MRR  100% |
| 44444 | 128 | 10420.7 | 164846.0 | - |
| 5555 | 128 | 11901.9 | 201555.1 | 24.8 |
| 76923 | 197 | 14402.5 | 260223.7 | 23.5 |
| 90900 | 266 | 19505.9 | 264326.8 | 0.8 |

\*Urea cost=14 ETB, grain cost=22 ETB, labor cost 100 ETB; stover cost 1000 ETB/t and seed cost=170 ETB

## CONCLUSION AND RECOMMENDATION

Maize grain yield increased in response to the increase in plant population density and nitrogen rates for both medium and late-maturing varieties.  Increasing plant population and N rate maximized resource utilization such as solar radiation, space, light, water, nutrients, and other inputs for the production of more biological yield per hectare. For medium maturing varieties, maximum net benefit (220140.2 ETB ha-)with acceptable MRR (650%) was obtained at the interaction of 90909 plants ha-1 population density (55\*20 cm) and 266 kg ha-1 of nitrogen fertilizer rate to be recommended in Mecha and Achefer districts.  However, for the late-maturing hybrid maize variety, the combined effect of a planting density of 76923 plant ha-1 (65\*20 cm) and an N rate of 197 kg ha-1 recorded an economic optimum net benefit of 260223.7 ETB ha-1 with an acceptable MRR of 2350% to be recommended in Jabitehinan district.  Further research comparing various other suitable plant populations and N-containing fertilizer levels may be carried out in the future to validate the findings in other agro-ecologies.

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