

Response of Newly Released Late Maturing Maize Variety to Nitrogen and Plant Population Density at Jimma, Southwestern Ethiopia

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Abstract: The study was performed at two sites around Jimma Agricultural Research Center (Melko) and Kersa districts, Jimma Zone, from 2017 up to 2019 main cropping seasons. Five Nitrogen fertilizer rates (69, 92, 115, 138 and 161 kg N ha⁻¹), and four plant population densities (66,666 (75*20cm), 53,333 (75*25cm), 44,444 (75*30cm) and 62500plants ha⁻¹(80*40cm two plants per hill)) were factorial combined and laid down in a randomized complete block design (RCBD) with three replications. Late maturing maize variety BH661 was used. The analysis of variance showed that all parameters of maize were significantly affected ($p < 0.05$) by the main effects of N fertilizer rates and plant population densities except plant height but the interaction effects of the two factors had not significant effect ($p > 0.05$) on any of the measured parameters. The highest grain yield of 6.75 and 6.87 t ha⁻¹ and above ground biomass yield of 15.36 and 16.39 t ha⁻¹, were obtained from the highest N fertilizer rate of 161 kg ha⁻¹ and highest plant population density of 66,666 plants ha⁻¹(75*20cm) respectively. This is due to the late maturing habit of the crop variety that highly responsive to the highest N rate. In conclusion, sensitivity analysis on coexisting changes in field prices of inputs and maize grain ($\pm 15\%$) showed that, N fertilizer rates are sensitive under prevailing market conditions and based the partial budget analysis, application of 161 N kg ha⁻¹ gave the highest net benefit (41800.72 ETB ha⁻¹) with acceptable marginal rate of return (MRR) (122.38%). Concerning main effect of plant population density 66,666plants ha⁻¹ (75*20cm) gave the highest net benefit (47802.00 EtB ha⁻¹) with acceptable MRR (688.32%). Therefore, for a late-maturing maize varieties application of 161 kg N ha⁻¹(further research also needed because this treatment is sensitive to price fluctuation) with plant population density of 66,666 plant ha⁻¹(75*20cm) recommended for farmer's under rain fed condition at Melko and Kersa district, Jimma zone and other similar agro-ecology of the Southwest of Ethiopia.

Keywords: BH661, Maize, Nitrogen Fertilizer Rates, Plant Population Density

1. 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 [1]. 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 tef [1].

In Ethiopia some soil types contain enough amounts of essential nutrients for the plant's development. But majority of the soils in the country contains total N low to medium and low in available P. Long term cultivation practice depletes plant nutrients and increases soil resource degradation. Modern agriculture production techniques such as the adoption of hybrid maize varieties in line with appropriate crop management practices (use of fertilizer and optimum plant density for example) can enhance maize

productivity.

The BH661 maize hybrid variety is among the highest yielding maize variety which is highly responsive to N fertilizer level and sensitive to plant density. Under high plant density and high nitrogen rate, the height of the plant increase vertically with decreasing stalk strength resulting in high lodging [2]. However under 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 [3, 4]. So that working on such important factors (plant density and N rate) is a mandatory. 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 yield and yield components of late-maturing maize hybrid BH661 under rainfall conditions of Jimma zone.

2. Materials and Methods

2.1. Description of the Study Areas

The field experiment was performed on farmers' fields during main cropping seasons of 2017 up to 2019 in Melko and Kersa districts, Jimma Zone Southwestern Ethiopia. The Melko site is located at 12 km distance from Jimma town and is found at 7°40'N latitude and 36°47'E longitude with 1,754 m. a. s. l. The mean maximum and minimum temperature was 26.3 and 11.6°C respectively with a mean annual rainfall of 1,572mm. The Kersa site is located at about 28 km East of Jimma town and 7°40'N latitude and 36°50'E longitude at an elevation of 1740 m. a. s. l. The average maximum and minimum temperature is 28.8°C and 11.8°C, respectively and receives reliably rains, ranging from 1,200 – 2,800 mm per annum in main cropping seasons.

2.2. Experimental Treatments and Procedures

The late maturing maize variety BH661 was used and it is adapted to an altitude of low to medium (1000-1800 m. a. s. l) areas. The variety was white-colored and has good yield potential and accepted by the farmers. The treatments consisted of five Nitrogen fertilizer rates (69, 92, 115, 138, and 161 N kg ha⁻¹) and four plant population densities (66,666 (75*20cm), 53,333 (75*25cm), 44,444 (75*30cm), and 62,500plants ha⁻¹ (80*40cm two plants per hill). The treatments were arranged in 5*4 factorial combinations. Treatments were laid out in a randomized complete block design (RCBD) with three replications. The distance between the blocks and plots were 1.5m and 1 m, respectively. The gross size of each plot was 4.0 m length by 5.25m width (21 m²). To increase the nitrogen use efficiency, it was applied at planting time with NPS blended fertilizer and at 30 days after emergence.

The land was furrow opened by oxen and prepared following the conventional tillage practice. At planting two

seeds of maize was planted per hill and thinned to a single healthy plant per hill except for plant population density of 62,500 plants ha⁻¹ (80*40cm two plants per hill was left). The recommended rate of Phosphorous (69 kg P₂O₅ ha⁻¹) was uniformly applied in all the plots at planting. All other agronomic practices were applied uniformly in all experimental plots as per their respective recommendations for maize in the study areas.

2.3. Soil Sampling and Analysis

A composite surface soil (0-30 cm depth) sample was collected from both sites with a gauge auger before planting. The samples were dried, cleaned and analyzed for certain physio-chemical properties such as soil pH, total nitrogen, available phosphorus, organic matter content, and Cation Exchange Capacity (CEC) at Jimma Agricultural Research Center soil laboratory.

Soil pH was determined in a 1: 2.5 soil-water suspension using a combination of the glass electrode. Organic carbon was estimated by the Walkley and Black method [5] and organic matter was calculated by multiplying the percent organic carbon (OC) by a factor of 1.724. Total soil N was measured using the micro-Kjeldahl digestion, distillation, and titration procedure as described by Bremner [6]. After extraction of the soil sample by sodium bicarbonate solution as per the procedure outlined by Olsen *et al.* [7], available P was determined by measuring its absorbance using a spectrophotometer. The investigated soil properties are shown in Table 1.

Table 1. Selected Physico-chemical properties of the soil of the experimental sites before planting.

Soil characters	Location	
	Kersa	Melko
pH (1: 2.5)	4.96	5.03
Available P (mg kg ⁻¹)	3.72	4.42
Total N (%)	0.20	0.13
OC (%)	2.12	6.88
OM (%)	3.65	----
C: N ratio	10.61	----
CEC	----	15.71

Where pH= Hydrogen power, OC=Organic carbon, TN=Total Nitrogen, Av. P=Available phosphorous, OM=Organic matter, CEC=Cation exchange capacity. Values are the means of duplicated samples.

2.4. Data Collected

2.4.1. Plant Height (cm)

It was measured at ground level to the terminal stem using a measuring stick at the point where the tassel starts branching from six randomly selected plants.

2.4.2. Lodging Percent

It was obtained by counting the total number of stalk and root lodging in each plot and divided to the total number of plant stand at harvesting.

2.4.3. Above Ground Biomass (kg ha⁻¹)

All above-ground biomass was harvested from the net plot

and weighted, ears were removed and weighted separately, six plants were selected, chopped and oven-dried till getting uniform weight.

2.4.4. Grain Yield (kg ha^{-1})

Grain yield per plot was recorded using an electronic balance and then adjusted to 12.5% moisture and converted to a hectare basis.

2.5. Partial Budget Analysis

The costs and benefits were performed with different plant population density and Nitrogen fertilizer rates as described by CIMMYT [8]. It was done using the prevailing market prices of specific sites the experiment was done and all costs and benefits were calculated on ha^{-1} basis of Ethiopian Birr (ETB). To reflect the difference between the experimental yield and the yield farmers expect the actual yield was adjusted downward by 10%. As detailed in CIMMYT [8] the dominance analysis was performed to select potentially profitable treatments. The percent marginal rate of return (MRR) for each pair of ranked treatments was calculated and thus the MRR of 100% or greater was used. To test the ability to withstand price changes and fluctuation of the price sensitivity analysis was carried out. Through sensitivity analysis, the maximum acceptable field price of input was calculated with the minimum rate of return as described by Shah *et al.* [9].

2.6. Data Analysis

Analysis of variance (ANOVA) for all collected data was computed using SAS software version 9.3. The significant of differences between samples was separated using the least significance difference (LSD) at 5% level of significance.

3. Results and Discussions

3.1. Plant Height

The plant height was not shown significant ($P>0.05$) effect

by the main effects of N fertilizer rates and plant population density (Table 2). Even though, statistical were not significant numerically the highest plant height 275.17 and 274.77cm were recorded from 161 kg ha^{-1} N rate and plant population density of 53,333 plants ha^{-1} respectively. While the shortest 268.29 and 269.73cm were recorded from 92 kg ha^{-1} N fertilizer rates and plant population density of 62,500 plants ha^{-1} (80*40cm two plants per hill) respectively. The results were indicated, an increase in plant height with an increase in N rate especially up to the highest N rate of 161 kg ha^{-1} . The current result was in agreement with the result of Sisay [10] who reported that the plant height of maize was increased with increasing levels of N and P fertilization. Similarly, Woldesenbet and Haileyesus [11] reported that the height of the maize plant increased with increase in nitrogen rates.

3.2. Lodging Percentage

Lodging percentage was significantly ($P<0.05$) affected only due to plant population density, but main effect of N rate and interaction effect were not significantly ($P>0.05$) affected it (Table 2). The highest lodging percentage of 45.13 was obtained from the highest population density of 66,666 plants ha^{-1} (75*20cm) followed by 62,500 plants ha^{-1} (80*40cm two plants per hill). While, the lowest lodging percentage was (34.79) was recorded from the lowest population density of 44,444 plants ha^{-1} (75*30cm). There was a linear decrease with a decrease in plant population density and it directly related to plant height. Similarly, Muhidin *et al.* [12] reported that the highest lodging percentage was obtained due to the highest plant population even though there were other factors like wind. Increasing plant density can aggravate competition for natural resources like nutrient, air, water and light that produced tall and weak stalks which are susceptible to lodging. Similarly, Begizew., *et al.* [13] reported increasing of N fertilizer rate under high plant population density that increase vertical growth towards the light or towards free space that resulted in susceptible stalks for lodging.

Table 2. Main effect of plant population densities and N-fertilizer rate on yield and yield related parameters of maize at Melko and Kersa district Jimma zone during 2017-2019 cropping seasons.

Nitrogen rate (kg ha^{-1})	Grain yield (t ha^{-1})	AGB (ton ha^{-1})	Plant height (cm)	Lodging (%)
69	5.97	14.13	273.21	41.38
92	6.03	14.32	268.29	39.69
115	6.28	15.05	272.29	40.73
138	6.45	14.82	272.08	36.30
161	6.75	15.36	275.17	38.48
LSD (0.05)	0.45	1.15	ns	ns
Plant Population Density ha^{-1} (Inter* Intra row spacing)				
66,666 (75*20cm)	6.87	16.39	273.17	45.13
53,333 (75*25cm)	6.69	15.51	274.77	37.56
44,444 (75*30cm)	6.14	13.82	271.17	34.79
62,500 (80*40cm)	5.49	13.24	269.73	39.79
Mean	2.70	14.73	272.20	39.31
LSD (0.05)	0.40	1.02	Ns	6.46
CV (%)	21.89	23.78	5.09	24.05

* CV=Coefficient of variation; LSD= Least significant difference; AGB= Above ground biomass. Values followed by the same letter within a column are not significantly different at $P>0.05$.

3.3. Grain Yield

Grain yield was highly significantly ($P < 0.01$) affected by both the main effect of N fertilizer rates and plant population density but the interaction effect of the two factors was not significant ($P > 0.05$) (Table 2). The results showed that the highest mean grain yield of 6.75 and 6.87 t ha⁻¹ were recorded from the application highest N rate of 161 kg ha⁻¹ and from the highest plant population density of 66,666 plants ha⁻¹ (75*20cm) respectively. In contrast, the lowest grain yield of 5.97 and 5.49 t ha⁻¹ were obtained from the lowest N rate of 69 kg ha⁻¹ and plant population density of 62,500 plants ha⁻¹ (80*40cm two plants per hill), respectively. Similarly, Begizew *et al.* [13] reported that the positive relationship between grain yield and plant density was due to the high number of plants per unit area. The grain yield productivity was significantly increased by 13.07% t ha⁻¹ at application of 161 kg N ha⁻¹ compared to the lowest application rate of N 69 kg N ha⁻¹. Also Sisay [9] reported that the grain yield advantage of 15.2% was obtained from 115/86 kg ha⁻¹ N/P₂O₅ when compared to 69/52 kg ha⁻¹ N/P₂O₅ fertilizer rate. In general, application of the highest rate of N fertilizer combined with highest plant population increases the maize grain yield.

3.4. Aboveground Biomass Yield

The above ground biomass yield was significant ($P < 0.05$) due to N fertilizer rates and highly significant ($P < 0.01$) due to plant population density but no significant ($P > 0.05$) due to interaction effect (Table 2). The highest above-ground biomass yield 15.36 t ha⁻¹ and 16.39 t ha⁻¹ were recorded from application of the highest N rate of 161 kg ha⁻¹ and plant population density of 66,666 plants ha⁻¹ (75*20cm), respectively. On the contrary, the lowest above ground biomass of 14.13 and 13.24 t ha⁻¹ was recorded from the lowest N rate of 69 kg ha⁻¹ and plant population density of

62,500 plants ha⁻¹ (80*40cm two plants per hill). It implies that increased application of N rate directly increases plant dry matter. Tariku *et al.* [14] research result indicated that application of higher nitrogen increased the dry matter of maize. The biomass yield was significantly increased from 13.24 to 16.39 t ha⁻¹ (by 23.79%) from plant population density of 62500 plants ha⁻¹ (80*40cm two plants per hill) to plant population density of 66,666 plants ha⁻¹ (75*20cm). The above ground biomass yield increase as plant population density increase because the plant per meter square area increase and consequently number of cob harvested [15].

3.5. Partial Budget Analysis

It was performed by considering seed rates, fertilizer rates, and labor costs across the seasons and locations. The costs of NPS fertilizers was 15.90 ETB kg⁻¹ and that of Urea was 12.65 ETB kg⁻¹ and the sale of grain maize at Melko and Kersa district open market average price was 8.00 ETB kg⁻¹. The dominance analysis was performed and it led to the selection of 115, 138 and 161 kg N ha⁻¹ from N rates and from plant population density the un dominated treatments were 53,333, 62,500 and 66,666 plants ha⁻¹ (Table 3). The treatments having MRR below 100% were considered and unacceptable to farmers; thus, 115 and 138 kg N ha⁻¹ were eliminated [8] (Table 4). This was because such a return would not offset the cost of capital (interest) and other related deal costs while still giving an attractive profit margin to serve as an incentive. The analysis of partial budget showed that, the application of 161 kg N ha⁻¹ gave the highest net benefit of 41,800.72 ETB ha⁻¹ with acceptable MRR of 122.38 % (Table 3 and 4). Concerning plant population density, 66,666 plants ha⁻¹ gave the highest net benefit of 47,802.00 ETB ha⁻¹ with acceptable MRR of 688.32% (Tables 3 and 4).

Table 3. Partial budget analysis of plant population density and N fertilizer rates at Jimma (Melko) and Kersa district during 2017-2019 main cropping seasons.

N fertilizer rates (kg ha ⁻¹)	Grain yield t ha ⁻¹	Adjusted Grain Yield t ha ⁻¹	Gross Benefit ha ⁻¹	TCV ETB ha ⁻¹	Net Benefit ETB ha ⁻¹	Dominance
69	5.97	5.373	42984.00	2913.98	40070.02	--
92	6.03	5.427	43416.00	3885.30	39530.70	D
115	6.28	5.652	45216.00	4856.63	40359.37	U
138	6.45	5.805	46440.00	5827.95	40612.05	U
161	6.75	6.075	48600.00	6799.28	41800.72	U
Plan Population Density plants ha ⁻¹ (Inter*Intra row spacing)						
62,500 (80*40cm)	5.49	4.941	39528.00	1114.07	38413.93	--
44,444 (75*30cm)	6.14	5.526	44208.00	1378.00	42830.00	U
53,333 (75*25cm)	6.69	6.021	48168.00	1497.60	46670.40	U
66666 (75*20cm)	6.87	6.183	49464.00	1662.00	47802.00	U

Retail price of grain = 8.00 Birr per kg; TCV= total cost that varied; Cost of Urea fertilizer = 12.65 Birr per kg; Cost of NPS = 15.90 Birr per kg; ETB = Ethiopian Birr; NB = Net benefit; D=Dominated; U=Un-Dominated treatment

Table 4. Partial budget with estimated marginal rate of return (%) for N fertilizer rates and plant population density at Jimma (Melko) and Kersa district during 2017-2019 main cropping seasons.

N fertilizer Rates (kg ha ⁻¹)	TCV (ETB/ha)	Net Benefit (ETB/ha)	Raised Cost	Raised Benefit	MRR (%)
69	2913.98	40070.02	----	----	----
115	4856.63	40359.37	1942.65	289.35	14.89

N fertilizer Rates (kg ha ⁻¹)	TCV (ETB/ha)	Net Benefit (ETB/ha)	Raised Cost	Raised Benefit	MRR (%)
138	5827.95	40612.05	971.32	252.68	26.01
161	6799.28	41800.72	971.33	1188.67	122.38
Plan Population Density plants ha ⁻¹ (Inter*Intra row spacing)					
62,500 (80*40cm)	1114.07	38413.93	----	----	----
44,444 (75*30cm)	1378.00	42830.00	263.93	4416.07	1673.20
53,333 (75*25cm)	1497.60	46670.40	119.60	3840.40	3211.04
66,666 (75*20cm)	1662.00	47802.00	164.40	1131.60	688.32

Retail price of grain = 8.00 Birr per kg; TCV= total cost that varied; Cost of Urea fertilizer = 12.65 Birr per kg; Cost of NPS = 15.90 Birr per kg; MRR= Marginal Rate of Return; ETB = Ethiopian Birr; NB = Net benefit

A price variation of 15% was used to perform the sensitivity analysis. The price changes are sensitive under market conditions prevailing at Melko and Kersa district which was plant population densities of 53,333 (75*25cm), and 66,666 (75*20cm) plants ha⁻¹ gave above the minimum acceptable MRR of 100%(Table 5). Concerning N fertilizer

rates all N rates were below the minimum acceptable MRR and sensitive to price fluctuations (Table 5). Therefore, this investigation remained with application of 161 N kg ha⁻¹ and plant population density of 66,666 (75*20cm) plants ha⁻¹. These results agree with Bekele [16].

Table 5. Sensitivity analysis based on a 15% rise in total cost and maize price of gross field benefit fall.

N Fertilizer Rates (kg ha ⁻¹)	TCV (ETB ha ⁻¹)	NB (ETB ha ⁻¹)	Increment Cost	Increment Benefit	MRR (%)
138	6702.14	34520	----	----	----
161	7819.17	35531	1117.03	1011	90.5
Plan Population Density plants ha ⁻¹ (Inter*Intra row spacing)					
62,500 (80*40cm)	1281.18	32652	----	----	----
44,444 (75*30cm)	1584.70	36406	303.52	3754.00	1236.82
53,333 (75*25cm)	1722.24	39670	137.54	3264.00	2373.13
66,666 (75*20cm)	1911.30	40632	189.06	962.00	508.83

* Retail price of grain = 8.00 Birr per kg; TCV= total cost that varied; Cost of Urea fertilizer = 12.65 Birr per kg; Cost of NPS = 15.90 Birr per kg; MRR= Marginal Rate of Return; ETB = Ethiopian Birr; NB = Net benefit

4. Summary and Conclusions

The growth, yield components and yield of the late maturing maize variety BH661 responded strongly to both N fertilizer application and plan population density. Accordingly, grain yield was increased with increases of N fertilizer rates and plant population density. From the range of tasted treatments, 161 kg N ha⁻¹ and plant population density of 66,666 plants ha⁻¹ gave significantly higher grain yield. The grain yield was significantly increased by 13.07 and 11.94 % from the application of 69 to 161 kg ha⁻¹ N rate and from 92 to 161 kg ha⁻¹ N rate respectively. The analysis of partial budget indicated that, the N fertilizer rates are sensitive under prevailing market conditions and based on partial budget analysis the application of 161 N kg ha⁻¹ gave the highest net benefit of 41800.72 ETB ha⁻¹ with acceptable MRR of 122.38%. Regarding plant population density, 66,666 plants ha⁻¹ (75*20cm) gave the highest net benefit (47802.00 ETB ha⁻¹) with acceptable MRR (688.32%). Therefore, for late maturing maize varieties the application of N rate of 161 kg ha⁻¹ (further research also needed because this treatment is sensitive to price fluctuation) and plant density of 66,666 plants ha⁻¹ (75*20cm) recommended for farmers under rain fed condition at Melko and Kersa, Jimma zone and other similar agro-ecologies of the Southwest of Ethiopia.

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