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Response of Maize Variety to Nitrogen and Plant Population Density in Jimma Zone, Southwestern Ethiopia

Sisay Gurmu*, EshetuYadete

Department of Agronomy and Crop Physiology, Jimma Agricultural Research Center, Jimma, Ethiopia

Email address:
sis.sis1835@gmail.com (Sisay Gurmu)
*Corresponding author

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Abstract: The field experiment was done at Jimma Zone during 2017 to 2019 main cropping seasons. The treatments consisted of factorial combinations of five Nitrogen fertilizer rates (69, 92, 115, 138, and 161 N kg ha^{-1}) and four plant densities 66,666 (75*20cm), 53,333 (75*25cm), 44,444 (75*30cm) and 62,500 plants h^{-1} (80*40cm two plants per hill) laid down in a randomized complete block design with 5x4 factorial arrangements using three replications. The maize variety BH546 (medium maturing variety) was used. The ANOVA data analysis indicated that all collected parameters were significantly affected by the main effect of N fertilizer rates and plant densities, but did not by interaction. The highest grain and above ground biomass yield (7580, 13990kg ha^{-1}) respectively were obtained from the highest N fertilizer rate (161 kg ha^{-1}). Also the highest plant population density of 66,666 plants h^{-1} (75*20 cm) gave the highest grain yield (7520 kg ha^{-1}) and above ground biomass (14140 kgha^{-1}). The grain yield was significantly increased from 6601 to 7580kg ha-^{1} which means increased by 13.07 and 11.94% over the lowest 69 N kg ha^{-1} rate and 92 N kg ha^{-1} (Optimum N recommended rate) respectively. Application of 115 N kg ha^{-1} fertilizer rate and using plant population density of 53,333 plants ha^{-1} (75*25cm) gave the highest net benefit of 48,279 ETB ha^{-1} and 52,394.40 ETB ha^{-1} respectively. In conclusion, sensitivity analysis on coexisting changes in field prices of inputs and maize grain (±15%) showed that 92 N kg ha^{-1} fertilizer rate and plant population of 53,333 plants ha^{-1} (75*25cm) gave the highest marginal rate of return (MRR) 205.75% and 738.57% respectively and more profitable under unstable market situations. Therefore, application of 92 kg N ha-^{1} fertilizer rate with plant population density of 53,333 plants ha^{-1} (75*25cm) is recommended at Jimma zone and other similar agro-ecologies of southwestern Ethiopia.

Keywords: BH546, Maize, Nitrogen, Plant Population Density and Phosphorous

1. Introduction

Maize productivity can be enhanced by use of modern production techniques such as the adoption of hybrid maize varieties in line with appropriate crop management practices including the use of fertilizer application and plant density. In order to increase the production and productivity of the maize an intensive supply of inputs mainly fertilizer and improved seeds of modern and superior hybrid varieties with their appropriate plant density is mandatory to fulfill the food security and instability of the increasing human population of our country.

The medium maturing (Example BH546) maize hybrid is among the high-yielding recently released maize varieties as its performance and yield potential is highly sensitive to N fertilizer level and plant population density. Under high plant density and high nitrogen rate, the height of the plant increases vertically with decreasing stalk strength resulting in high lodging [1]. But, under low plant density and low nitrogen rate the utilization and conversion of available resources like solar radiation, nutrient, and water into dry matter production decrease [2, 3]. In such case study on optimum plant population density and N fertilizer rate brings about a great change in grain yield as such modern hybrid has high yield potential. Previous result study showed that plant population density of 44,444 plants ha^{-1} with application of 92 kg N ha^{-1} was recommended for both medium maturing and late maturing maize varieties but it needs an update. Therefore, this study was done to determine the effect of nitrogen rates and plant population density on the yield and yield components of newly released medium maturity maize variety BH546.

2. Materials and Methods

2.1. Description of the Study Area

The field experiments were done at two sites (around Jimma Agricultural Research Center on farmers' fields) in Jimma zone Southwestern Ethiopia for three (2017-2019) consecutive main cropping years. The Jimma (Melko) on farm sites were located at 12 km distance from Jimma town (7° 40′ N latitude and 36° 47′ E longitude) at an altitude of 1754 m. a. s. l The place has a mean maximum and minimum temperature of 26.3 and 11.6°C respectively with a mean annual rainfall of 1,572mm with agro-ecology characterized by humid mid altitude. The soil type of the experimental sites was Eutric-nitisols (reddish brown).

2.2. Experimental Treatment and Procedures

The medium maturing maize variety BH546 which is adapted to low-mid altitude (1000-1800 m. a. s. l) areas, white-colored and released recently was used for the field experiment. 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 62,500plants h^{-1} (80*40cm two plants per hill)) totally twenty treatments were laid out in a randomized complete block design (RCBD) with 5x4 factorial combinations in three replications was used. Recommended Phosphorous fertilizer rate of 69 kg P_2O_5 ha^{-1} was uniformly applied for all plots at planting. The distances between replications were 1.5 m, while plots within replications were 1 m. The gross size of each plot was 4.0 m in length by 5.25m width ($21m^2$). Nitrogen fertilizer was applied per hill. To increase the nitrogen use efficiency, it was split applied at planting time and 30 days after emergency.

The land was furrow opened by oxen through the conventional tillage practice. Two maize seeds were planted per hill and thinned after establishment to maintain a single healthy plant per hill except for plant population density of 62,500 plants ha^{-1} (80*40cm) of which two plants per hill was used. All other agronomic practices were applied uniformly to all plots as per their respective recommendations for maize in the study area.

2.3. Soil Sampling and Analysis

A composite surface soil at the depth of 0-30 cm was collected from each site by auger before sowing. 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 [4] 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 [5]. After extraction of the soil sample by sodium bicarbonate solution as per the procedure outlined by Olsen *et al.* [6], available P was determined by measuring its absorbance using a spectrophotometer. The investigated soil properties are shown in Table 1.

Table 1. *Before planting selected Physico-chemical properties of the soil of the experimental sites.*

Soil characters	Value
av P (mg kg^{-1})	4.42
OC (%)	6.88
pH (1: 2.5)	5.03
TN (%)	0.13
CEC	15.71

*Where pH= Hydrogen power; OC= Organic carbon; CEC=Cation exchange capacity, TN=Total
Nitrogen, Av. P=Available phosphorous. 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 with nitrogen rates and plant population densities were done as described by CIMMYT [7]. All costs and benefits were calculated on the hectare basis of the Ethiopian Birr (ETB). The actual yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. The inputs and/or concepts used in the partial budget analysis were the mean grain yield of each treatment in both years, the field price of maize grain (sale price grain yield minus the costs of fertilizer, seed, labor) the gross field benefit (GFB) ha^{-1} (the product of field price of the mean yield for each treatment), the field price of seed rate kg ha^{-1}, fertilizer and wage rate, the total costs that varied (TCV) which included the sum of field cost of seed, fertilizer and its wage for planting and application. To select potentially profitable treatments from the range that was tested the dominance analysis procedure was used. The minimum Marginal Rate of Return (MRR) of 100% was used. To test the ability to withstand price changes sensitivity analysis was carried out. The maximum acceptable field price of input was calculated with the minimum rate of return as described by Shah *et al.* [8].

2.6. Data Analysis

All collected data was computed using SAS software version 9.3. The least significance difference at 5% level of significance was used.

3. Results and Discussions

3.1. Plant Height

The plant height was not significantly (P>0.05) affected by the main and interaction effects of N fertilizer rates and plant population densities, however there were highly significant (P<0.01) main effect of plant population densities (Table 2). As a result, numerically the highest plant height (270.22 cm) was obtained from plant population density of 53,333plants h^{-1} (75x25cm) followed by plant population density of 44,444 plants ha^{-1} (75x30cm). In contrast the shortest plant height 260.53cm was recorded from plant population density of 62,500 plants ha^{-1} (80x40cm two plants per hill). Generally, the results showed that a linear increase with increasing plant population density up to 53,333 plants ha^{-1} but decline with further increase in the plant population density. This result was in agreement with Begizew *et al*. [9], who reported maximum plant height (328.47cm) was recorded under the highest plant density (66,666 plants ha^{-1}) with the application of 138 kg N ha^{-1}.

3.2. Lodging Percentage

Lodging percentage was not significantly (P>0.05) affected by the main and interaction effect of N fertilizer rates and plant population densities, but it was highly significantly (P<0.01) affected by main effect of plant population density (Table 2). The highest lodging percentage (18.49%) was recorded from the highest plant population density 66,666 plants ha^{-1} (75x20cm) followed by plant population density of 53,333 plants ha^{-1}(75x25cm). In contrast the lowest lodging percentage (13.52%) was obtained from the lowest plant population density of 44,444 plants ha^{-1} (75x30cm). Significantly the lodging percentage was decreased with decreasing in plant population density which was directly related to plant height. Similarly, Begizew *et al,* [9] reported that increasing in N rate under the dense population increase vertical growth towards the light or towards free space that resulted from susceptible stalks for lodging. Also Sisay *et al*., [10] reported that as the plant population density increased the lodging percent also increased and vice versa.

3.3. Grain Yield

It was significantly (P<0.01) affected by both the main effect of N fertilizer rates and plant population density, whereas the interaction effect did not shown a significant (p>0.05) difference (Table 2). As a result the highest mean grain yield of 7.58 and 7.52t ha^{-1} were recorded from the application of highest N fertilizer rate of 161 kg ha^{-1} and plant population density of 66666 plants ha^{-1} (75x20cm) respectively. While the lowest grain yield 6.61 and 6.86 t ha^{-1} was obtained from the lowest N fertilizer rates of 69 kg ha^{-1} and plant population density of 62500 plants ha^{-1} (80x40cm two plants per hill) respectively. It shows that the grain yield was significantly increased with increased N and plant population density. Grain yield was increased by 14.7% by the application of 161 kg ha^{-1} N over 69 kg ha^{-1} N. The 9.6% grain yield increase was obtained from plant population density of 66,666 plants ha^{-1}(75*20cm) compared with plant population density of 62,500 plants ha^{-1} (80*40cm two plants per hill). These results were in line with and supported by Obi [11], Kim [12], and Udoh [13] who reported that some hybrid maize varieties have a yield advantage over other maize varieties because they possess such special qualities as high yield, disease resistance, and early maturity uniformity in flowering and ear placement. Sisay *et al*., [10] reported that by planting 53,333 plants ha^{-1} there was 9.1% grain yield increase over plant population density of 44,444 plant ha^{-1}.

3.4. Aboveground Biomass Yield

The above-ground biomass yield was highly significantly (P<0.01) affected by the main effects of N fertilizer rates and plant population density, but not significantly (P>0.05) affected by the interaction effects. The highest aboveground biomass yield of 13.99 and 14.14t ha^{-1} were recorded from the application of highest N fertilizer rate of 161 kg ha^{-1} and highest plant population density of 66,666 plants ha^{-1} (75x20cm) respectively. On the contrary, the lowest 12.61 and 12.96 t/ha were obtained from the lowest N fertilizer rate of 69 kg ha^{-1} and from plant population density of 62,500 plants h^{-1} (80x40cm two plants per hill). The above ground biomass yield was significantly increased with increasing plant population density from 44,444 to 66,666 plants ha^{-1} by 7.5%. By planting 53,333 plants ha^{-1} there was 6% above ground biomass increase over plant population density of 44,444plants ha^{-1} [10]. Concerning the effect N fertilizer rates there was linearly increase of above ground biomass as N rate increase from 69 to 161 kg N ha^{-1}. There was 10.9% increase of above ground biomass at application of 161 kg N ha^{-1} when compared with 69 kg N ha^{-1} fertilizer rate. This result is in line with results of Tariku *et al.* [14] who reported that application of higher nitrogen increased the dry matter of plants.

Table 2. *Across season and over location of newly released BH546 maize variety to Nitrogen and Plant Population density at Jimma during 2017-2019 main cropping seasons.*

N rate (Kg ha^{-1})	Grain yield (ton ha^{-1})	AGB (ton ha^{-1})	Plant height (cm)	Logging percentage
69	6.61	12.61	262.53	16.15
92	7.11	13.38	262.83	13.78
115	7.38	13.70	266.22	17.33
138	7.55	13.94	267.83	17.11
161	7.58	13.99	266.08	14.93
LSD (0.05)	0.49	0.78	Ns	3.95
Plant population density ha^{-1} (Inter*intra row spacing)				
66,666 (75*20cm)	7.52	14.14	264.27	18.49
53,333 (75*25cm)	7.46	13.85	270.22	16.15
44,444 (75*30cm)	7.14	13.16	265.38	13.52
62,500 (80*40cm)	6.86	12.96	260.53	15.28
Mean	7.25	13.53	265.10	15.86
LSD (0.05)	0.44	0.69	5.95	3.52
CV (%)	14.57	12.35	5.39	23.37

* 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.

3.5. Partial Budget Analysis

The statistical data analysis results showed that plant population density and N fertilizer rate had a significant ($P<0.05$) effect on the grain yield but interaction effect was not significant (Table 2). Partial budge analysis of the combined results was thus performed [7]. The result of the partial budget analysis and the data used in the development of the partial budget is given in (Table 4). It was performed by considering N fertilizer rate, seed, application costs, and labor, average grain yield obtained. The costs of NPS blended fertilizer= 15.90 ETB kg^{-1} and urea = 12.65 ETB kg^{-1} and sale of grain maize at around Jimma (Melko) open market average price (8.00 ETB kg^{-1}) was used. Dominance analysis (Table 3) led to the selection of treatments 69, 95,115, and 138 N kg ha^{-1} from N rates and plant population density of 44,444, 53,333, 62,500 and 66,666 plants ha^{-1} were ranked in increasing order of total costs that vary. The treatments having MRR below 100% were considered and unacceptable to farmers; thus, 161 kg N ha^{-1} and 62,500ha^{-1} plant population density was eliminated [7] (Table 3). Therefore, this investigation remained with changes from 92, and 115 kg N ha^{-1}rates and plant population density of 53,333 plants ha^{-1} as promising new practices for farmers under the prevailing price structure since those treatments gave more than 100% MRR (Table 4). This might suggest the use of inputs that result in maximum net benefits [15].

Partial budget analysis based on the field prices of inputs and maize grain yield showed that the application of 115 kg N ha^{-1} gave the net benefit of 48,279 ETB ha^{-1} with acceptable MRR of 100.14 % (Table 3and 4). Concerning plant population density net benefit of 52,394 ETB ha^{-1} was recorded from plant population of 53,333 plants ha^{-1} with acceptable MRR of 999.24% (Tables 3 and 4).

The market prices are ever-changing so that a recalculation of the partial budget using a set of likely future prices i. e., sensitivity analysis, was essential to identify treatments that may likely remain stable and sustain satisfactory returns for farmers despite price fluctuations. The sensitivity analysis study indicates an increase in the field price of the total variable costs, and a fall in the price of maize grain, which represented a price variation of 15% (Table 5).

The price changes are sensitive under market conditions prevailing around Jimma (Melko). The new prices were thus used to obtain the sensitivity analysis which was above the minimum acceptable MRR of 100%. Despite that 115 kg N ha^{-1} gave below the minimum acceptable MRR of 74.02% which was not accepted whereas 92 kg N ha^{-1} gave acceptable MRR of 205.75% (Table 5). Regarding plant population densities acceptable MRR of 738.57% was obtained from 53,333 plants ha^{-1} (Table 5). These results agree with Saha *et al.* [16] whose findings that the application of 30 kg N ha^{-1} consistently gave acceptable economic returns.

Therefore, the application of 92 kg N ha^{-1} with plant population density of 53,333 plants ha^{-1} (75*25cm) with a net benefit of (47,307ETB ha^{-1}) and (52,394.40 ETB ha^{-1}) respectively were promising practices to give an economic yield response and also sustained acceptable even under projected worsening trade conditions in Jimma (Melko).

Table 3. *Partial budget analysis for N fertilizer rates and plant population density at Jimma during 2017-2019 main cropping seasons.*

N fertilizer rates (kg ha^{-1})	Grain yield t ha^{-1}	Adjusted Grain Yield t ha^{-1}	Gross Field Benefit	TCV (ETB ha^{-1})	Net Benefit (ETB ha^{-1})	Dominance analysis
69	6.61	5.949	47592	2950.98	44641.025	---
92	7.11	6.399	51192	3895.30	47296.70	U
115	7.38	6.642	53136	4866.63	48269.38	U
138	7.55	6.795	54360	5837.95	48522.05	U
161	7.58	6.822	54576	6809.28	47766.73	D

N fertilizer rates (kg ha^{-1})	Grain yield t ha^{-1}	Adjusted Grain Yield t ha^{-1}	Gross Field Benefit	TCV (ETB ha^{-1})	Net Benefit (ETB ha^{-1})	Dominance analysis
Plan Population Density ha^{-1}(Inter x Intra row spacing)						
44,444 (75x30cm)	7.14	6.426	51408	1108.00	50300.00	---
53,333 (75x25cm)	7.46	6.714	53712	1317.60	52394.40	U
62,500 (80x40cm)	6.86	6.174	49392	1544.07	47847.93	D
66,666 (75x20cm)	7.52	6.768	54144	1662.00	52482.00	U

Retail price of maize grain = 8.00 Birr per kg; TCV= total costs that varied; NB = Net benefit; Cost of Urea = 12.65 Birr per kg; Cost of NPS = 15.90 Birr per kg; EtB = Ethiopian Birr; D=Dominated; Un-Dominated

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

N fertilizer Rates (kg ha^{-1})	TCV (ETB ha^{-1})	Net Benefit (ETB ha^{-1})	Raised Cost	Raised Benefit	MRR (%)
69	2950.98	44678	---	---	---
92	3895.30	47307	944.33	2628.68	278.37
115	4866.63	48279	971.33	972.67	100.14
138	5837.95	48532	971.33	252.68	26.01
Plan Population Density ha^{-1}(Inter x Intra row spacing)					
44,444 (75x30cm)	1108.00	50300.00	---	---	---
53,333 (75*25cm)	1317.60	52394.40	209.60	2094.40	999.24
66,666 (75*20cm)	1662.00	52482.00	344.40	87.60	25.44

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

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

N Fertilizer Rates (kg ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	Increment Cost	Increment Benefit	MRR (%)
69	3394	37976.32	---	---	---
92	4480	40210.70	1086	2234.37	205.75
115	5597	41037.47	1117	826.77	74.02
Plant Population Density (ha^{-1})					
44,444 (75x30cm)	1274	42755.00	---	---	---
53,333 (75*25cm)	1515	44535.24	241	1780.24	738.57

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

4. Summary and Conclusion

The yield and yield components of the medium maturing maize variety BH546 responded strongly to both N fertilizer application and plant population density. Accordingly, higher magnitudes of grain yield increased with applied N fertilizer rates and plant population density. From the range of treatments tested, 161 kg N ha^{-1} and plant population density of 66,666 plants ha^{-1} (75x20cm) gave higher grain yield responses. The grain yield was significantly increased by 14.67% from the application of lowest 69 to 161 kg N ha^{-1}rate and increased by 6.61% from 92 to 161 kg N ha^{-1}rate which means over optimum Nitrogen recommendation of the area. The economic analysis showed that the application 115 kg N ha^{-1} gave the net benefit of 48,279 ETB ha^{-1}with acceptable MRR (100.14%) however it is sensitive to inflation of costs. Concerning plant population density 53,333plant ha^{-1} gave net benefit of 52,394.40 ETB ha^{-1}with acceptable MRR (999.24%) and sustained acceptable even under inflation. Therefore, based on partial budget analysis and current on-farm input availability for medium maturing maize variety (BH546) application of 92 kg N ha^{-1} and plant population density of 53,333 plants ha^{-1} (75x25cm) is recommended under rainfed condition of Jimma and other similar agro-ecologies of southwestern Ethiopia.

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